Cognitive Control in Verbal Task Switching

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Acknowledgements

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ABSTRACT

Task switching produces a number of reliable behavioural measures, the main focus of interest here being ‘switch cost’, the increase in response time when switching between tasks as opposed to performing them separately. Switch costs are typically measured between two tasks and compared to a single-task repeat condition. Current explanations of switch cost fall broadly into either active reconfiguration based accounts (e.g. Rogers & Monsell, 1995) whereby the extra time taken to switch between tasks is attributable to reconfiguration of task set, or passive carryover accounts (Allport, Styles & Hsieh, 1994) where extra time is accrued by the need to overcome conflict between the current task set and the enduring activity of the previous task set.

This thesis used the Continuous Series II (Gurd, 1995), a novel continuous verbal switching task which requires individuals to switch continuously between increasing numbers of overlearned sequences (e.g. days, numbers). The aim was to investigate the application of general (whole-task) switch costs (RT costs), memory-based switching and the differential pattern of errors produced by the task, with a view to determining the most appropriate theoretical model to explain costs in the task. General switch costs are measured over the whole time course of the task from beginning to end, instead of the more usual measurement of switch cost over a single switch or repeat within the whole task. Such long-term measures of switch cost account for ‘global representational structures’ in the task, which are said to contribute to the cost of switching yet are absent from local transitional measures (Kleinsorge, Heuer & Schmidtke, 2004). Global representational structures account for not only the current and preceding trials actually performed but also the possible alternatives for

the preceding, current and subsequent trials, thereby reflecting all representations relating to performance of the tasks. The Continuous Series II (Gurd, 1995) measures costs continuously over time between increasing numbers of verbal tasks and as yet has not been linked to either a reconfiguration or carryover-based account.

Initial administration to healthy controls and neurological patients confirmed difficulty-related increasing costs and revealed a dissociation of errors between two versions of the task, one including semantic categories. This suggested differential sources of control overseeing conflict detection and resolution, linked in this work to Kahneman's dual system model (Kahneman, 2011) and suggesting the implication of active control. Further work with monozygotic twins mirrored for handedness revealed no predicted effect of handedness but did reveal the employment of vocalised inner-speech as a successful self cueing device, known to be supportive of active reconfiguration in switching (Monsell, 2005). Such cueing was employed by this sample of older adults but had not appeared to benefit the neurological patients who clearly had reconfiguration deficits. Further development of the two versions of the task also allowed rejection of a passive carryover explanation of switch-cost on the basis that switching to the easier task was *not* more difficult, counter to the prediction of Allport, Styles & Hsieh (1994). At this stage it was evident that some portion of general cost for the task may be artefactual, as participants displayed behaviour suggesting the order of tasks and their updating nature (task content) may be inflating cost beyond a pure measure of switching (an inevitable risk of general switch cost measurement). Investigation of task order showed that production of the category 'days' appeared to conflate sources of error. Reducing the difficultly of component tasks (removing the need to update items) demonstrated that a substantial proportion of general cost was indeed purely switch-related. Returning to the question of cueing (previously demonstrated to be beneficial when self-generated), the final study introduced explicit external cues, consistently predicted to benefit switching (Monsell, 2005). These cues did not reduce time costs in verbal task switching and furthermore failed to prevent errors of task order. The lack of *external* cue benefit supports an amended version of the Rogers & Monsell (1995) task-set reconfiguration model as the best explanation of switch costs in verbal task-switching. This amended model relies entirely on internally generated representations in a closed system and supports the role of active control in generating switch-cost. General cost, while incorporating task-related artefacts, rehearsals and error recovery, nevertheless has at its core a switch related element. Furthermore, the failure of cues to extinguish between-task errors negates excessive reliance on working memory and further supports the rejection of passive carryover accounts of task switch cost.

Consider, briefly, that you are sitting on a couch, playing a video game in which your character is struggling to vanquish a seemingly unassailable enemy, when suddenly your phone, in the real world, rings. It's the pizza delivery person, lost and asking for directions. Instead of pausing the game, you continue your battle, simultaneously guiding your sword toward your enemy and the pizza toward your home. Left swing for the armor, "Right turn on Main Street." But as the skirmish heats up, does your ability to direct the delivery person waiver? As your character sustains damage, sending a twang of empathy through your real-world heart, do you temporarily forget about the rumblings of your real-world stomach? More to the point, do you guide the delivery driver according to the game-play map, or even notice when you do?

Ratan, Santa Cruz & Vorderer (2007), p. 167

"Blink. Blink. Blink. It's an instant message from my wife. I'll check it as soon as I finish this paragraph. Blink. Blink. Could be important. Okay, I'll check it after this sentence. Blink. I'd better just check it. I multitask all day and I'm not using "multitask" in that buzz-term kind of way."

Northrup (2004)

CHAPTER ONE: LITERATURE REVIEW – PART ONE: THEORIES OF TASK SWITCHING

1 Introduction and chapter overview

In an increasingly information rich and time poor world, task switching is something most of us encounter on a daily basis. True multi-tasking is virtually impossible to achieve without detriment to performance – while we may be able to carry out more than one task at a time this will always and immediately be subject to time and accuracy costs (‘switch cost’). Constituent tasks may be relatively simple, such as searching for your car keys, making a cup of coffee or speaking on the telephone. However, these tasks will generally take longer to complete simultaneously than consecutively and will very likely be more prone to error than when they are carried out individually (Monsell, 2003). To what degree we succeed will also depend on a number of other factors. Performance can depend on how easy or well practiced the tasks are, although familiar tasks are not necessarily easier when multitasking (see Monsell, Yeung & Azuma, 2000), and practice does not seem to ‘make perfect’ (Rogers & Monsell, 1995). How far in advance we know we need to switch to another task can also have an effect. Sufficient preparation time is generally acknowledged as advantageous (Logan, 2003; Monsell, 2003), although Altmann (2004) asserts that when only a single option for preparation is available it will fail to have an effect, regardless of how long it is. More than eighty years ago it was suggested that switching between *easier* tasks took longer than switching between harder tasks (Jersild, 1927) and more latterly it has been proposed that it is more difficult to switch *to* an easier task (Allport, Styles & Hsieh, 1994). Performance is also affected by what type of tasks we try to carry out in concert. It has been speculated by Meyer (as reported in Motluk, 2007) that common everyday combinations within a single domain such as instant messaging and report writing are doomed to failure, although research into real world multitasking is currently limited. Switching between tasks in this manner requires us to actively maintain the processes required to complete each task (what Rogers and Monsell (1995) termed *task set*), correctly selecting the appropriate set of processes for the task at hand and successfully changing those processes when they become redundant.

Experimentally, the task switching paradigm has long been used as a measure of cognitive control in action. Keeping the cognitive system updated in light of changing task demands is a fundamental aspect of such control processes. Dependent on tasks, the switching paradigm could include all five[1] areas flagged by Norman and Shallice (2000) as requiring focused cognitive control, although it is already clear that the relationship between executive and switching processes is far from straightforward. Task switches can occur within a single cognitive domain or between domains. Examples of single domain switches include Jersild (1927), who used addition and subtraction in some experiments and also Gurd (1995) who used verbal fluency for ordinal sequences and semantic categories. An example of switching between domains is that of Sohn & Anderson (2001; 2003) who used a combination of vowel/ consonant letter and odd/ even number decisions. Gurd and colleagues (2002) specified three main distinctions of the type of switch that can be made: *changing sorting criteria*, as in the Wisconsin Card Sorting Test (Berg, 1948), categorising bi- or multivalent stimuli according to differing features (e.g. colour then shape); *dual task performance*, typically manifesting as divided attention tasks, with switches determined by internal or external demands according to the need to maintain or monitor tasks; *alternating*

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[1] Planning and decision making; error resolution; novel behaviours; difficult tasks, and the requirement to overcome habitual behaviours.

task demands, switching between several tasks according to a defined alternation sequence. Clearly any consensus over the source of switch cost has to account for the variation in stimulus and response demands to be found in the literature.

Although stimuli are varied there are some commonalities. Stimuli often used are letters, numbers or symbols (e.g. Koch, 2008) – tasks might involve deciding if, for example, a symbol is a mathematical or text symbol. One marked exception to this is the *Continuous Series II task* (Gurd 1995), which uses no external stimuli but instead requires participants to switch between producing items in order from increasing numbers of overlearned word sequences such as months and letters. Participants start switching between two sequences then work through three and four sequences. Sequences cycle (when 'December' is reached in months the next correct response is 'January') and performance is continuous and self paced for a set number of iterations. For example, switching between three sequences might result in the responses "January, 3, Wednesday, February, 4, Thursday..." and so on, continuing to both update each sequence and switch between them (see Appendix A for full instructions for the task). The task is unusual in having verbal responses rather than button presses. One benefit of verbal responses is that it allows for analysis of the type of errors made rather than just a calculation of accuracy.

In this thesis the Continuous Series II will be investigated to establish which existing theoretical account of the causes of switch cost can be used to describe the behavioural data. Thus far (e.g. Gurd 1995, Gurd et al., 2002) the verbal task has not been associated with any one theoretical account of switch cost. In addition it is not clear how the unique features of the task contribute to the calculation of switch cost and the type of errors produced. For example, what is the contribution of switching between several tasks in isolation from the complex content of those tasks? Does the order in which the tasks are presented have any effect? What contribution is made by the lack of external stimuli and reliance on memory for the task order? Switching within working memory of this nature is noted to be quite separable from the more usual perceptual switching (Wager, Jonides & Smith, 2007) and so investigation of the contribution of WM (working memory) processes to the overall calculation of switch cost in the Continuous Series II is an important factor to investigate. The involvement of WM within the task is a relevant factor in determining which account of switch cost is most useful for explaining behavioural effects.

The first study will assess the effect of manipulating the Continuous Series II to contain alternating tasks of greater and lesser difficulty (the Mixed Category task). Using a single case series of neurological patients and a healthy control sample, the Mixed Category task will be investigated to assess the explanatory suitability of the task-set inertia hypothesis (Allport, Styles & Hsieh, 1994). The second study uses the same two tasks with a sample of monozygotic twins mirrored for handedness, assessing the combined effects of left and right hemisphere language processing and split frontal control (left and right) during commission of more than one task. The data is assessed to see if this results in differential processing of frontally controlled verbal tasks, as evidenced by differences in switch cost and errors. The third study extends the number of switching categories for the Mixed Category task (the Mixed Category II task), looking specifically for evidence of asymmetry in switch cost between individual categories (Allport, Styles & Hsieh, 1994), relating again to the task-set inertia (TSI) hypothesis. The fourth study examines a methodological issue with the Continuous Series II task, namely whether the order of the categories has any effect on switch cost – this also addresses the previously noted phenomenon of most errors occurring in the category ‘days’. The fifth study further probes methodological issues, assessing the contribution to costs of switching between four categories in the absence of any complex content for those categories – this is done by using repeating colour names instead of continually updated overlearned sequences. The sixth study addresses the memory load implicit in the task by introducing initial letter and whole word cues – this allows for further assessment of proactive interference accounts of switch cost which propose memory of the preceding task set interferes with establishment of the upcoming set. Finally the results from these studies will be used to propose the task-set reconfiguration (TSR) model offered by Rogers & Monsell (1995) as the most suitable explanation of behavioural measures for complex verbal task switching.

The remainder of this chapter will review the relevant literature in order to identify research issues that the rest of the thesis will address. This review will be presented as follows: The first part of the rest of this chapter examines a range of theoretical accounts of task switching and switch cost. This starts with an overview of the original alternating tasks paradigm (Jersild, 1927), comparing blocks of switching and non-switching trials, followed by a discussion of bivalent stimuli, tasks which can afford two possible responses (as in Stroop stimuli). The question of asymmetric costs is addressed, whereby costs are greater when switching to an easier task, linked to the passive task-set inertia (TSI) hypothesis (Allport, Styles & Hsieh, 1994). This is countered with the task-set reconfiguration (TSR) hypothesis (Rogers & Monsell, 1995) whereby switch cost reflects active control and requires the arrival of external stimuli for this switch to complete. This includes description of residual switch costs, a preparation-resistant portion of cost that reflects this external component of reconfiguration. The failure to engage hypothesis (De Jong, 2000) is addressed, an explanation of residual cost that relies on the failure of an individual to take advantage of preparation time. The thesis then moves to look back to redevelopment of the passive TSI account, considering associative interference (Wylie & Allport, 2000) a build up of interference from previous task associations. Another interference-based account is that of backward inhibition (Mayr & Keele, 2000), whereby repetition of a recently practiced task increases switch cost more than executing a new task. The role of cues is addressed (Meiran, 1996) considering how closely cues are associated to tasks, whether there is an additional cost of cue processing (Logan & Bundesen, 2003) and the use of inner speech as a self cuing device (Emerson & Miyake, 2003). Finally the section considers combined dual mechanism models (Braver, Reynolds & Donaldson, 2003) which account for elements of both passive carryover and active reconfiguration accounts.

The second half of this chapter turns to look in depth at the verbal switching paradigm (Gurd, 1995), initially giving an overview of the task and its aims, identifying two important features related to the early presentation of the task (Gurd et al., 2002, 2003) – namely the specific pattern of neural activation seen during the task and the relationship (for this uncued task) to working memory. Each of these questions is explored in more detail, looking first at neural activity associated with task switching in terms of both existing models and the Continuous Series II. The issue of memory load is considered in relation to the verbal task and to its contribution to wider measures of switch cost. A number of pertinent methodological issues are considered: The calculation of general switch cost (e.g. Kray & Linedenberger, 2000), a measure comparing blocks of switching and non-switching trials as opposed to individual switches or repeats within a mixed block. The contribution of global task difficulty and the unusual issue of switching between multiple tasks rather than just two. The use of verbal rather than manual responses and its relationship to inner speech and task verbalisation. The classification of errors committed during the task, positing a model based on Kahneman’s (2011) two-system model of attention and thinking. The section then moves to consider in some depth the relationship of the Continuous Series II to existing models of task switch cost, finally touching on the real world relevance of the task and ending with the thesis aims.

2 The origins of task switching – the alternating tasks paradigm

To switch effectively from one task to another involves the cognitive system activating and inhibiting relevant task sets as they become, and cease to be, required (Baddeley, Emslie, Kolodny and Duncan, 1998). The majority of theorists place the switch cost at this response selection stage, relating either to inhibiting the previous task set or activating the upcoming one (Table 1 gives an overview of the main theories covered in this literature review). The earliest account (Jersild, 1927) used an “A-B-A-B…” *alternating tasks* design, comparing time taken to alternate between tasks A and B with that to complete each task separately, identifying a clear time disadvantage for certain switching conditions. The additional time cost of switching, taken over the additive costs of the individual tasks, was proposed as a direct measure of the time taken to exert executive control. Jersild’s tasks used stimuli presented in the form of lists, either single task (Task A performed on every item) or alternating tasks (Task A performed on odd numbered items and Task B on even numbered items). In addition, items within both kinds of lists could be either *bivalent* (as later termed by Fagot, 1994 – items affording a response from *either* Task A or Task B), or *univalent* (as termed by Pashler, 2000 – items could only be responded to using one task). An example of a bivalent stimulus would be a digit affording responses from both Task A (making an odd or even decision) and Task B (making a parity decision). Task time costs were measured as the total amount of time taken to work through the list, with alternating performance compared to single task. Jersild found performance on bivalent *alternating* lists to be slower than bivalent *single task* lists. Conversely, performance on univalent alternating lists was faster than univalent single tasks lists. It is somewhat surprising that Jersild only found what we now call switch costs (Jersild's 'shift loss') when using bivalent stimuli and even more surprising that univalent alternating lists demonstrated a time advantage over the non-switching condition. Jersild concluded that the bivalent-only switch cost was due to the lack of explicit cueing of the correct response. The 'negative' switch cost for the univalent switching condition was attributed to a more efficient single 'mental set' encompassing both clearly distinguishable tasks. These results were partially replicated by Spector and Biederman (1976). While there was still a cost for bivalent items (albeit a more modest one than that found by Jersild) they were able to extinguish the univalent switching advantage by presenting stimuli on single cards instead of as a list. This removed foreknowledge of the upcoming task[2]. The reduction in bivalent switch cost was attributed to the introduction of an additional 'disambiguating cue'.

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[2] While there is largely agreement in later work that advance preparation affords a time advantage (Altmann (2004); Kray (2006); Meiran & Daichman (2005)), internally generated foreknowledge is taken to be less efficacious than externally generated cues (e.g. Kleinsorge & Gajewski, 2008). Advance preparation effects therefore more commonly refer to those processes occurring between the presentation of a task-specific cue and execution of the task, rather than having advance warning of the task order at the beginning of the switching session.

Table 1 Overview of Main Theoretical Accounts of Task Switching presented in the Literature Review

Theory/ model	Overview	Author
Alternating tasks paradigm	Alternating task lists take longer than single task lists, signifying cognitive control. Criticised for disparate memory load between alternating/ single lists.	Jersild (1927)
Task-set inertia (TSI) hypothesis	Switch cost reflects carryover of activation from the preceding task set – there is an inertial effect in instigating the second task. Criticised for being restricted to Stroop-like stimuli.	Allport, Styles & Hsieh, (1994)
Task-set reconfiguration (TSR)	Uses the alternating runs paradigm (A_A_B_B_A_A...). Switch cost represents active top-down reconfiguration of task set. Cost is reduced by sufficient preparation time. A portion of switch cost (residual cost) is resistant to preparation time, representing reconfiguration, which can only complete once the stimulus arrives. Criticised for the interpretation of residual cost.	Rogers & Monsell (1995)
Failure to engage (FTE) hypothesis	Residual switch cost represents a failure to take advantage of preparation time. Criticised for a failure to replicate results.	De Jong (2000)
Mixing costs	The phenomenon of repeats within a mixing block taking longer to complete than repeats within a single task block, thus inflating switch cost.	Fagot (1994)
Associative interference hypothesis	Previously learned associations between task and stimuli (where one stimulus affords two tasks) build up over time. Costs are also related to starting a task, whether switching occurs or not (restart costs) – this may inflate residual switch cost.	Wylie & Allport (2000)
Backward inhibition	Previously learned associations cause interference – the third task of an A-B-A sequence is more costly than a C-B-A sequence, due to the recency of the task A appearance.	Mayr & Keele (2000)
Explicit cueing paradigm	Allows for random presentation of trials (unlike alternating runs) and accurate manipulation of the pre- and post-stimulus interval, determining the point at which switch processes engage. There may be cue processing costs.	Meiran (1996)
Dual-mechanism models	Both passive carryover and active reconfiguration processes act in concert with each other. Some models posit more than one type of active control.	Braver, Reynolds & Donaldson (2003)

This particular method used by Jersild of calculating switch cost, by subtracting non-switching from switching reaction time, has continued to attract adherents e.g. Rogers and Monsell, 1995[3]; Gurd, 1995; Gurd et al., 2002; Logan, 2006. However, the alternating tasks paradigm itself has not held as much favour, being largely superseded by approaches designed to address perceived disparity in processing demands between single and alternating task lists (e.g. the alternating runs design presented by Rogers & Monsell (1995) as described on page 33). Specifically, the alternating tasks approach was viewed by Rogers & Monsell to be flawed, in that switching and non-switching blocks (or lists) had very different requirements that may contribute to what was being classed purely as a switch-related cost. Alternating required two task sets to be held active and for reconfiguration between these two task sets to occur for every item, which was not the case for single task blocks. These additional processes may have contributed to the overall cost for completing the list or block. Nevertheless, the alternating tasks design has continued to be used for studies with specific design requirements. For example, Rubinstein, Meyer & Evans (2001) and also Gurd (1995) and Gurd et al. (2002) using continuously updating verbal categories which required a task switch on every response and could not encompass a repeat within trial blocks (as per the Rogers & Monsell (1995) design).

2.1 The use of bivalent stimuli

As well as the alternating tasks design itself, it is proposed that the use of bivalent stimuli could also be a possible contributor to switch cost. Much research subsequent to Spector and Biederman (1976) has concentrated on bivalent stimuli. More recent work has speculated again on the role of bivalency and whether it adds a further confound to the

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[3] Rogers & Monsell (1995) applied their subtractive calculation to individual switches within a block rather than comparison of switching blocks to non-switching blocks.

switching process. Although already interpreted as being more costly due to an absence of explicit cueing (Jersild) or unresolved ambiguity (Spector & Biederman), its effects appear to be more far reaching. Rather than just reflecting reaction to the stimulus, it has been proposed that increased costs associated with bivalency reflect uncertainty in response selection, in addition to activation of the upcoming task set and inhibition of the previous one (Kray & Lindenberger, 2000). This has been reframed as ‘cognitive caution’ in the face of response choice (Woodward, Meier, Tipper and Graf, 2003), from findings that the addition of a small number of bivalent stimuli to an otherwise univalent switching block resulted in larger time costs but often reduced errors. Slowing is incurred by *all* tasks, not just those afforded by the bivalent stimuli, known as *bivalency cost* (Woodward et al., 2003). The idea that additional cost was due to an increase in the number of active task sets to be inhibited was rejected (Woodward et al., 2003). Arguably this could be a case of interference from prolonged priming of *control* processes (Meier, Woodward, Rey-Mermet and Graf, 2009), which could also explain costs spreading over to univalent stimuli. Task uncertainty is seen as being a relatively short lived phenomenon (Woodward et al., 2009). That the bivalency cost persisted over long inter-trial intervals (up to 5000 msec) showed that top-down caution was the cause of cost. Bivalency effects have also been interpreted (Meiran, 2008) as evidence of the need to recode responses between each stimulus presentation. Meiran used the ‘alternating runs’ switching paradigm (described in detail on page 33), which alternates between *runs* of tasks (AABB…) rather than Jersild’s *consecutive* task alternation (ABAB…) Response recoding would be required when repeating responses as well as switching responses in the alternating runs paradigm, explaining the univalent advantage in earlier work and evidenced by a bivalent-only preparation advantage – enough time to prepare for the upcoming task reduced switch cost but only for bivalent stimuli.

Repeated recoding and ‘cautious hesitancy’ both offer plausible explanations for these cost patterns. Additional evidence from imaging data indicating increased parietal activity during responses to bivalent stimuli (Woodward, Metzak, Meier & Holroyd, 2008) is consistent with both attention shifting and storing of phonological material in working memory. This could possibly account for (at the single stimulus level) confirmatory verbal representation or recall of task instructions to assist in response checking (or recoding). While bivalency affords flexible task design, like many aspects of the wider task switching paradigm it seems to bring with it an additional source of cost, namely response selection uncertainty (‘bivalency cost’) and the need for repeated encoding. Extinguishing or subtracting the effect of these additional ‘inflationary’ processes is for many the ‘holy grail’ of task switching research. For others, such as Allport, Styles & Hsieh (1994) and Altmann (2002; 2003), costs accrued by switching between tasks reflect nothing but these additional processes.

3 Asymmetric Switch Costs: Task Set Inertia and Task Set Reconfiguration Accounts

The notion that task switch cost represents not active top-down executive processes but instead passive bottom-up peripheral processes represents one of the first major revisits to the topic since Spector & Biederman (1976) replicated Jersild’s work. While most theories agree that switch cost occurs at the response selection stage, there is much debate as to exactly what causes that cost. Theories can be broadly divided into passive inhibition/ interference or active reconfiguration accounts. Examples of passive interference accounts include interference from the last task performed (Allport Styles & Hsieh, 1994), varying interference from recent and less recently performed tasks (Mayr & Keele, 2000) or sustained interference from previously made stimulus-response mappings (Wylie & Allport, 2000). Alternatively, many still follow Jersild's assertion that switch cost instead reflects active cognitive control in reconfiguring the system from one task set to the next (e.g. Rogers & Monsell, 1995; Rubinstein et al., 2001) , albeit using a less direct translation of time costs to control.

3.1 Task set inertia (TSI)

Further replication of Jersild's experiments was carried out by Allport, Styles and Hsieh (1994); they completed a series of experiments including use of a Stroop switching task, switching between colour naming and word reading in a single block. In addition to expected Stroop incongruency effects (slowing for incongruent colour naming but not word reading, as per Stroop (1935)), they found much larger switch costs when switching from colour naming to word reading than vice versa (Experiment 5). Switching to the 'easier' more dominant task appeared to be more difficult to achieve, producing *asymmetric switch costs*. That the asymmetry runs in the opposite direction to that of the Stroop (while it is easier to read words, the task results in greater switch cost) is surprising. This seemingly runs counter to the argument that switch cost directly reflects the cognitive control used to switch task set, which would predict that the harder task would require more executive input to be initiated. If switch cost represents the time taken to exert cognitive control then tasks requiring *more* control will result in larger switch costs – colour-naming in the Stroop is taken to be "…the very paradigm of a 'controlled' task…" (Wylie & Allport, 2000, p.215). As larger switch costs are found for the task which requires *less* control (word reading) then it would seem that switch cost cannot be a direct measure of such control processes.

Advocates of reconfiguration-based accounts, which ally themselves to a control-based interpretation of switch cost, concede that asymmetry initially seems incompatible with such an explanation (for example, see Monsell, 2003). Allport and colleagues interpreted this asymmetry as interference from the previous 'harder' task set delaying activation of the upcoming 'easier' one. Task sets are proposed to endure over the time course of a switching scenario, having a dynamic inertial effect on the activation of a new task set. Harder tasks, requiring more executive support, will exert more of this active interference on easier tasks, resulting in larger 'harder-to-easier' switch costs; this asymmetric interference effect was termed *task set inertia (TSI).* When features of one task set had previously been associated with different S-R mappings in the previous task set (as is the case for Stroop switching) then proactive interference from Task A to Task B occurred. Further strong evidence of asymmetry from bilingual task switching (digit naming in alternating languages, Meuter & Allport (1999)) was taken to add support to the TSI theory of switch cost in tasks of unequal difficulty; asymmetry was reduced as language proficiency converged. Additionally, there was no evidence of a cumulative inhibition effect (the degree of interference from word-reading to colour-naming did not increase over the time course of the task), suggesting that TSI is a localised pre-stimulus event.

The drawback of the TSI hypothesis is that evidence to support it comes almost exclusively from asymmetric task pairings. Allport's argument is that such pairings, resulting in asymmetric costs, cannot (and do not) reflect actively imposed control processes which shift the cognitive system from one task set to the next. Asymmetric tasks are therefore an exemplar of TSI in action – proactive interference is greater when tasks are asymmetric. The assertion of Allport and colleagues that such tasks do not show evidence of any costs which reflect the time taken to switch task set leads them to question the suitability of control processes as an explanation for switch costs.

But does the specific nature of the tasks used to demonstrate TSI limit its applicability? One later study by Yeung, Nystrom, Aronson & Cohen (2006) looked for associated brain activation that would support enduring residual activity related to the previously performed task, thus supporting a hypothesis of TSI interference as a source of cost. The study used far more symmetric tasks, face and word classification (gender or two/ not two syllables), with no overlap of S-R mappings. Findings indicated a correlation between switch cost and neural activity for the now irrelevant task following a switch, supporting the existence of task set inertia, but crucially not as the *sole* source of switch cost. Separable activation was also found for the task being switched *to* – further analysis identified these as two distinct processes rather than a blanket level of activation over time during switching. While this evidence supports some role for TSI it does not do so at the exclusion of concomitant executive control processes, which is a departure from Allport's original presentation of the hypothesis (Allport, Styles & Hseieh, 1994). It also extends the application of proactive interference beyond the confines of S-R overlap between tasks, suggesting that such interference may be more widely indicated in conjunction with controlled task set switching processes.

While interference from the non-current task set is intuitively appealing as a source of switch cost, the reliance of TSI on counter-intuitive asymmetric costs limits its explanatory usefulness[4]. Competing theories of switch cost relying on input from active control processes (such as that of Rogers & Monsell, 1995) acknowledge the contribution of inhibition but question the cause of asymmetry, having found it occurring in both ‘directions’ (Yeung & Monsell, 2003a; see also Glaser & Glaser, 1995) using a Stroop-style task with both simultaneous and word-delayed presentation of the word-colour combination. Presenting word and colour simultaneously (a black word on a coloured background) as per the normal Stroop allowed for replication of Allport’s asymmetric switch cost. When presentation of the word occurred 160ms after presentation of the colour, a reverse asymmetry effect was found with greater switch costs being attached to the harder task of colour naming. This change in asymmetry direction is attributed to the extent to which the strong task is *able* to interfere with the weaker one, suggesting a ‘suppression threshold’ for interference. This reverse effect was repeated using both the feature-delayed Stroop (as described above) and differing response modalities for the tasks (key press versus spoken response) (Yeung & Monsell, 2003a).

So in what way is this ‘suppression threshold’ explained? Asymmetry was ascribed to a combination of priming for the difficult task in the face of competition from the stronger, easier task (difficult to easy switch) and control of the easier task to reduce competition with the harder task (easy to difficult switch). The ability of one task to interfere with the other is relative to the initial strength of the tasks (prior task-stimuli associations), the requirement to switch or not and to the direction of that switch. Greater interference may require greater suppression of the easier task during harder task performance, resulting in difficulty

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[4] Sumner and Ahmed (2006) later specified three possible sources for this interference, including stimulus-response associations for the previous task (accounted for in a later adaptation of the TSI model (Wylie & Allport, 2000)) and interference control active for the last task (controlling interference from the now current, but previously unwanted, task set).

switching from hard to easy, but this is dependent upon the level of initial activation required for each task as demonstrated by the ability to reverse asymmetry through feature manipulation (Yeung & Monsell (2003a) as reported in Monsell, Yueng & Azuma (2000)[5], namely temporal separation of the presentation of colour and word.

Further examples of reverse asymmetry (e.g. Rubinstein, Meyer & Evans, 2001; Wager, Jonides & Smith, 2006) add weight to the conclusion that the asymmetry effect is confined to specific pairings of tasks that not only differ on difficulty but do so to a specific degree. A high degree of variability in the Rubinstein data (using arithmetic tasks) fits well with the relative interference hypothesis component of baseline task strength. Passive carryover of inhibition (as evidenced by asymmetry, itself dependent on disparate, threshold-related task difficulty) is inflexible as a sole descriptor of switch cost and so the TSI account is limited in its application to explain all instances of switch cost. The phenomenon of asymmetric costs continues to attract interest (for example, Schneider & Anderson, 2010) but explanations have not remained confined to offering support for the TSI hypothesis. Manipulation of the direction of asymmetry (Yeung & Monsell, 2003a) and proposals that costs relate to preceding task difficulty regardless of the need to switch (i.e. also on repeat trials) (Schneider & Anderson, 2010) somewhat dilute the initially strong TSI-based role for asymmetric costs.

Later work which also utilised asymmetry is that looking at the phenomenon of backward inhibition, which is the *active* (rather than passive) sequential inhibition of the

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[5] Support from connectionist modelling of Stroop-type switching (Gilbert & Shallice, 2002) indicates easy tasks require little activation and little inhibition of competing nodes, due to their strong associative profile; harder tasks require the opposite, manifesting as greater input to the network, and result in hard to easy asymmetry.

immediately preceding task set. Asymmetry (greater costs associated with switching from a harder to an easier task than vice versa) was used when switching to indicate a role of both inhibition and activation processes. Backward inhibition dictates that if three tasks are performed in the sequence A-B-A then the third task will be slower than in the sequence C-B-A, because the inhibition of Task A from its first appearance needs to be ‘undone’ when it reappears[6] (e.g. Koch, Gade & Phillipp (2004), Mayr & Keele (2000) as described on page 53). In investigating the effect of asymmetry on backward inhibition, Arbuthnott (2008) found both asymmetric and reverse-asymmetric costs were shown, depending on the relative strength of the tasks, in accordance with Yeung & Monsell's (2003a) active control threshold account. The active control threshold account proposed that the presence of asymmetry or reverse asymmetry depends on the ability of the harder task to interfere with the weaker, which may be variable and is dependent upon some threshold. Independently of asymmetric switch costs, asymmetric backward inhibition occurred when task sequence A-B-A took the form easy-difficult-easy, regardless of relative task strength and highlighting the role of inhibition. The backward inhibition hypothesis therefore accommodates both activation and inhibition processes as a source of cost.

Returning to the question of relative difficulty between asymmetric tasks, it is also worthy of note that Jersild (1927) found switching *between* two easy tasks to be more costly than switching between two harder tasks. Introducing the cost related to switching to two tasks that are relatively unpractised resulted in less loss in terms of time. Jersild related this to the relative difference in practice or familiarity between two harder tasks being less than that between two easy tasks. The effect of the introduction of switching was likened to the

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[6] When switching between three tasks, performance on task 3 is slower when it is a repeat of task 1 than if all tasks are different, attributed to dissipation of inhibition over time.

introduction of any other disrupting effect to a well practiced (easy) or less practiced (hard) behaviour – the interruption has more effect on the more habitual behaviour, due to the stronger S-R associations built up for the easier tasks. Jersild's interpretation does not make sense in terms of an additive interpretation of switch cost (time Task A + time Task B + time switch) but does suggest some effect of inhibition. Coupled with the relative strength hypothesis of Yeung & Monsell (2003a) this would seem to suggest that in certain combinations tasks do have the ability to interfere with one another.

Some eighty years later (and apparently independently from Jersild's findings) Bryck and Mayr (2008) cited asymmetry in the absence of switching as evidence of interference from long term memory traces rather than a localised transient switch-dependent effect. That both difficulty for easier tasks and asymmetry should occur without a switch questions whether some proportion of the asymmetric cost is in fact a non-switch related measure. Further to this, a confound from coinciding task and difficulty of switches has been proposed as masking the contribution of the latter (Schneider & Anderson, 2010). The contribution of the change in difficulty is not fully accounted for when the task itself also changes. The ensuing "…sequential difficulty effects" (Schneider & Anderson, 2010, p.1873) impair performance *following* a difficult task regardless of the need to switch, resulting in asymmetry. It is not, they argue, the switch that causes the difficulty but the fact that the previous task was difficult. Difficult tasks require more (unspecified) resources, leaving less available for subsequent tasks and taking time for the 'resource' to recover.

Continuing with this question of relative task difficulty and how the tasks relate to each other, Allport's passive interference account of asymmetry was eventually abandoned in favour of a continuous (rather than transient) build up of interference from previous task set associations during switching (Wylie & Allport, 2000, described in more detail on page 46). This latter model has also consistently resisted the inclusion of an executive component. This is despite asymmetry-based evidence that activation and inhibition are not mutually exclusive descriptors, such as was proposed in Arbuthnott’s activation-inhibition hypothesis (Arbuthnott, 2008) and in Schneider and Anderson’s conclusion that both executive control and working memory are plausible candidates for their difficulty-related resource (Schneider & Anderson, 2010).

Some years earlier to his work with proactive and continuous interference, Allport (1980) had posited that divided attention studies, while seeking to specify some generalised processing (resource) capacity limit, were often using tasks which instead imposed a ‘data-limit’, with overlapping task requirements (for example listening to speech and reading text) being responsible for much of the time costs. In seeking to avoid such a data-limit, Allport introduced an additional task-bound cost. Task switch inertia (TSI) might be an artefact of Stroop stimuli – asymmetric costs are reliant upon tasks of differing difficulty and, it seems, differing relative strength above a certain threshold (according to Yeung & Monsell (2003a). Therefore any interpretation of asymmetric costs must be equally task specific. Enduring inhibition of the easier task has not remained a popular explanation for asymmetric switch cost (and indeed is not a necessary one, as evidenced by reverse switch cost asymmetry) but, as demonstrated by Arbuthnott (2008), it may well contribute to costs indirectly and in tandem with activation processes.

3.2 Task-set reconfiguration: Alternating runs

The thesis now turns to look at a second theory of task switching, developed concomitantly to the TSI hypothesis of Allport, Styles & Hsieh (1994). This second reconsideration of Jersild's work (Roger & Monsell, 1995), concurring with Jersild's much earlier proposition that switch cost reflected active cognitive control – this was a hypothesis reliant on top-down processing. However, in the original task Jersild (1927) assumed no additional processes to executive control to be inherent in switching. As the thesis has already examined (page 21-24, relating to *'switching and non-switching blocks (or lists) had very different requirements'*) processes such as holding more than one task set active during switching and reconfiguring for every item during switching (when compared to non-switching) were additional to the actual switch itself. Rogers and Monsell (1995) questioned the contribution to switch cost from the additional load on working memory of maintaining two tasks sets for the switching trial compared to one for the non-switching trial. They proposed an *alternating runs* design (AABBAABB…), comparing task repetitions (AA or BB) and task switches (AB) within a single trial block, ensuring comparable memory load for both repeats and switches, as two tasks sets had be maintained throughout[7]. Like Jersild they used letter and number decision tasks (vowel/ consonant, odd/ even), presenting stimuli pairs e.g. 'G7' consecutively and clockwise on a 2 x 2 grid, with grid position providing an explicit cue for the task to be carried out e.g. top row/ letter decision. The presentation pattern meant that two letter decisions were followed by two number decisions, and so on.

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[7] In their original set of experiments, Rogers and Monsell were unable to directly address asymmetry (as per Allport, Styles & Hsieh (1994) Experiment 5) as tasks were deliberately chosen to be comparably difficult.

3.2.1 Residual switch cost

Unlike Allport and colleagues, Rogers and Monsell posited the view that switch cost (at least for alternating runs of AABB...) reflected the input of intentional control, through the need to *reconfigure* the system between one task and the next. Their more regimented method of presenting stimuli (using a grid pattern to cue response) triggered specific *response* selection rather than task set selection. This method allowed the time between a response and the next stimulus (*response to stimulus interval* – RSI) to be manipulated and used as a measure of preparation time for the upcoming task. Switch cost decreased as RSI increased, but was not fully extinguishable even at the longest interval of 1,200 msec [8]. Rogers and Monsell termed this practice-resistant portion of cost *residual switch cost*, located specifically to the first trial of a run (their Experiment 6). This was attributed to an *exogenously controlled* part of reconfiguration, which could only *complete* once stimuli were presented. Exogenous control of reconfiguration is manifest from "...the availability, frequency and recency of the alternative tasks afforded by the stimulus…" (Monsell, 2003, p.134). Endogenous control processes are afforded by internally generated goals. The exogenously controlled component was thus not able to benefit from any amount of practice time. While endogenous control was intentional, self initiated and a pre-stimulus preparatory process, exogenous control was an involuntary, stimulus-bound action. As noted by Monsell, "…there is ample evidence that stimuli can of themselves activate or evoke in a person a tendency to perform actions (or tasks) habitually associated with them, irrespective of prior intention, and sometimes in conflict with prior intentions" (Rogers & Monsell, 1995, p. 208).

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[8] Interestingly Rogers & Monsell (1995) found no reduction in switch cost when RSI was randomly varied within a single block (Experiment 2), which they interpreted as conscious reluctance to reconfigure in advance when there was a possibility that the process would be interrupted due to an unpredictably short RSI, resonating with the 'cognitive caution' explanation of responses to bivalent stimuli (Woodward et al., 2003).

However, the relationship between the endogenous and exogenous components of control was under specified by Rogers and Monsell (see Waszak, Hommel & Allport, 2003). While an external ‘trigger’ for completion of the reconfiguration process fitted their residual cost data, the exact role of this trigger was not clear (their explanation stops short of a confirmatory feedback role). The notion of exogenous and endogenous control per se is well established (Pashler, Johnston & Ruthruff (2001) offer an extensive review), but definitive and consistent evidence supporting Rogers & Monsell’s exogenous completion hypothesis is elusive. Using tasks that differed in familiarity (unfamiliar or familiar), rule complexity (simple or complex) and presence of visual cues (present or absent), Rubinstein, Meyer & Evans (2001) determined what portions of the switching process are additive. They found that task switching and task difficulty (as indicated by the complexity of rules) are additive contributors to switch cost. They interpreted this as favouring a model that included a separate pre-stimulus goal shift (in line with Rogers & Monsell, 1995) and a rule activation process that was stimulus dependent. They found that this post-stimulus completion of reconfiguration did act in a confirmatory role to the pre-stimulus goal shift. As noted this was not established by Rogers & Monsell (1995).

Further ‘circumstantial’ evidence can be taken from the identification of neurally separable processes for endogenous preparation and exogenously triggered modification of task sets (Sohn, Ursu, Anderson, Stenger & Carter, 2000). In this instance, lack of foreknowledge maximises exogenous reliance, although motor response selection and execution cannot be ruled out entirely as a major contributor to the parietal component of their model. In a separate study, Sohn & Carlson (2000) found foreknowledge facilitated *faster* task performance but did not extinguish switch cost, suggesting a role for the exogenous (stimulus) component. They proposed the exogenous ‘controller’ facilitated application of the endogenously triggered *current* task set by completing disengagement of the *previous* task set. In this model, residual costs reflect the need for the fully prepared current task to wait for confirmation that the previous task is no longer applicable, rather than confirmation that the current task *is* applicable. The exogenous component, while seemingly necessary and present in residual costs, is separable from the preparation stage. While concurring with the notion of reconfiguration as a "…sort of mental 'gear changing'…" (Monsell, 2003, p.135), the exogenous element of the task 'clears a path' for the gear change rather than finalising it – an exogenous-*disengagement* hypothesis.

3.2.2 Response selection, cue processing and asymmetry as sources for residual switch cost

As an alternative to this somewhat piecemeal picture of the role exogenous control *might* take, attempting to eliminate residual costs altogether would seem a more straightforward approach to defining this exogenous-completion hypothesis. Monsell has described such attempts as "...rare and...problematic" (Elchlepp, Lavric' Mizon & Monsell, 2012, p.1138), citing only two examples[9] (Verbruggen, Liefooghe, Vandierendonck and Demanet, 2007; Lien, Ruthruff, Remington & Johnston, 2005). Verbruggen and colleagues were able to reduce (and in one case completely remove, Experiment 2) residual switch cost by reducing the availability of the cue during preparation. Short cue presentation forced the cue to be used early on in the process, purportedly encouraging early completion of advance preparation. It was hypothesised that residual costs were cue- rather than stimulus-bound. The criticism from Elchlepp et al. was that the potential existed for a confound between the *task* switch cost and the *cue* switch cost, a phenomenon identified by Monsell & Mizon (2006) (cue switch costs are discussed in more detail on p.46 of this document). Such confounds are

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[9] Perhaps in itself an example of the overly-judicious choice of literature so decried by Altmann (2000).

reported to be overcome by the use of two cues per task (Monsell & Mizon, 2006) – the Verbruggen study used only one. However, there is not complete agreement on the contribution of cue switches to switch costs (see Altmann 2006: Schneider & Logan, 2007).

A second possible source for residual cost is as an artefact of the response selection process. Examining response-switches as well as task-switches and task-repeats, Meiran (2000) interpreted residual costs as a reflection of post-stimulus/ post-*switch* response-bound processes. Costs are accrued after the stimulus is presented and after the switch is made – residual costs are bound to response selection. According to Meiran's model, residual costs reflect reconfiguration of 'response set', associations made between specific responses and salient features of the current task, for example 'press Z key' might denote 'small' in a size decision task and 'red' in a colour decision task. The response set is reconfigured separately from reconfiguration of *task* set; TSR can occur in advance (in response to a cue or foreknowledge) but response set reconfiguration must by necessity occur *after* the current task has been completed. Similarly, Hunt and Klein (2002) also linked residual costs to response selection. They were able to extinguish residual costs, by affecting a 'hyper-compatibility' of response and stimulus. The task/ response involved looking towards or away from a shaded box – they proposed that this bypassed the motor response selection stage, drastically reducing the need to actively select a response. The S-R mapping is so strong that very little attention or memory is required to exact it. Such S-R mappings have previously been described to include tasks with high ideomotor compatibility (such as repeating something that is heard, Greenwald (1970)) or those with highly overlearned responses[10] (Mowbray & Rhodes, 1959). Alternatively, the hyper-compatibility may be so

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[10] As such this has resonance with the Continuous Series II verbal switching task which uses verbal overlearned sequences

close as to skip rule activation (rather than response selection), causing completion to be triggered by the cue rather the stimulus; the net effect would be approximately the same, albeit mediated by cue rather than response.

A further example of response dependent residual cost also been cited by González, Milán, Pereda & Hochel (2005), using a pre-switch task-related response (key press during inter-trial interval) to extrapolate processes related to the response set. The aim was to see whether residual costs could be eliminated by an extra response – this had the effect of determining how much response selection contributed to costs. The extra response was completed before completing the switch trial. An extra key was pressed during the inter-trial interval in order to proceed with the task – this time was seen as an opportunity for task preparation. Inclusion of this extra ‘task-free’ response resulted in an elimination of residual switch cost. It was concluded that the additional response was enough to trigger the completion of reconfiguration – it was making a response rather than making a task-specific response that triggered this. This effect only occurred when there was a choice to be made between responses (either related to the two tasks or not) – it did not occur when a non-choice response of pressing the space bar was made. The supposition was made that only tasks requiring different S-R decisions could result in such an effect. However, the application of this interpretation is again limited to particular circumstances. Meiran’s interpretation, of residual costs being response bound, is only applicable for tasks in which there is an arbitrary additional response requirement, such as using the same response to mean different things for different tasks. In those using verbal responses e.g. Arbuthnott & Frank (2000) and those where task and response sets are intrinsically bound, this response-bound hypothesis is negated. An example of such binding would be Gurd’s (2000) use of sequential incremental switching between verbal categories such as numbers and months where, for example, the response ‘Tuesday’ is intrinsic to the category ‘days’. Although these are overlearned sequences they are not compatible with Hunt & Klein’s definition of ‘hyper-compatibility’, where the S-R mapping (including those which are overlearned) is so strong as to dispense with the need for active response selection. This is because of the need to update the category on every response – responses are explicitly bound to tasks but not hyper-compatible. Indeed, caution should also be exercised in interpreting evidence from ‘cognitively stripped-down’ tasks such as Hunt & Klein’s (2002) which are *so* exogenously bound as to almost eliminate the need to actively impose switching.

Finally, credence should be given to the notion that asymmetry is a potential source of residual-type costs without recourse to an exogenous reconfiguration component (Hübner, Kluwe, Luna-Rodriguez and Peters, 2004). Response *repetitions*, particularly of the more difficult task, inflated switch cost in such a way as to *mimic* results attributed to exogenous reconfiguration, due to a lack of control over the task sequence. If residual costs are greater for more complex tasks needing more reconfiguration then an exogenous account can be accepted. In the Hübner study, complexity and familiarity of S-R rules was varied. It was found that if tasks were more complex or less familiar there was *no* increase in switch cost. This was taken to exclude an explanation using exogenously based reconfiguration. In particular, stimulus repetitions (excluded from the analysis) were found to inflate switch costs, particularly for more difficult tasks with increased difficulty of response selection. It was posited that inclusion of such repetitions in the wider literature inflated switch cost – inclusion of such repetitions, particularly for more difficult tasks, could lead to erroneous conclusions of residual costs. Hübner concludes that task switch costs relate to different processing strategies on switches and repeats rather than exogenous reconfiguration or proactive interference, stating that a lack of control over the task sequence may account for residual costs. As previously discussed, sequential effects can mask task contribution in asymmetry (Schneider & Anderson, 2010), adding weight to just such a faux effect. Arbuthnott & Frank (2000) have suggested the need to overcome previous inhibition of a current task (‘backward inhibition’ as described on page 53) may be a major component of residual costs. Switch costs in that study were significant for series of two tasks but not of three, suggesting inhibition dissipated over time rather than being entirely stimulus bound. Paradoxically, Sohn & Carlson (2000) found that performance was faster with foreknowledge for the task but that switch cost was not reduced, leading them to conclude that switch cost is dependent upon reconfiguration rather than inadequate preparation time.

In summary, Monsell says attempts to eliminate residual costs are not consistent and the evidence would seem to support that. Attempts to do so seem reliant on potentially confounding issues such as cue presentation. Selection of response rather than task set can be limited by a lack of cognitive input to the task (Hunt & Klein’s ‘hyper-compatibility’) and does not apply to tasks where the response is implicitly bound to the task (e.g. Gurd, 1995). Hübner and colleagues state that inclusion of repetitions may inflate switch cost in a way that mimics residual costs particularly for more difficult or asymmetric tasks. However, like the original TSI hypothesis (Allport, Styles & Hsieh, 1994) this explanation is limited by its choice of stimuli. Not all studies include more difficult tasks; in particular the study which proposes reconfiguration as a source of cost, Rogers & Monsell (1995) chose tasks to be of comparable difficulty. The verbal paradigm of Gurd (1995) also includes entirely comparable tasks, those being overlearned sequences. It would seem that while there are examples of eliminating residual costs these are far from consistent.

4 The failure to engage hypothesis of residual switch cost

One further prominent explanation of residual costs is the suggestion that residual switch costs are due to a *failure* to engage (FTE) advance preparation time (for a proportion of trials) rather than an *inability* to complete reconfiguration endogenously (a reliance on exogenous completion) (De Jong, 2000). In this explanation advance preparation is seen as optional and advantageous, rather than a necessary requirement as advocated by Rogers and Monsell. Advance preparation may be faster, but reconfiguring after the stimulus has arrived achieves the same outcome, noted by De Jong as a slower, more accurate process. Analysis of data to confirm the FTE hypothesis involves considering the whole distribution of RT rather than just means, in order to find the instances where there is a failure to engage with advance preparation. Like Hübner et al. (2004) who questioned the inclusion of repetitions in the last section of this thesis, this questions the calculation of switch cost for the alternating runs paradigm as masking some of the effects. Long RSI should therefore produce a mixture of outcomes rather than just evidence of residual costs on every first trial.

Failure to engage may be due to a failure to grasp the advantages of preparation (results gained by Allport et al. (1994) and Roger & Monsell (1995) are cited as possible examples of this). There needs to be an additional intention to use the advance preparation time, extra to the intention to change task set. The intention must be retrieved at the appropriate time to be used. Individuals need to hold in memory an associative cue-action pairing in order to subsequently retrieve the intention for action – in such a pairing the action would be taking advantage of advance preparation time. It is possible that in some circumstances such a pairing is never made. This is proposed to be due to a failure to appreciate the benefits of advance preparation time. It is posited that this may account for studies where preparation has not found to be advantageous (Allport, Styles, and Hsieh 1994; Rogers and Monsell 1995, Experiment 2). A second reason for failure to engage is that of a low threshold representation of the cue and its associated task (S-R mappings). In this case the activation level or strength of the cue-action association is too low for the cue to act as a trigger to prepare in advance. There may be several reasons for this – low subjective utility of the expected benefits of the action; limited capacity for maintaining intentions in WM; the effort related to maintaining the cue-action representation at a high level of readiness. De Jong notes the possibility that instructional specificity may have a part to play in this; his instructions explicitly directed participants to make use of the RSI to prepare, a method also employed by Altmann (2004, Experiment 3).

Failure to take advantage of preparation time is also noted to occur when only one option for preparation time is available (Altmann, 2004). Residual costs are said to occur only in situations (e.g. experimental procedures) where the amount of time to prepare is varied. In light of this variation of available preparation times, the cognitive system will take advantage of the *longer* preparation time (SOA/ RSI). When there is no variation in available preparation times the system will fail to make use of this time, even if the length of time matches that which gave an advantage in varied experimental conditions. Both De Jong’s and Altmann’s descriptions bear close resemblance to the ‘cognitive caution’ explanation for bivalency effects (Woodward et al., 2003), whereby inclusion of a small number of bivalent stimuli in a univalent switching block results in a pervasive slowing on *all* trials regardless of bi- or univalent status. A *mix* of stimulus affordances or preparation availability appears to have a similar effect. The bi- and univalent mix employed by Woodward and colleagues would have differing requirements for response-set reconfiguration, as in the Meiran (2000) model – there switches and repeats contributed differentially to switch cost. De Jong proposes that reconfiguration in failed preparation trials occurs as a post-stimulus event, seen by Meiran as the site of consequential response reconfiguration. This is in contrast to the stimulus led completion of reconfiguration proposed by Rogers & Monsell (1995). It seems difficult to rule out even partial response bound inflation in such mixture-models; while *response*-set reconfiguration as proposed by Meiran may not be a sole source of residual costs, it would seem more likely as a contributory factor if we are to accept such a mixture of preparation (or Woodward's response affordance) during switching. Acceptance of De Jong's model would seem to imply the need for this element of post-switch disambiguation and thus an alternative (or dichotomous) source of cost.

However, De Jong's explanation has not gone unchallenged – Monsell has replicated key elements of the study with quite different outcomes. In addressing De Jong's model, Nieuwenhuis & Monsell (2002) were able to reduce but not extinguish residual costs by maximising motivation to engage advance preparation, noting "…our carefully instructed, highly motivated, young, bright, and nonfatigued participants, were still failing to engage… It is interesting to speculate what one could do to increase the probability of preparation further." (Nieuwenhuis & Monsell, 2002, p.91). De Jong's finding of zero residual cost was linked, they speculated, to the presence of highly explicit cues[11]. If these were a necessary component for successful endogenous activation in advance of the stimulus, they would in effect constitute a variation of their own exogenous completion hypothesis (Rogers & Monsell, 1995). The explicit nature of the cue (e.g. the cue containing the two colours that have to be distinguished between for the task) might constitute an exogenous driving force to successfully engage intention activation on all trials. While this proposition does no more to specify the role of the exogenous controller from their earlier work (other than to allude to its

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[11] Monsell (2005) later noted that he had still not seen evidence of such an effect

necessity), it does suggest another possible contributor to the zero cost result (De Jong, 2000). It can be argued that, in the presence of highly explicit cues, all of the complexity requirements (and thus much of the control requirements) of the task are stripped away, resulting not in exogenously-controlled completion of endogenously-activated control, but removal of an entire processing step in the task, as previously noted in relation to Hunt & Klein's (2002) hyper-compatibility hypothesis.

There are further challenges to the FTE hypothesis. De Jong's model has been criticised for insufficient demonstration that repeat trials are fully prepared (Kiesel et al., 2010). Indeed, Meiran & Chorev (2005) believe a single preparation process to be inadequate and cite a second 'phasic alertness' process (potentially enhanced by increased incentive) as responsible for extinguishing residual costs. Phasic alertness is the optimisation of response readiness subsequent to a cue in a cued RT task (Sturm & Willmes, 2001). Lien, Ruthruff, Remington and Johnston (2005) sought to increase incentive even further by applying a rigid response time limit (cost-reflecting responses violated the limit and resulted in errors), with highly explicit positive and negative visual feedback embedded within a game scenario[12]. They concluded that *partial* rather than full preparation was possible (by virtue of preparation occurring for only *one* task relevant S-R mapping[13], not all) and that it occurred on all trials. It is possible that failure to fully utilise preparation time occurs at a more intrinsic level than that suggested by De Jong, thus not fulfilling his 'all or nothing' *trial* preparation requirement, or that preparation is not a single time-dependent process.

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[12] Nieuwenhuis & Monsell (2002) had used a performance related monetary incentive, with negative feedback on repeated errors. Lien et al. (2005) believed the avoidance of negative feedback within their game scenario task to be a more rigorous incentive. Feedback consisted of a yellow smiley face (positive) and an affected explosion (negative) for Experiments 2 and 3.

[13] They manipulated instructional presentation for three S-R mappings (left, centre, right) to take advantage of left-right reading direction and encouraging preparation for the first presented.

5 Mixing costs

The issue of repeat trials, however, has further relevance than just an unspecified element of the FTE hypothesis (De Jong, 2000) and the thesis will now turn to look at the relevance of these repeats in more detail. It has been proposed that an additional source for time costs in the alternating runs paradigm is that of *mixing costs* (Fagot, 1994) [14], the reaction time difference between repetitions in switching blocks and pure task blocks. These are in effect the time cost of *mixing* tasks together but not switching between them. While this would potentially inflate measures of general or whole-task switch cost, it could also render mixed block repeats a questionable basis for calculating local costs (see Kiesel et al., 2010). A method used to counter additional working memory load during switching is the alternating runs paradigm (e.g. Rogers & Monsell, 1995). Wylie, Murray, Javitt and Foxe (2009) maintain the value of separate pure task blocks (as per Jersild's alternating tasks) as a baseline in extrapolating cue and task switch costs in mixed blocks.

Mixing costs were initially thought to reflect working memory load in relation to the number of task sets (Los, 1996). More recently this has been refined to task or response conflicts attributable to the use of bivalent stimuli (Rubin & Meiran, 2005) – mixing costs were not found in switching trials using univalent stimuli (their Experiment 1). This is attributed to competition rather than merely having to hold the task sets in working memory. The less predictable the set of S-R mappings for the task, for example as demonstrated by Koch, Prinz and Allport (2005) (also Poljac, Koch & Bekkering, 2009) using consistent and

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[14] There is a notable lack of consistency in the definition of mixing costs which can be problematic in comparing studies on the phenomenon. For example, Schneider & Anderson (2010, p.1875, emphasis is mine) "...mixing costs, which are performance decrements for *easy* stimuli in *mixed* blocks (consisting of easy and difficult stimuli for the same task) compared with pure blocks (consisting of easy stimuli only)". Kiesal et al. (2010, p.850) state that: "Mixing costs reflect the "general" costs associated with task switching compared with performance in single-task situations" – general costs reflect both mixing *and* switch costs e.g. Verhaegen and Hoyer (2007)

varied mappings, the greater the mixing costs. This was viewed as indicative of involuntary interference for both repeats and switches, in line with earlier inhibition-based accounts of switch cost (e.g. Allport, Styles & Hsieh, 1994; Wylie & Allport, 2000). Later work (Phillip, Kalinich, Koch & Schobotz, 2008) further defined mixing costs as reflecting conflict resolution on the *current* trial. Switch costs were found to reflect both this current trial conflict and carryover of proactive interference from the *preceding* trial. Thus mixing costs do appear to contribute to switch costs.

However, mixing costs in the *absence* of time switch costs[15] (and vice versa, see Allport & Wylie, 2000) as reported by Koch et al. (2005), may be indicative of a task or response-*type* specific phenomenon. More specifically, mixing costs were found in the absence of RT switch costs, although switch related error costs were found. Mixing costs were greater for bivalent than univalent stimuli. It was proposed that these bivalent mixing costs reflected appropriate task and or/ response retrieval. This relates again to Meiran’s (2000) response (rather than task set) selection explanation of residual costs. Thus there is further overlap between mixing costs and specifically the residual portion of switch cost. To take this selection idea further, as an alternative to localised ‘inhibitionist’ interference Steinhauser and Hübner (2005) suggested sequential selection for task *components* rather than task set or individual tasks. Mixing costs reflect a sequential process of elimination of irrelevant components with each choice further restraining the eventual response[16]. Control is data driven, which would be sufficient for *repetitions* as the task doesn’t change – the response is afforded by a repeat of the last one made. This cognitively economical ‘increasing reduction’ explanation could be plausible as a low-level switching mechanism (in effect,

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[15] Error switch costs *were* reported.

[16] Whether the selection process is additional to (Mayr, 2001) or slower than (Hübner ,Futterer & Steinhauser, 2001) is not definitively demonstrated, but both possibilities are cited as plausible from the data.

treating everything as a repeat until proven otherwise). This would encompass the assertion by Phillip et al. (2008) that interference responsible for mixing cost also contributes to switch cost, without having to accept this interference at the level of task set, thus still accommodating a role for reconfiguration.

Mixing costs therefore appear, with a degree of consensus, to be indicative of competition between task related representations at some level. However, while the underlying processes may additionally contribute to switch cost, the two are seemingly separable phenomena and so do *not* necessitate extensive reliance on resolution of competitive S-R mappings (as opposed to reconfiguration) as a source of practice-ameliorated slowing (see Wylie & Allport (2000) and Wylie, Javitt & Foxe (2003) as exponents of this competitive model). Evidence for separable mechanisms comes, for example, from behavioural dissociation from restart costs, with mixing costs alone benefitting from predictability (Poljac et al., 2009). Restart cost is a first trial cost effect regardless of whether that trial is a switch or repeat (Allport & Wylie, 2000). There is also identification of functionally distinct neural mechanisms[17] attributed to different forms of control indicated for mixing and switching costs (Braver, Reynolds and Donaldson, 2003).

However, in a study using ERP data, Wylie, Murray, Javitt and Foxe (2009) say the *same* mechanisms are responsible for mixing and switching, albeit with differences in the *strength* of involvement. They found ERP amplitude differences[18] between pure and repeat/ switch trials but not between repeat and switch. Thus they further expound an associative

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[17] Right anterior PFC in relation to mixing costs, lateral PFC in relation to advance use of cues and left superior parietal in relation to switching between tasks.

[18] Some numerical rather than statistical similarities between pure and repeat trials were apparent.

competition and control-free model of task switching, by virtue of the *absence* of competition during pure task trials and *presence* of competition in both mixing and switching. Fronto-parietal involvement is interpreted as more competition than control oriented. That mixing costs (and a proportion of switch costs) are suggestive of associative competition seems a safe assumption on the current evidence. However, disregarding the potential role of reconfiguration (without demonstrating its absence) on the basis that this process also *contributes* to switch cost does not seem so safe.

6 Inhibitory Accounts of Switch Cost: Revising the Inertial Account – Associative Interference and Restart Costs

Mixing costs therefore appear to be contributory to residual switch costs, yet this explanation of costs alone is not able to discount the plausibility of a reconfiguration account. One hypothesis that sought to do this was the associative interference account of Wylie & Allport (2000). They sought to address this enduring issue of residual switch cost using similar Stroop style stimuli as before (Allport, Styles & Hsieh, 1994) and Monsell's alternating runs paradigm. While there was still evidence of forward interference, they conceded that TSI (and, indeed, *all* pre-existing theories pertaining to switch cost) could not adequately account for such costs under conditions allowing for adequate task preparation (as was noted by Rogers & Monsell, 1995). This was particularly as Allport and colleagues demonstrated interference effects in non-switching baseline trials. They had in effect moved from an inhibition to a retrieval-based account of switch cost, stating that "…a new hypothesis, based on the learned associations between stimulus representative representations and response representations, does very much better." (Wylie & Allport, 2000, p.231). In a complete revision of the original TSI theory, they proposed model interference occurred not just because of lingering overactive control from the preceding task, but because of previously activated (and now erroneous) stimulus-response (S-R) mappings to the non-current bivalent attribute. For example, if a digit stimulus afforded both a subtraction and addition task, the previously associated subtraction attribute might interfere with associating the stimulus with the current addition attribute. Every time a task is associated with a particular stimulus they become bound, not only to the particular response for that S-R mapping but also to other properties such as the context and goal of the task (Monsell, 2005). Associative interference is proposed to be a major contributor to residual switch cost. This was demonstrated by Waszak, Hommel & Allport (2003). They used a stimulus set of object pictures with an object name superimposed, the task being to name either the object or the word, using an alternating runs design. Costs were greater for words that had previously been picture named, even after a gap of more than one hundred trials between the two related events. This can be said to occur for retrieval of task set rather than just retrieval of task response because it happened for congruent stimuli, where the same response was made on the previous trial – if it were only the response being retrieved there would be no difference in switch cost (Monsell, 2005). As such this would seem to have resonance again with accounts that report greater bivalent costs, such as Koch et al.'s (2005) report of greater mixing costs for bivalent stimuli. Yeung and Monsell (2003) later provided a reciprocal concession that TSI (not associative interference) *was* a contributory factor in switch cost but only in circumstances where both the preceding and upcoming tasks had been recently practiced. Associative interference was viewed as occurring only under certain circumstances e.g. during switching for Stroop word reading, but for switching *and* repeats in Stroop colour naming (Waszak, Hommel & Allport, 2003).

The associative interference model claimed that these negative priming costs (or "…negative transfer…" Allport & Wylie, 2000, p.64) imposed significant and enduring impedance in the face of S-R mapping change. However, Allport and Wylie proffered the caveat that their interference based model may be confined to explaining results from Stroop-style tasks where such a reversal of mappings was implicit. Meiran's (2000) response-bound source of residual cost implied competition between *meaningful* response dimensions as problematic, so Allport's model may indeed be artefactual to Stroop-style tasks. Monsell (2005) concurs that associative interference occurs at a broader level (and thus contributes to switch cost in more general terms) than that of response selection, citing evidence (using non-word stimuli, Monsell, Taylor & Murphy, 2001) that Stroop interference arises in part at the level of the whole task set for reading per se. Rather than just the *response* for the word reading/ colour naming competing, there is actually competition between task sets. This notion arose from the finding that non-colour words interfere with the naming of the ink colour. Words (regardless of their frequency) offered no greater interference than pseudowords. Unprimed interference was concluded to be activated by task set rather than response tendency. *Any* word prompted the act of reading, which in turn interfered with colour naming. Priming was interpreted to *supplement* rather than be solely responsible for this process. Additionally Rogers & Monsell (1995) found faster RT for neutral than congruent stimuli which (says Monsell) can only be explained by interference occurring for the task set – enduring activation would otherwise have facilitated response selection for the congruent stimuli. Monsell (2005) also offers the observation that associative interference, at whatever level, cannot be the only determinant of residual costs as repeated bivalent stimuli would inevitably become equally associated with both task sets. Any long term associations would seemingly cancel each other out. Stroop stimuli are an unusually dominant bivalent pairing.

In addition to Monsells' assertions, it is of note that Gurd (1995) viewed non-Stroop verbal task switching (producing words from alternate overlearned sequences) as inherently different in its requirements from Stroop switching. Ward, Roberts and Phillips (2001) identified fundamentally different mechanisms underlying Stroop switching as oppose to partially shared mechanisms relating to non-Stroop switching tasks. Similarly, Waszak & Hommel (2007) identified discrepancies in comparison to their earlier work (Waszak, Hommel & Allport, 2003), specifically a failure to incur negative priming from single stimulus presentation, which they attributed to the level of encoding associated with the Stroop-style presentation used in the earlier work. Although Allport acknowledged the limitations in his earlier work presenting the TSI hypothesis (Allport, Styles & Hsieh, 1994), the adherence to Stroop-style switching may offer further restrictions to the application of his later model.

In considering Allport's proposal of reversal (i.e. swapping between one and the other) in S-R mappings as a retrieval-based source for switch cost, it should be noted that Gade & Koch (2007) have linked such a build up of associations to explicit cues as well as stimuli. They found the same reversal-costly effect for arbitrarily associated cues, such as a shape indicating a consonant decision. This suggests the effect may not be entirely task bound, although the potential translational requirement of such cues has been cited as an inflationary contributor to the long-term inhibitory costs found in backward inhibition[19] (Grange & Houghton (2010), Houghton, Pritchard & Grange (2009)). Although Wylie and Allport (2000) didn't switch cues, Waszak, Hommel and Allport (2003) later extended the costliness of such mappings to *all* operations related to completing the switch and achieving

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[19] An explanation of backward inhibition is given on page 61.

its goal, not just S-R mappings. This is confirmed by Monsell's (2005) assertion that task context and goal as well as S-R mappings relate to associations.

After Allport's original presentation of associative interference, Gilbert and Shallice (2002) offered a computational replication of Allport's Stroop-style task using a parallel distributed processing (PDP) architecture. They implemented a proportionate carryover of unit states into subsequent trials to mimic the persistence of previously activated dominant task sets as proposed by Allport et al. (1994). They used the rationale that if implementation of this method could duplicate human behavioural data on the task, this would negate the need for an exogenous element in explaining switch costs. Their production of a number of phenomena (switch and restart costs, asymmetric costs in both directions, first-trial confinement) was proposed as support for the associative interference account as a panacean model of task switch costs. Later work by Yeung (2010) has located carryover effects such as those shown by the PDP model to the response selection stage and has suggested that the contribution inevitably occurs in combination with (and secondary to) exogenously driven processes. Competition between task sets of the type posited by Allport is subsequent to a failure to activate the upcoming task set. While Gilbert and Shallice's data undoubtedly supports the associative interference model, it would seem that this model is specifically confined to response selection in differentially dominant competing task sets as exist in Stroop. Indeed, Baddeley, Chincotta & Adlan (2001) fund no evidence for associative interference in Jersild's list paradigm. Interaction between switch cost and a concurrent task rules out negative priming – such a hypothesis would predict additive secondary effects with an equal cost across all conditions.

In summary the associative interference hypothesis seeks to extend the original TSI hypothesis, supplanting transient interference from the just performed task to long term interference from competing S-R mappings. Associative interference does, of course, only apply to tasks that use bivalent stimuli. Such an account cannot explain why switch costs (including residual switch costs) occur using univalent stimuli as demonstrated by Rogers & Monsell (1995) and Ruthruff, Remington & Johnston (2001). Clearly in this instance there is no associative competition between responses. Further, as pointed out by Monsell (2003) there are also instances where no switch costs occur for bivalent stimuli – if associative interference is a factor it should be consistently present. An example of such a lack of bivalent costs is from Hunt & Klein (2002) where switching was between prosaccades and antisaccades (visual movement towards or away from) to peripheral targets. Such a design should produce the type of interference posited by Allport – why does it only seem to occur for particular types of bivalent stimuli? Although there is some computational evidence (Gilbert & Shallice, 2002) supporting the negative priming effect, Yeung (2010) says that the effects from the PDP model are related only to response selection. As Monsell (2005) had earlier noted cost effects must be related to task-set switching rather than just the response tendency. As such the associative interference model is again a limited explanation of task switch effects, bound specifically to Stroop-like stimuli which must be seen as a special class of bivalency.

6.1 Restart costs

Is the apparently Stroop-limited associative interference hypothesis completely inapplicable for non-Stroop stimuli? At the same time as proposing the negative priming account, Allport found evidence for a cost related to the first trial of a run, regardless of whether it was switch or repeat (Allport & Wylie, 2000). This was an additional contributor to residual switch cost and one which does not *rely* on competition between response or task set (although it was proposed to work *with* such interference). As previously discussed, the alternating runs paradigm revealed that switch cost was only increased for the first trial of a run, which Rogers and Monsell offered as evidence against Allport's passive TSI account. The TSI account required interference to persist over several trials (although Allport retrospectively asserted that TSI was not inconsistent with some kind of active goal setting element of task switching behaviour (Allport & Wylie, 2000). However, Allport returned to this 'first trial confinement' of residual switch cost. Continuing with Stroop style switching and again using alternating runs, Allport and Wylie (2000) found this 'first trial' or *restart effect* to be evident also on the first trial of *non*-switching runs. Additionally, they proposed that the effect was compounded (for bivalent stimuli previously encountered for the alternative task) by associative interference from competing S-R mappings. Renewed first-trial slowing occurred after a gap of as little as two seconds. Restart of the *same* task (a repeat) was interpreted as triggering *renewed* interference from earlier competing S-R mappings. Thus the restart cost also triggered associative interference. Rather than this restart effect being evidence against interference persisting over time (as cited by Rogers & Monsell, 1995), Allport and Wylie maintained that restart costs were a feature of starting a set of speeded responses (quite separately from switching), often compounded by previously learnt stimulus associations (these augmented repeats of restart costs were termed the *rebound effect*).

Another issue that comes up with restart costs is that they can be asymmetric (harder for the easier of two tasks) although this time such asymmetry is not explained by the TSI hypothesis. Asymmetric restart costs in the absence of switching were incompatible with the original TSI concept of both switch cost and asymmetry being due to the repeated application of dominance-related task set perseveration. The associative interference model accounted for this mid-task first trial effect as the long term result of previously laid down associative learning of S-R mappings. A variation of this explanation comes from Bryck & Mayr (2008), who also found asymmetric restart costs – they had easy (E) and difficult (D) tasks with long (--) and short (-) gaps in between, presented as follows E-E—E-E—D-D—D-D—E-E—E-E—D-D—D-D... Restart costs on repeats after a long gap were greater for the easier task. They say this cannot be explained by models such as the Gilbert and Shallice (2002) PDP model which relies on switches (not repeats) to produce asymmetries. Both task switches and delayed repetitions require LTM retrieval, specifically encoded as examples of prior task performance. The more control that is required to perform a task (for example, a difficult task), the more examples are encoded. When retrieval occurs, interference would come from irrelevant encoding examples – these would be more likely for the easier task as it had fewer correct encoding examples. However, Schneider & Anderson (2010) point out that the easier task is likely to have many more encoding examples from outside of the experimental structure and should therefore be dominant in LTM. The same could be said for the associative interference account, with previously laid down associations actually being more broad-ranging than the confines of the switching scenario. As such neither necessarily explains the occurrence of asymmetry.

7 Backward Inhibition

Both the TSI hypothesis and associative interference have been shown to be limited to Stroop style bivalent stimuli. However, there are other explanations reliant on effects from inhibition of a previous trial that go beyond this two-task bivalent paradigm. Using three tasks, the *backward inhibition* hypothesis (Mayr & Keele, 2000) shows that switching to a *recently* inhibited task is more costly. In terms of practice effects on switch cost, Yeung and Monsell (2003) note that a TSI-based hypothesis would predict larger switch costs for a recently practiced task (the unpractised task being the 'weaker' one). An associative interference-based hypothesis would predict smaller costs for a recently practiced task as S-R mappings would still be current. However, persisting task set *inhibition*, as well as activation, can impinge upon subsequent switches (Baddeley et al., 1998). A number of studies have looked at inhibition and practice more closely, specifically the phenomenon of greater switch cost and error being incurred by a switch to a recently performed task than to one performed not so recently. This type of sequentially applied inhibition, so-called *backward inhibition,* was first demonstrated by Mayr and Keele (2000). By including three tasks in the switching scenario it is possible to compare the effects of both one and two intermediate tasks (e.g. A-B-A and C-B-A), thus manipulating the recency of the task being switched *to*. In A-B-A sequences, the more recently applied inhibition of task A still persists, whereas in C-B-A sequences it has had time to dissipate. Mayr and Keele purportedly demonstrated this effect to be confined to top down control of switching, to be robust in the presence of foreknowledge and to be contributory rather than additional to exogenously driven 'shift costs' (as per Monsell).

Mayr & Keele (2000) had used an odd-one-out task with tasks varying on colour, orientation or motion. They used verbal cues indicating the next dimension to be attended to, which would need translating from 'orientation' to discerning which is the anomalous representation of this. However, for presentation of a cue which directly relates to what needs to be done i.e. a picture of the target item, the need to actually *do* anything in terms of active switching is largely superseded (as Logan noted "Executive control is the instrument of volition” (Logan, 2004, p.218)). Mayr & Keele believed that backward inhibition occurred only in the context of endogenously driven switching and was a complex variant of Allport’s negative priming. Top down processing was instigated by the verbal cue, bottom up by merely having to find the odd one out in a display with no indication as to what dimension should be attended to. While the stimuli were switched between trials so that the odd one out followed the C-B-A sequence, there was no affordance for active preparation. While this may be dubious in terms of being classified as true task switching, to an extent it allows analysis of sequential task set activation, though there must necessarily be increased interference from all task sets on every ‘switch’. While ‘switching’ may have been sequential, the likelihood is that competition between all task sets was more equivalent on each trial and so potentially masked any possible backward inhibition effect. The task required participants to look for the odd one out, which happens to be on a different parameter each time. Task set activation and search was forced to an extent by including an additional distracter on one of the parameters, which participants were told to disregard, but switching is ultimately *too* passive. Backward inhibition is not found because task sets are comparably active on each trial.

In line with Allport and Wylie (2000), Koch (e.g. Schuch & Koch, 2003; Koch, Gade & Philipp, 2004; Philipp & Koch, 2005) proposes that inhibition is applied to response processes. For example, backward inhibition was shown to be extinguishable when no response was elicited for task B in an A-B-A sequence, using a go/ no-go approach (Schuch & Koch, 2003). Although interference at other stages is acknowledged, Koch, Gade, Schuch and Philipp (2010) suggest that interference occurs primarily at the response stage. Later work has refined this view, suggesting that it is not only response processes but those processes that contribute the most interference which are the target for inhibition. It has been proposed that backward inhibition relates to ‘cue-target translation’ (Houghton, Pritchard and

Grange, 2009). This is the need to convert task-cues (indicators of what task to apply to the upcoming stimuli, for example looking for an angled/ shaded/ outlined shape in a visual search) into a representation of what the task actually is. The degree of translation required from the cue to the target determines the amount of backward inhibition related cost. Externalising the site of translation by increasing the explicitness of the cue (and excluding Koch's response-based inhibition by maintaining identical task response requirements) allowed Houghton and colleagues to remove the effects of backward inhibition. Thus cue ambiguity necessitates translation and backward inhibition is said to relate to this translation rather than to task responses per se. In addressing top down versus bottom up processing, Mayr and Keele say "A potential problem… was that… participants in the top down condition did not *have* to use the explicit cues because the stimulus information was not ambiguous" (Mayr & Keele (2000), p.13, my emphasis). However, Mayr & Keele found backward inhibition in an unambiguously-cued more bona fide switching paradigm – Houghton and colleagues' task instigated a search of the 'odd one out' (Mayr & Keele, Experiment 3) but using such an exogenously driven task that the requirement to actively impose switching control is negated and thus eradication of backward inhibition must be considered an artefact of this very specific and very stimulus-dependent task design.

8 Explicit Cueing

Backward inhibition was particularly dependent on the role of the cue to instigate top-down processing. As used by Mayr & Keele (2000) cues could vary in their explicitness, needing translating (from the word to the associated action) or being quite direct (two colours indicating a colour choice is to be made). This could directly access the goal or require an additional processing step to interpret the cue. But what other effects could the cue have within the switching scenario and what additional analyses does inclusion of a cue facilitate? While manipulation of preparation time in the alternating runs paradigm has a clear effect on switch cost, there is no way of determining when (if at all, as proposed by De Jong, 2000) reconfiguration occurs during this interval. While stimuli act as implicit cues for the task to be performed, the introduction of separate explicit cues (Meiran, 1996) allows trials to be presented randomly with accurate manipulation of both pre- and post-stimulus intervals and so determines the point at which switch-related processes can be engaged. By introducing task-specific cues before the stimuli, Meiran (1996) proposed that preparation effects and residual costs did indeed represent an exogenous component of control, rather than dissipation of TSI during the preparation period. Meiran was able to show that the longer the cue to stimulus interval (CSI), the shorter the RT costs. In previous studies the CSI was said (by Meiran) to be confounded by ‘remoteness’ from the previous trial. A longer CSI meant that the subsequent stimulus was ‘further away’ from the last response than trials with a shorter CSI. This meant that a longer interval gives not only the chance to adequately prepare (Rogers & Monsell, 1995) but also the opportunity for carryover to dissipate (Allport, Styles & Hsieh, 1994). Therefore it cannot be said with certainty that longer preparation time actually reflects preparation. In the Meiran (1996) study while the interval between cue and stimulus was varied, the interval between the *response* on the previous trial and the *stimulus* on the current trial was kept constant. Thus the ‘distance’ between response and subsequent stimulus remains constant regardless of the length of the CSI. Dissipation of carryover did not occur and so switching was associated with advance preparation and thus executive control. A longer CSI resulted in fast switch cost decline; longer response-to-cue interval (RCI) produced a slower decline. This led Meiran to propose three separate sources for switch cost: passive decay of task set A, active TSR for task B and a residual stimulus-bound source. With reference to this, Meiran, Chorev & Sapir (2000) had stated that switch cost cannot be taken as a measure of executive function alone. There is a role for dissipating carryover (in tasks that do not regulate the RSI) which does not reflect executive control. Residual costs reflect a failure of preparation, although long CSI reduction of switch cost does reflect success of control to an extent. It was proposed that the relationship between preparation and control was not straightforward. A small preparatory contribution to cost could equally reflect lack of engagement (no indication of control) or fast an efficient control. Preparation reflected a variety of processes, including "...phasic arousal, predicting target onset, and reconfiguration" (Meiran, Chorev & Sapir, 2000, p.251).

Cues have also been investigated from the point of view of just the type of carryover Meiran sought to refute. Using a cued digit parity/ magnitude task, Koch & Allport (2006) investigated the relative contributions of cue based preparation and stimulus based priming to switch cost. The cue effect was proposed to overcome priming with a long CSI to allow for preparation. A long response-to stimulus interval (RSI) allowed for greater decay of the preceding task set and so reduced switch cost, supporting (they said) the associative interference account of switch cost through mitigation of the priming effect. The task is activated by the cue – activation increases as a function of the length of CSI. This activation then decays as a function of the length of RSI. This does of course suffer from the non-standardisation of the RCI as noted by Meiran, leading to the confound of remoteness from the previous trial. In partial agreement with Meiran they suggested separable stimulus and response based aspects of switch cost attributable to manipulation of CSI and RSI respectively. Conversely, Monsell and Mizon (2006) advocated reduction of cost with long CSI as evidence of endogenous reconfiguration when there was *low predictability* of the upcoming switch. Reconfiguration could not occur in the absence of foreknowledge until specifically cued. Meiran's earlier model (1996) encompasses both passive decay and active reconfiguration. However, the subtle disparity between tasks (independently cued bivalent stimuli for Allport, directional Stroop-style switching for Monsell and a directional task involving spatial shifts for Meiran) would urge caution in interpreting an exact overlay of these explanations.

8.1 Cue-task association

A secondary consideration for interpretation of the explicit cueing paradigm relates to the *type* of cue chosen to signify the task, specifically the degree to which the cue has to be translated, something already noted in relation to backward inhibition (Mayr & Keele, 2000). It has already been noted by Hougton and colleagues (Houghton, Pritchard & Grange, 2009; Grange & Houghton, 2010) that cues with a less logical affiliation to the task result in increased levels of backward inhibition. Using explicit verbalisation cues and arbitrary symbols Arbuthnott and Woodward (2002) found greater switch cost with the lower association symbolic cues. They posited this to either reflect reduced time to retrieve task set due to additional cue encoding or longer time required to retrieve the task set from LTM (in part resonating with Mayr & Kliegl’s (2003) interpretation of cue switch costs). Schneider and Logan (2006) later favoured the LTM position with a mediator hypothesis of transition cue processing. In this instance cue meaning is used in conjunction with knowledge of the prior trial’s task to access a mediator (suggested by Saeki & Sato (2009) to be verbal) to the task identity. Using multiple cues per task, they looked at situations where the cue and task both repeated, the cue changed but the task repeated and both the cue and task changed. Switch cost was lowest under conditions of frequent task alternations, higher under conditions of frequent cue repetition and greatest under conditions of frequent task repetitions. Looking at these three types of transition and using mathematical modelling they were able to demonstrate that these different cost magnitudes were reliant on priming of cue encoding. Cues were automatically primed according to instances in memory of past task transitions. The frequency of the transition determines how many instances are available from memory[20].

8.2 Cue processing

Of course, comparability between predictable uncued switching and unpredictable switching signified by cues is limited. Altmann (2007) draws a stark comparison between alternating runs and explicitly cued switch costs, favouring the latter as a less confounded measure and criticising the apparent lack of distinction between the two in the literature (e.g. reviews such as Logan, 2003 and Monsell, 2003). Predictable uncued switching requires internally represented implicit task sequences. Initial task instructions are processed once at the beginning of the task block as oppose to repeated processing of explicit task cues (Logan & Schneider, 2006a), arguably requiring less attention (Koch, 2008). A number of studies have suggested that switch cost in the explicit cues paradigm is heavily confounded by the need to process and switch *cues* rather than task (Logan & Bundesen, 2003, 2004). A similar structure as that of Schneider & Logan (2006, described in the last section) was used, with multiple cues per task and three different cue/ task transitions (repeats of both, task only changing and both changing). It was found that participants were responding to the compound of the cue and the target rather than just switching task set. Such a compound response brought into question the ability of switch cost to reflect executive control in the explicit cueing paradigm.

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[20] This has resonance with Bryck & Mayr’s (2008) explanation of restart costs, where the more control that is required to perform a task the more examples of it are encoded in memory.

Conversely, there may also be a reverse *benefit* from cue encoding (priming from cue repetitions) rather than *detriment* from task switching (Arrington & Logan, 2004a; Logan & Schneider, 2006b). Association between the cue on the current trial and the cue on the previous trial led to quicker responses to *task* repetitions. This in turn would affect any measure of switch cost calculated as the difference between task alternations and repeats. The probability of a task switch is thus said to enable *strategic* memory-based priming rather than the automatic priming proposed by Allport and colleagues (e.g. Waszak, Hommel & Allport, 2003). The compound strategy of the cue and stimulus is said to give unique identification of the correct response. One task set (encode cue, encode target, select response) can then be used to address every task, removing the need to *switch* task set. Associations between the current and previous cue trigger encoding examples from memory. This body of work substantiates the prevailing view of Logan and colleagues that task switching performance is essentially a memory problem. However, this stance has been radically revised to acknowledge the limitations of cue-encoding effects in explaining all cued switching performance (e.g. Arrington, Logan & Schneider, 2007). This is in line with neurophysiological evidence (Jost, Mayr and Rösler, 2008) that cue-switch and task-switch processes are dissociable (see also Altmann (2006) for a refutation of this ‘cue reductionist’ stance[21]). In addition, Mayr (2006) found probability effects rooted (at least in part) in task rather than cue transitions, explained in terms of task-driven adaptive reconfiguration (although this does assume the system is able to exert probability-based strategic control over inhibition processes). Cue switch costs increased and task switch cost decreased as a function of the probability of an upcoming task switch. It was concluded that participants were responding to the probability of a task switch, given the cue switch. Task switches were thus more important in determining switch cost. High switch probability could lead to suppressing

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[21] Although it should be noted that Altmann is himself a fervent ‘switch cost dissenter’, stating not only that the alternating runs paradigm is an inadequate measure of switch cost (hopelessly confounded by restart costs), but that switch costs do not reflect executive control (see Altmann, 2003 and Altmann & Gray, 2002).

the previous task set on *all* trials. This would lead to costs on task *repetitions*, resulting in a net reduced switch cost (repeat/ alternation difference) which would be independent of a cue switch.

8.3 Inner speech and self-cueing

It has been earlier noted that uncued switching requires internal representation of task sequences. While cues may carry an extra processing cost (albeit extrinsic to switch cost itself), they do remove the requirement to hold the task sequence in memory[22]. It has been suggested (Koch, 2003) that this 'internal cue' of task order representation primes the system for more efficient use of external cues, while still facilitating successful (but slower) switching itself. The use of inner speech as a 'self-cueing' device[23] to reinforce this representation is well established. Reliance on internal cues diminishes as external cues become more available and more task-specific (Emerson & Miyake, 2003; Miyake, Emerson, Padilla & Ahn, 2004). When articulatory suppression is used to disrupt the action of inner speech (which it does significantly), this is ameliorated when external cues are closely linked to the upcoming task (Emerson & Miyake, 2003). This suggests the role of inner speech as a self-cuing device for retrieval and activation of a phonological representation of the task, which comes to the fore in the absence of explicit cues. As noted already in the discussion of explicit cueing, mediators to task identity, formed by the compound of cue and stimulus, are believed to take the form of phonological representation (Saeki & Sato, 2009). Inner speech and explicit cueing would seem to be fulfilling the same role in accessing this representation.

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[22] While this internal representation may place increased demand on working memory, both Barch et al. (1997) and Logan (2004) found working memory load to be dissociable from other processes active during task switching.

[23] Bechtel (1994) suggested inner speech, as a product of a cognitive system, must be external to it; Vygotsky (1934/ 1962) viewed it as an extension of 'outer' speech and so able to be responded to and used in the same way as hearing an external speaker. Such external representations of information (for example, note taking or presumably spoken 'memos') have been proposed as a form of external memory trace (e.g. Donald, 1991).

In a non-cued switching task it could be argued that inner speech as a self cuing device is a more direct route than *arbitrary* external cues as there is no requirement for translation between cue and representation. This would however need to be mediated against the additional (non-switching) costs of holding the task order in WM. As previously noted this cost is dissociable from switching costs but will contribute in an additive manner nonetheless. However, reliance on cues, whether externally provided and transient or internally generated and constant, does appear to be a necessary feature of switching between tasks.

It has been found that reliance on inner speech is greater in children and older adults (Kray, Eber & Lindenberger, 2004; Kray, Eber & Karbach, 2008), known to have switching deficits. As well as compensating for paucity of explicitness in external cues (as noted earlier), inner speech also offers a supportive role for age-related task switching deficits (Kray, Eber & Karbach, 2008). Older adults are known to benefit more than children from *overt* concurrent task-congruent verbalisation during task preparation – incongruent verbalisation has a strong interference effect (Kray, Eber & Lindenberger, 2004), akin clearly to articulatory suppression. Again greater reliance in these groups on inner speech was found in the absence of environmental cues. Functional imaging data from younger and older adults on a continuous performance task (Braver, Paxton, Locke & Barch, 2009) confirms more response to ambiguous ‘probes’ (akin to transition cues, which indicate a task switch but not what that task is) and contextual (task specific) cues respectively, in line with an adaptive[24] model of cognitive control. This age-related evidence would support accounts of switching control that advocate a multiplicity of mechanisms to account for varying task, response and perhaps even population demands. For example, Ravizza & Carter (2008) compared two

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[24] Adaptive in terms of both task and resources. Spieler, Mayr and LaGrone (2006) suggest that age-related changes in switching ability are only really obvious with the use of external cues, but that this may be more of a case of a change in ability rather than impairment.

tasks requiring perceptual and rule based switches, surmising that there are multiple mechanisms for switching dependent on task requirements. This must include varying types and availability of cues and varying levels of age-related control adaptation. Age-related differences in the use of inner speech therefore illustrate another way in which ‘one model fits all’ is an ineffective construct.

As already noted the application of articulatory suppression (incongruent concurrent speech) during the commission of inner speech leads to greater switch costs (e.g. Miyake, Emerson, Padilla & Ahn, 2004). One viewpoint of this effect of articulatory suppression is that there is a specific executive role for the phonological loop in task switching (Saeki & Sato, 2004). However, this would challenge the notion of the phonological loop as a slave system to the central executive, positing a more active role. There is no need to take such a controversial view of the findings. In interpreting similar results, Baddeley (2002) agrees that at first sight it seems there is a role for the phonological loop. However, he cites Vygotsky’s (1934/ 1962) assertion that verbalisation is implicit in the control of action. As such the central executive rather than the phonological loop is implicated, given that such verbal strategies would need to be accessed from LTM. Further consideration of the role of memory in task switching is given in the second half of this literature review (see page 82).

So, if there is a role for the central executive in the application of inner speech can we say that this internal verbalisation is indicative of active control processes during task switching? Goschke (2000) again found that verbal labelling (overtly naming the upcoming task) reduced switch costs. He proposed that this reflected retrieving the intention to perform a task and was supportive of advance reconfiguration. It was hypothesised by Goschke that retrieval of the intention or task representation was an intrinsic part of advance reconfiguration (again, refer to Vygotsky 1934/ 1962). Crucially the length of CSI was key – too short and the verbal labelling had no beneficial effect as there was not time to complete advance preparation. Therefore the process reflected advance reconfiguration. Dissipation of previous task set (the TSI hypothesis) was rejected on the grounds that the *content* of the verbalisation was responsible for switch cost reduction. The endogenous aspect of control specifies the addition of new goals to supplant old ones (as specified by Rubinstein, Meyer & Evans, 2001), as actioned by intention retrieval. Overt verbalisation (and, it can be assumed, its internal silent counterpart) therefore represent a key aspect of top-down controlled goal shifting. It is also suggested that such verbalisation actively suppresses interference from previous task sets. Monsell (2005) concurs that linguistic self-instruction assists task set reconfiguration (TSR), having noted participants intermittently verbalising task instructions (something that also happens frequently in the Continuous Series II verbal switching task).

In summary, inner speech acts as a self cuing device, particularly when environmental cues are absent or when they are not explicitly linked to the task. It would appear to act in a supportive role to active reconfiguration. The more explicit the external cue, the less the reliance on inner speech (Emerson & Miyake, 2003; Miyake et al., 2004). Verbalisations additional to inner speech are less disruptive when they are concurrent to the task (naming to upcoming task) (Kray, Eber & Karbach, 2008). Additionally we know that verbal cues are more effective than pictorial or abstract cues (e.g. Monsell & Mizon, 2006; Lavric, Mizon & Monsell, 2008). What then would be the effect, in a task that relies wholly on inner-speech as a cue, of providing verbal (visual) environmental cues that are concurrent with the upcoming task? The Continuous Series II is uncued and self paced, relying entirely on (according to Baddeley from Vygotsky) central executive retrieval of verbal strategies from LTM and use of inner speech to cue retrieval of intention (Goschke, 2000). Constantly available whole word cues signifying the upcoming task would relieve the need to retrieve verbal strategies or instructions from LTM, thus reducing the net WM load (more of this on page 82). The visual presentation of cues would eliminate any articulatory suppressive tendencies even in a cue that matched the task – in previous studies matched task and verbalisation still resulted in some cost. Such cues would be supportive of the role of inner speech, perhaps reducing the need to rely on it at all or freeing up the phonological loop to rehearse items within the categories (e.g. Monday, Tuesday, Wednesday...) instead of the categories themselves (e.g. Numbers, Days, Months...). Cue free switching such as the Continuous Series II is reliant on inner speech – if this inner speech is indicative of the involvement of WM then the result of supporting this process should result in reduced switch cost and fewer errors when WM load is reduced. Experiment 6 in Chapter 8 explores this in full, using visual cues with varying degrees of verbal explicitness. Additional analysis for Experiment 2 in Chapter 4 looks at the effect of incidental overt verbalisations for the Continuous Series II. Although not as controlled of verbal labelling, this is nonetheless informative of the ways in which overt speech might reflect or support inner speech.

9 Dual Mechanism Models of Control

Throughout the thesis thus far there has been a stark distinction between bottom-up passive accounts and active top-down reconfiguration-based accounts of switch cost. The passive accounts propose either a transient carryover of activation of the preceding task set or more long term interference from previous S-R mappings of bivalent stimuli. The active TSR account advocates preparation for the switch occurring during adequate preparation time, with completion of this task set reconfiguration occurring once the stimulus arrives (an exogenous component of control). However, there have been mentions of one account conceding the involvement of the other – for example, Yeung & Monsell (2003) acknowledge that transient carryover of the type advocated by the TSI hypothesis is implicated in some types of task switching.

Proactive control (as advocated by reconfiguration-based accounts such as Rogers & Monsell, 1995; De Jong, 2000; Rubinstein et al. 2001; Sohn & Anderson, 2001) relates to preparatory task set activation in advance of switching, requiring sufficient time to complete. Reactive control relates to overcoming the persistence of a previously active (and no longer relevant) task set (e.g. Allport, Styles & Hsieh, 1994; Allport & Wylie, 2000). Neither Allport et al. (1994) nor Rogers and Monsell (1995) were able to make a definitive distinction between inhibition or reconfiguration effects in their data; it was not possible to entirely rule out one or the other. Meiran (1996) proposed three components of switch cost: passive decay, active reconfiguration and a stimulus-bound residual cost. Task *expectancy* affects the amount of time required to reconfigure for the upcoming task, but task *recency* affects the amount of time needed to execute this reconfiguration (Ruthruff, Remington & Johnston, 2001), hence supporting Meiran and accounting for both TSI and TSR. While TSI and backward inhibition appear to be transient localised sources of interference, S-R associations provide a sustained source of interference throughout the task.

Similarly, rather than a single central executive process controlling task switching, Goschke (2000) advocated a modular control ‘panel’ overseeing both maintenance and reconfiguration of task sets. This demonstrated advance reconfiguration, reducing cost via pre-stimulus verbal access of the task. Monsell (2005) has advocated such verbal representations as being implicit to the reconfiguration process (see description of representation in inner speech page 60). As previously described, the verbal content of the task retrieval represented the active introduction of a replacement goal, negating the role of TSI dissipation. This was in line with Woodward et al's (2003) confirmatory verbal access (page 25 of this document) and Mayr & Keele's (2000) verbal prompting of top down processing (page 53 of this document). Goschke's modular 'control panel' model also established carryover of activation via stimulus evoked (bivalent) erroneous responses. However, involuntary or passive effects from previous task sets were not conceived of as entirely triggered by the stimulus. Active control was not seen as being wholly directed by conscious intentions. Rather, conscious intentions were said to offer constraints that modulated the readiness of responses automatically triggered by stimuli – in this way conscious intentions configure automatic processes. For Goschke the stimulus-bound cost is not constant but translates as a dynamic requirement for control in the face of fluctuating stimulus-based response constraint, such as in the case of bivalent stimuli.

A further dual mechanism account of control during switching (Braver, Reynolds and Donaldson, 2003; Braver, Gray & Burgess, 2007) combines sustained (proactive) control with transient (reactive) control. Sustained control is an 'overseeing' function controlling fast switching between several tasks throughout the duration of the task. Transient control is a variable function relating to both internal reconfiguration of goals and linking task cues to their appropriate S-R mappings, akin to Goschke's dynamic control. In light of this model, Meiran's (1996) residual component would appear to equate to confirmatory stimulus-bound feedback. Imaging data revealed three distinct areas of activity associated with different phases of the switching process. Sustained control was located to right anterior prefrontal cortex (PFC) and transient control was located to left superior parietal cortex[25]. A third area of activity, in the lateral PFC, was related to representation and maintenance of task set, separate from switching of those task sets. Left-lateral PFC has been associated with a "...general role in task-set representation and response preparation..." (Braver, Reynolds & Donaldson, 2003, p.721), a role that is *not* dependent on having recently switched tasks[26]. This is highlighted as agreeing with the associative interference account of Allport & Wylie (2000), which reported proactive interference effects on non-switch trials. Costs arising from transient control do so from localised switching of one task to another, with costs reflecting the speed or efficiency with which task set reconfiguration occurs. Sustained control, being long-term control for the whole time period of the task, is thought to contribute to costs relating to performing tasks in a mixed environment, this also being able to explain mixing costs. In trials where there is preparation for the upcoming task this is achieved through proactive sustained control, while trials that are wholly reliant on cues depend on reactive transient control. Thus different types of switching are reliant on different types of control, both of which are separable from maintenance of the task set.

Reconfiguration is stimulus dependent (Rogers & Monsell, 1995) – this model allows control of reconfiguration to be separate from stimulus *response* mechanisms (Meiran's (2000) response bound source of residual cost). A lack of proactive reconfiguration could be construed as analogous with a failure to engage (FTE) (De Jong, 2000). Variation in the speed or efficiency of reconfiguration is built into the model, so a serious deficiency here would account for FTE-type results. Conflict resolution, as occurs during *frequent* task

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[25] The task relied on visually presented stimuli which may have contributed in part to this activation.

[26] Other work (Yeung, Nystrom, Aronson & Cohen, 2006) suggests that representations in the PFC relate to TSI effects, although this is not at the expense of a concomitant role for active control processes.

switching or presentation of incongruent stimuli (and as may happen also repeatedly in the *absence* of switching) is posited by Brown, Reynolds and Braver (2007) to require top-down processing. Conflict may come between expected and actual responses, when switching frequently – this might be addressed by slowing of responses, to prevent premature introduction of the expected response. It may also be induced by incongruent stimuli – task requirements might remain similar but conflicting stimuli might appear, requiring a change in attentional focus. A single source for control would not be able to respond adaptively to such contrasting task demands. For example, response slowing would not affect a suitable shift of attention in a case of responding to incongruent stimuli. Replication of Goschke's (2000) results of post-incongruency *speeding* (enhanced after a task repeat) were interpreted as evidence that control exerted on incongruency-conflict resulted in subsequent RT improvement for the same task but increased switch cost when the task had to change. Mechanisms for resolving conflict were proposed to detect change and incongruency *separately*, thus proposing a method by which active control accounts for asymmetry (Allport, Styles & Hseih, 1994).

Further computational modelling of switching by the authors (Reynolds, Braver, Brown & Van der Stigchel, 2006) showed task switching *could* be controlled under a passive associative learning mechanism (Allport Styles & Hseih, 1994; Allport & Wylie, 2000) but at the cost of susceptibility to previous trial carryover effects. 'Overseeing' maintenance of the task in PFC-analogous units reinforced task dimension input (as per verbal reinforcement Goschke, 2000 and Saeki & Sato, 2009), reducing the susceptibility to carryover effects and arguably providing impetus in the same way as Monsell's 'exogenous' cue for reconfiguration (Rogers & Monsell, 1995). To define more clearly, whether active maintenance of the task was present or absent in PFC units had a significant impact on switch cost. When switch cost was minimal, it was predicted that there was an increase in delay-related responses in the PFC units, reflecting active maintenance. When switch cost was greater, it was predicted that there would be an increase in target-related responses in the PFC units, reflecting task-set reactivation. Analysis showed both these predictions to be true. The model showed a combination of active maintenance and associative learning to be responsible for several features of task switching behaviour. It demonstrated that selection of a correct response in the absence of an actively maintained task (which happened in some trials) was driven by the associative learning mechanism. However, this was at the cost of influence from previous activity. Such an impact is negated by active maintenance in the PFC units, which provides a different source of input for task dimensions. Without active maintenance, both target dimensions (for bivalent stimuli) competed, with one gaining an advantage due to prior learning. Passive maintenance of task switching is possible but is not the most efficient route and comes with its own source of cost. Both routes for switching are available, dependent on environmental and task demands. Although not tested, the model of Braver and colleagues (Brown Braver & Reynolds, 2007) purported to account for asymmetric costs. In the Stroop task they predict that colour naming is conflicted from word reading, leading to greater conflict activity in the model and thus more attention paid to colour naming, resulting in enhanced performance. The resultant increased activation to the harder task (colour naming), opposing a switch to the easier task. While more generally there are contributory effects from TSI-like carryover, asymmetric costs are accounted for via a mechanism of over-compensatory conflict control.

Meiran (2010) came back to this concept of dual control mechanisms, proposing sources of rigid and flexible self control (analogous to the transient and sustained control posited by Braver and colleagues), with processes impeding or facilitating switching.

Localised inertia, such as implied by the passive mechanism in the previous model (Reynolds et al., 2006) and specific in Meiran's previous (1996) account, imposes rigidity to the system through automotive (passive) activation of processes relating to the now defunct task set. Preparation and inhibition are facilitatory flexible effects which, although actively imposed, do not entirely outweigh the influence of rigid control processes. The search for the 'elusive' homunculus may be misplaced if control is thus modular and reactive.

10 Conclusion

Inhibition and reconfiguration are by no means mutually exclusive; Goschke (2000) proposed that switch costs reflect both intentional preparation for reconfiguration and interference from recent or previously learned task set associations. Monsell acknowledges that at least part of the switch cost is attributable to inhibition in some form (Yeung & Monsell, 2003). Indeed, a case can be made for the under-specified, passive, stimulus-bound exogenous controller from the TSR account (Rogers & Monsell, 1995) and Allport's passive transient (and, according to Monsell, stimulus-bound) interference (Allport, Styles & Hsieh, 1994) to be one and the same thing, although agreement on this matter does not seem to be likely. Altmann and Logan (e.g. Altmann, 2002; Logan, 2003) take a more extreme view in that switch cost is nothing at all to do with control and that task switching is more of a memory problem than one of cognitive control. It is clear that a number of factors can inflate, mask and otherwise change switch cost, although it would seem that there is a core 'value' which relates to the act of switching, although how much centralised active control is required depends upon task and stimulus demands (e.g. Monsell, Yeung & Azuma, 2000; Hunt & Klein, 2002; Gurd et al., 2003).

The picture we have is one of a slow/ accurate or fast/ error prone route to switching – inhibition carryover (Allport, Styles & Hsieh, 1994) or ‘waiting for the cognitive gear change’ (whatever its nature) (Rogers & Monsell, 1995); or it might be that you just forget what you are supposed to be doing (Altmann & Gray, 2000; 2002). Few studies look at real-time whole task (continuous) switching, instead focussing on individual switches or repeats within task trials. Switch cost is stripped down to isolated error-free measures of these minute phases of the overall process. In reality it seems that one size does not fit all; different task, switch and response requirements employ different processes which result in different causes of switch cost. While there may be a core common element of cost, its exact nature is as yet far from determined. Yehene & Meiran (2007) do identify a general switching ability linked to residual switch cost (cost remaining with ample preparation time) and mixing cost, but this notion of generalising only to some functions (not to switching under short CSI conditions or congruency effects) does not sit well with the idea of a single central function for switching. Given that residual costs, like other contributors to overall switch cost, are extinguishable in certain circumstances, the likelihood is that multi-source models (e.g. Meiran, Chorev & Sapir, 2000) will offer the best explanation of switch cost. We should even consider the need for multiple separate models to account for different types of task, response and circumstance, as more recent work suggests (Ravizza & Carter, 2008).

CHAPTER ONE: LITERATURE REVIEW – PART TWO: THE VERBAL TASK SWITCHING PARADIGM – CONTINUOUS SEQUENTIAL SWITCHING USING AUTOMATIC SPEECH TASKS

11 Continuous Series Switching

The Continuous Series (Gurd, 1995) was developed as a verbal task switching paradigm to track deterioration in the switching abilities of Parkinson’s disease (PD) patients, in a task with no visuo-spatial or motor demands (set shifting dysfunction in PD is well documented e.g. Lees & Smith, 1983; Owen et al., 1993; Woodward, Bub & Hunter, 2002). The task requires participants to produce items alternately, sequentially and *continuously* from increasing numbers of overlearned sequences such as numbers, days, months and letters. The overlearned nature of the stimuli means the task is not liable to the verbal fluency difficulties usually found in PD (Gurd & Ward, 1989; Gurd, Ward & Hodges, 1990). Such examples of ‘automatic speech’ are typified not only by a high degree of practice but also by syntactic and semantic simplicity (Bookheimer et al., 2000) and are known to be preserved in a variety of pathologies (e.g. Code (1997) cites intact automatisms in aphasic and left hemisphere damaged patients). Switches are predictable and uncued – participants are told in advance the order of the category switches and progression *within* each category follows their implicit sequential structure. No externally presented stimuli are used, allowing maximum preparation time and minimal additional processing requirements; response production is entirely self-paced (as per Jersild (1927), Spector & Beiderman (1976) and Allport, Styles & Hsieh (1994)).

Further rationale for using the task lay in the potential to address both parts of Shallice and Burgess's (1991) predictions for a dysfunctional Supervisory Attentional System (SAS). The tasks contrasted due to the low novelty/ high switching requirements of the Continuous Series task and the highly novel/ minimal switching requirements of tasks such as the colour Stroop. This contrast allied itself to the contention scheduling and non-routine scenarios in which Shallice & Burgess (1991) had proposed a fully functional Supervisory Attentional System (SAS) was implicit. Failure of the SAS to modulate the action of contention scheduling would result in (1) perseverative behaviour, or (2) an inability to deal with novel tasks. The Continuous Series, colour Stroop and an alternating verbal fluency task were employed by Gurd (1995) to address the then contention that a dysfunctional SAS was implicated in the PD profile. An absence of correlation between Continuous Series and verbal fluency (both frontally mediated tasks) was taken as evidence against impairment of a *unitary* frontal function. In addition, two types of error were recorded for the PD group during the Continuous Series task, contention scheduling errors and WM errors. Separate cases of double dissociation for these two error types within the PD group highlighted the non-universality of perseveration and so again questioned the application of an unfractionated SAS dysfunction. The use of verbal responses to distinguish between these two error types was later mirrored by Arbuthnott (Arbuthnott & Frank, 2000), who identified executive wrong-task errors and WM decision-errors (choosing a response within a task).

A modified version of the task (Continuous Series II, using non-canonical start points for the sequences, Gurd & Oliveira, 1996) was used to further define the dissociation between task switching and other abilities in PD, contrasted this time with a guided semantically-stratified verbal fluency search task adapted from Neisser & Beller (1965). Impaired performance on the two tasks was again found to be dissociable, in accordance with previous results from Gurd (1995). In addition to the clinical usefulness of the Continuous Series II task in tracking switching deterioration in PD, Gurd and Oliveira proposed that a unitary SAS-type dysfunction was unlikely to be the source of impaired performance for both tasks. Rather, executive control was said to be of differential relevance (the nature of which was unspecified) to each of the two tasks, concurring with Allport's (1992) suggestion of several distinct fractionated central executive functions.

The Continuous Series II task was further employed (Gurd et al., 2002) to assess the contribution of the parietal cortex during switching. As noted by Gurd and colleagues, reports of such switch related activation were primarily made from tasks with visual or visuo-spatial task demands (e.g. Kimberg et al., 2000; Sohn et al., 2000; Dove et al, 2000). The Continuous Series II offered a unique opportunity to look at switching in the absence of such demands, using silent self-paced repetition of the verbal task. The assertion of Gurd and colleagues, that verbal task switching "...had no spatial and no visual component whatsoever" (Gurd et al. (2002), p.1030) was pivotal to their interpretation of the data as supporting a major integral role for the parietal cortex in switching per se. At the time this involvement was not well established. However, the possibility of an abstract spatial aspect to the task should not be overlooked. During later work with the Continuous Series II (Essig, 2004a), participants were observed tapping or pointing from left to right to mark out the order of the categories; anecdotal reports confirmed that some were holding an image of the category order in a spatial configuration[27]. However, the strength of the assertion should not be lessened, only

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[27] There may be some argument that the arrangement of the component tasks or the ordinal nature of the categories does itself constitute a spatial element – Eagleman (2009) has noted a synaesthete-like spatial arrangement for overlearned sequences in non-synaesthetes. Fias, Lammertyn, Caessesn & Orban (2007) detail processing of abstract ordinal knowledge (letters and numbers) in the horizontal segment of the intraparietal sulcus – letters are seemingly processed in a way that closely mimics that of number processing, re: specificity of the horizontal plane of the intraparietal sulcus to ordinal number processing (see Dehaene, Piazza, Pinel &

tempered, by this caveat, given that the task involved no physically mediated response, no externally delivered stimuli (with ensuing spatial or visual attributes) and the impetus to switch is entirely endogenous. The verbal switching parietal activity is as a result of general switch cost[28] (defined by Kray & Lindenberger, 2000), with (as defined by Gurd et al.) no exogenously driven task demands. While the ordinal nature of the overlearned sequence categories may be construed as having a spatial arrangement (which could partially account for the parietal activation in a supposedly non-spatial task). The persistence of this activity during non-ordered semantic category switching (as reported by Gurd et al., 2002) would suggest a significant switch related role.

The imaging data from the Gurd et al. (2002) study revealed broad prefrontal cortex (PFC) activity[29] and importantly increased activity in the superior posterior parietal cortex (PPC) as a main effect of verbal task switching compared to single verbal category fluency[30]. PFC activation was variable in its location whereas parietal activation was found to be more consistently bilateral and more consistently seen (64% and 82% respectively, see Gurd et al., 2003 for further analysis). Gurd and colleagues suggested a *supramodal* role for the parietal cortex, in addition to any modality specific functions indicated by tasks with visual, spatial or aural task demands. Several published studies concur with this interpretation e.g. Barber and Carter (2005), Collette, Hogge, Salmon and van der Linden (2006), Cohen, Dehaene, Vinckier, Jobert and Montavont (2007) and Lu et al. (2009). It has been suggested by Wylie, Murray, Javitt and Foxe (2009) that the fronto-parietal network identified by Gurd and others

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Cohen (2003)). Fias & colleagues propose this may be due to transformation of letter ordination to a numerical form.

[28] Costs derived from comparison of a switching block with a non-switching block, as opposed to comparison of switching and non-switching within the same block (alternating runs).

[29] Bilateral anterior cingulate cortex, bilateral frontal operculum.

[30] The nature of the Continuous Series II does not allow for comparisons with switching repetitions within a trial in the same way as the alternating runs paradigm.

(see section on page 75 ‘neural activation during task switching’) may be involved more in the regulation of competition than actual control. However, their own data relating to such competition (Wylie, Javitt and Foxe, 2004) arises from the utilisation of an explicit cued design (they attribute competition to the arrival of the cue), something absent from the data of Gurd et al. (2002). Consistent switch related activation of the superior posterior parietal cortex in the absence of visual, spatial or cue requirements would appear to be an unusual finding.

The Continuous Series II therefore represents a highly unusual form of task switching. There are two key themes related to the task that warrant further interpretation in relation to the broader task switching literature. One is the apparently switch specific activation of the superior posterior parietal cortex – although the involvement of a fronto-parietal network in task switching is well established (e.g. Sohn, Ursu, Anderson, Stenger &Carter, 2000; Brass, Ullsperger, Knoesche, von Cramon & Phillips, 2005), this is nearly always in the presence of visual and spatial task demands and often in relation to the use of cues which has been shown to increase activation in this area (Sohn, Ursu, Anderson, Stenger &Carter, 2000, although *c.f.* De Baene & Brass, 2011 for a recent refutation of this cue related activity). The other aspect of the paradigm that requires further discussion is the entirely self-paced reliance on internal representations. Although Gurd presents this absence of cues and stimuli as a positive feature of the task, it inevitably increases the load on WM, particularly as the task reaches a maximum of switching between four tasks. The evidence for the effects of WM load on switching abilities is mixed but it is evident that switching calls on these resources (Vandierendonck, 2012). The fundamental question is whether taxing WM separately from the switching function (as holding a sequence of four tasks would do) has a detrimental effect on that switching function. Reliance on verbal WM is implicit, as previously noted by

Monsell (2005) in participant verbalisation of task sequence (see also Goschke, 2000) and by Baddeley, Chincotta and Adlam (2001) in the detrimental effects of articulatory suppression. However, other studies have shown that while WM span relates to task switching performance (higher span, better performance) the two abilities do not interact (low span does not equate to greater costs) (Kane, Conway, Hambrick & Engle, 2007). Both of these issues will now be addressed, as will the relevance of the Continuous Series II to major theories of task switching.

11.1 Neural activation during task switching

The Gurd et al. (2002) study shows a commonly found fronto-parietal network being activated during task switching. However, the wide range of stimuli and varied task demands is noted by Gurd et al. (2003) as proving problematic in determining a universal model of activation generally applicable to switching. It is even more difficult in applying these findings directly to the activation found in the Gurd study as switching occurs between tasks but within a single cognitive set of overlearned sequences. Additionally the lack of sensory stimuli means "*...no* disengaging, *no* moving to a desired location*...no modulating sensory inputs*, and *no executing motor actions to target events.*" (Gurd et al., 2003. p.S55). The verbal task offers switching in the absence of many of the necessarily associated functions and so activation seen during this task may offer a purer picture of task *switch* relevant activity. Neural activity associated with verbalisation is of course implicit but this is the case with all task switching (Monsell, 2005). Particular credence is given to parietal activity found during this task, due to the lack of additional task demands usually associated with such activation (e.g. Kimberg, Aguirre & D'Esposito, 2000 using visuo-spatial displays). The parietal cortex is well established in the role of directing spatial attention (Halligan, Fink, Marshall & Valler, 2003), including redirection of movement or movement intention ('motor attention') (Rushworth, Johansen-Berg, Göbel & Devlin, 2003) and has been implicated in switching tasks with visual input (e.g. (Sohn, Ursu, Andersen, Stenger & Carter, 2000). Further analysis of the role of the parietal cortex in switching has been carried out since, suggesting, for example, a role in the selection of action rules (Philipp, Weidner, Koch & Fink, 2013 – although still with visuo-spatial demands) but the suggestion that the parietal cortex has a supra-modal role in switching that is free from additional demands (Gurd et al., 2002) remains notable.

Evidence from lesion-based studies shows the pre-frontal cortex (PFC) to be widely implicated in the control of task switching. Early work related deficits to dorsolateral (DLPFC) damage (Rubinstein, Evans & Meyer, 1994). Deficits are commonly found in relation to both left and right PFC damage (Rogers et al., 1998; Aron, Monsell, Sahakian & Robbins, 2004) – Aron et al. (2004) particularly highlighted damage to the inferior frontal gyrus (IFG) in relation to inhibition. There is also some evidence for involvement of the anterior cingulate cortex (ACC) (Burgess, 2000; Burgess, Veitch, de Lacy Costello & Shallice, 2000). This is suggested by Braver, Barch, Gray, Molfese and Snyder (2001) to be related to response conflict resolution (see Brown, Reynolds and Braver (2007), page 65 of this document), similarly cited by Burgess et al. (2000) as implicit in task-related rule breaking. Conflict monitoring by the ACC results in appropriate recruitment of the DLPFC to resolve competition issues (Botvinick, Braver, Barch, Carter & Cohen, 2001). MacDonald III, Cohen, Stenger and Carter (2000) confirm DLPFC involvement in rule implementation and ACC in processing of incongruent stimuli. Incongruency would clearly represent a case of conflict, confirming this already established role. The PFC, while highly implicated in control during task switching (e.g. Dove et al., 2000; Braver, Reynolds & Donaldson, 2003; Brass & von Cramon, 2004) does not appear to have any area solely devoted to switch control which is not also implicated at a lesser level of activation during repeat or baseline task trials. For example, Dreher, Koechlin, Ali and Grafman (2002) found fronto-parietal activation increased in switching compared to separate task performance but not in comparison to holding two tasks in memory without switching.

As noted by Gurd et al. (2002; 2003) activation in the parietal cortex is established in the task switching literature, though largely in relation to tasks with visual and spatial task demands (Kimberg et al., 2000; Sohn et al., 2000; Dove et al, 2000; Sohn et al., 2000). Primate studies have also indicated a role for the posterior parietal cortex (PPC) in attentional and set shifting (Yamazaki, Hashimoto & Iriki, 2009 review data supporting non-spatial representations in the PPC) and task encoding (Stoet & Snyder, 2006). More generally part of the parietal cortex (the medial superior parietal lobule) has been associated with cognitive control “...during shifts between perceptual, mnemonic, and [crucially] rule representations” (Esterman, Chiu, Tamber-Rosenau & Yantis, 2009, p.17974), although again in relation to perceptual-motor tasks. The relationship between frontal and parietal regions during switching is predictably frontally led. Using EEG Brass, Ullsperger, Knoesche, von Cramon and Phillips (2005) found that PFC activity temporally preceded and so biased activity in the parietal cortex. This was thought to relate to task representations and stimulus-response associations respectively (see also Rushworth, Passingham & Nobre, 2002 for similar results). The role for the parietal cortex seems largely stimulus bound although going beyond that of mere stimulus processing as might be construed by results from visual-based tasks. There is however evidence for a parietal role in higher order cognitive functions in the absence of spatial requirements (Gottlieb & Snyder, 2010). Amongst other functions this includes encoding task context or task rules, crucially sometimes before the presentation of the target stimulus as shown from single neuron studies (Stoet & Snyder, 2004; Balan &

Gottlieb, 2006). Liston et al. (2006) say that the PPC is sensitive to a dissociable form of conflict from the ACC, stimulus and response related respectively, reinforcing Gurd and colleagues' assertion of a supramodal role for the PPC. Interestingly they reported activity in this region *preceding* an increase of activity in the DLPFC (unlike Brass et al., 1995), suggesting the possibility of an independent role for the PPC (although the study used event-related fMRI rather than EEG). The notion of PPC-mediated conflict resolution would tie in with the assertion of Birn et al. (2010) that parietal activity of the type found by Gurd and colleagues relates to controlled retrieval; commenting specifically on Gurd et al. (2002), Booth, Bebko, Burman and Bitan (2007) note that the semantic nature of the task may impose increased retrieval demands. Retrieval may be of abstract rules rather than merely motor responses (Stoet and Snyder 2004; 2007), again supporting Gurd's assertion that the parietal cortex has a more fundamental role in task switching.

The recruitment of a fronto-parietal network (FPN) is evidently implicit to task switching (e.g. Dove et al., 2000). But this same network is well documented as being involved in a range of executively demanding tasks (e.g. Cole & Schneider, 2007; Niendam et al., 2012) and is implicit to goal-directed behaviour (Corbetta & Schulman, 2002). As noted there is no distinct area or network devoted solely to task switching. The FPN does not work in isolation, recruiting other networks according to task demands (Vincent, Kahn, Snyder, Raichle & Buckner, 2008). The ability of this network to be applicable in so many tasks and situations is attributed to the existence of 'flexible hubs' within the network – these are regions that are able to rapidly change their "...brain-wide functional connectivity patterns…" (Cole et al., 2013, p.1) and allow for cognitive control across a variety of tasks. Clearly then the network responsible for switching is specialised more for cognitively demanding goal-directed tasks than switching itself. It is noted that although *switching* activity is seen in the parietal cortex this is in relation to different task parameters than those causing activity in the PFC (e.g. Badre & Wagner, 2006 show a dissociation between the two areas[31]). Although the two areas act in concert, Karayanidis et al. (2010) state that preparatory and task related control associated with cued switch/ repeat trials are related to at least partly distinct activity in the PFC and PPC. As previously noted activity in the network is also temporally differentiated, being frontally led (Brass et al., 2005). Additionally recruitment of the network differentiates according to the type of switching task being carried out. Although there are some common areas (the inferior frontal junction and the PPC) different types of task (perceptual, response or context switching) recruit differentially across the network (Kim, Cilles, Johnson & Gold, 2012). Recruitment of the FPN is diverse – although there are no switch specific areas there are switch *common* areas. Control of task switching is not carried out universally by a single set of brain regions but instead a multiple range of regions (perhaps mediated by the core elements of the FPN overseeing complex tasks *per se*) depending on the phase of the switching process being completed and the type of task.

Involvement of frontal and parietal regions during task switching is therefore well established, but how does this relate specifically to the action of reconfiguration and inhibition? Determining a neural basis for reconfiguration has not been straightforward, not least because several imaging studies have reported no increase in activity during preparation for a switch compared to preparation for repeat trials. Necessarily (because of haemodynamic lag) studies have had to use preparation intervals of several seconds rather than the fractions of seconds used in behavioural studies (e.g. Kimberg et al., 2000; Sohn et al., 2000). Activation seen during this period could therefore be reflecting task maintenance rather than

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[31] Under a situation of increased preparation there was *reduced* switch-repeat activity in PFC areas but *increased* activity in parietal areas.

reconfiguration (Lavric, Mizon & Monsell, 2008). Some cued fMRI studies have used techniques such as varying CSI from trial to trial or including occasional cues with no stimuli to separate out cue and stimulus related activity. However, as noted several of these have found no difference between switch and repeat preparation (e.g. Brass & von Cramon, 2002; Luks, Simpson, Feiwell & Miller, 2002; Ruge et al., 2005). However the picture is not all bleak – in a cued response task using bivalent and univalent stimuli it was found that rule representation and task-set reconfiguration are dissociable processes, finding a clear difference in activation levels for switch and repeat trials (Crone, Wendelken, Donohue & Bunge, 2006). Task-set reconfiguration was linked specifically to medial PFC activity. Further dissociation has been found between cue switch and task switch (Bryck, 2008), in a pattern consistent with a hypothesis of endogenous control. Use of ERP data has been more successful in determining the action of reconfiguration, allowing for separation of pre-stimulus preparation and post-stimulus completion. These studies show a clear difference between switch and repeat trials (e.g. Nicholson, Karayanadis, Poboka, Heathcote & Michie, 2005: Swainson, Jackson & Jackson, 2006; Astle, Jackson & Swainson, 2006). Interpretation of latencies, in particular a posterior positive deflection at ~400ms into the preparation period reported in several studies, has led to the proposition that this is a direct reflection of advance reconfiguration (Lavric. Mizon & Monsell, 2008). By independently manipulating cue and response to stimulus intervals, it has been possible to separate out the action of active reconfiguration from passive interference (Nicholson et al., 2005, see also Li, Wang, Zhao & Fogelson, 2012). While some fMRI studies have not found a switch-repeat difference (Brass & von Cramon, 2004; Ruge et al. 2005), the picture gleaned from ERP data is more consistent. Reconfiguration (along with some degree of inhibition) is clearly defined as a component process during task switching (Rushworth et al., 2002). This reconfiguration is anticipatory, as predicted by the TSR hypothesis (Rogers & Monsell, 1995). Reconfiguration of task set and implementation of task set are associated with distinct phases of ERP modulation (Rushworth et al., 2002) which would certainly fall in line with a prediction such of that of Meiran (2000) that switching consists of several different associated processes.

As noted, the inferior frontal gyrus has been linked to inhibition (Aron et al., 2004). However, studies investigating inhibition are not widespread (most look at processes supporting active reconfiguration or preparation) and further confirmatory empirical evidence is sparse. Hence a piecemeal picture of inhibition-related neural activity is presented. Secondary evidence of residual activity in areas relating to the preceding task would suggest a role for carryover of the previous task set (Yeung, Nystrom, Aronson, & Cohen, 2006). But is there neural activity specifically related to inhibitory processes? Dissociation between right prefrontal activity for inhibition and left prefrontal for activation of task sets was gleaned from a small sample of individuals with focal lesions, suggesting functional separation of these processes (Mayr, Diedrichsen, Ivry & Keele, 2006) and confirming similar previous results for inhibition (Aron, Monsell, Sahakian & Robbins, 2004). Looking specifically at *backward* inhibition (greater costs for the third task on sequence A-B-A compared to C-B-A due to its recent activation) in a sample of healthy controls, there is again a finding of right lateral PFC increased activity in relation to greater levels of inhibition (the A-B-A sequence) (Dreher & Berman, 2002). More recent work on backward inhibition found switch-related activity in the left medial superior parietal lobule, which appeared to also recruit the left intraparietal sulcus and posterior cingulate cortex (Piguet et al., 2013). Inhibition of a previous task set (backward inhibition sequence A-B-A) resulted in *deactivation* of these parietal regions when the same task was returned to – there was no inhibition-related *increase* in activity, only a decrease in regions related to specific demands of the task. This is certainly in line with proposed predictions for the TSI hypothesis (Yeung, Nystrom, Aronson, &

Cohen, 2006), that activity would be decreased in switch related areas, rather than an increase in an inhibition specific area. However, equally one could predict an increase as more effortful processing is required in the face of competition. The absence of any increased activity in areas previously highlighted as relating to inhibition is troublesome, although the body of literature is frustratingly small so these apparently marked differences have little context. Again there is a high level of visuo-spatial task demands that could account for the switch-related activity. It is notable that these previous studies do not report parietal deactivation in relation to inhibition, perhaps highlighting the role of the specific task demands. As for all aspects of task switching there is no unique locus of activity for inhibition – all regions apparently involved are also recruited for other phases of the switching process.

In summary there is no switch-specific area – regions involved in task switching are also implicated in other complex or demanding cognitive behaviours. There is a reliable fronto-parietal network but this is diverse in the range of component areas involved, with the network recruiting a number of other areas and networks, according to task demands. Mapping these patterns of activation to elements of key theories of task switching, namely reconfiguration and inhibition, have been far from straightforward. Some forms of evidence can be conflicting (as is the case for fMRI data relating to reconfiguration) but others (ERP data for reconfiguration) offer a more certain picture. Certainly it seems that more combined methods studies would be the way forward here (Swainson et al., 2003 being an example of such a combined fMRI/ ERP study). The pattern of parietal activity in relation to non-visuo-spatial switching as in the Continuous Series II (Gurd et al., 2002) is not widely replicated in the literature but there is some small body of evidence that suggest this could be related to rule representations in the absence of such task demands (Gottlieb & Snyder, 2010). Medial superior parietal lobule has been shown to be supportive of initiation of task set reconfiguration in a range of domains, although this has been in the realm of perceptual-motor tasks (Esterman et al., 2009). However, given the single neuron results that parietal cognitive control occurs in the absence of spatial demands (Stoet & Snyder, 2004) it is entirely feasible that such activation is related to reconfiguration per se rather than being tied to a particular domain or response mode. Although there is arguably a spatial element to overlearned word sequences, this is far more abstract than for externally presented stimuli. As such the parietal activation shown in relation to the Continuous Series II can legitimately be taken as an early example of response-free cognitive control, perhaps relating to reconfiguration of task set.

11.2 Memory load during uncued verbal switching

Aside from the unusual non-spatial parietal activation seen during the Continuous Series II, the other outstanding feature is that it is entirely memory dependent. One obvious criticism of the Continuous Series II is that it is just a test of memory. Holding four tasks in WM with no supportive external cues or stimuli must by necessity be demanding. Are the increased time costs and errors seen at this level merely a reflection of an overloaded WM? Working memory load is implicit to all types of task switching, both cued and uncued. However, some types of switching (such as the Continuous Series II) require switching exclusively within WM. Both Barch et al. (1997) and Logan (2004) found working memory load to be dissociable from other processes active during task switching. Wager, Jonides & Smith (2007, p.1742) provide evidence that "…switching within working memory is separable from switching in perception." Excessive memory load will of course result in reduced ability to switch attention or inhibit irrelevant task sets (Hester & Garavan, 2005) but

Gurd et al. (2002) assert that the constraint of using overlearned sequences minimises this as much as possible. Although categories have to be held in working memory during switching fewer *items* have to be maintained resulting in reduced per category iterations, rendering working memory possibly comparable but differently distributed between switching and non-switching conditions. Circuits associated with verbal working memory (inferior parietal cortex (left supramarginal gyrus) and PFC regions as noted by e.g. Braver et al. (1997)) were reportedly not “maximally associated” with switching in the data collected by Gurd and colleagues. Parietal activity was therefore not primarily associated with active maintenance of items in working memory through attention shifting (e.g. Jonides et al. 1998).

However, there may be additional costs relating to working memory not foreseen by Gurd – it has been proposed that memory switching may incur an additional cost to task switching in the same was as cue switching. Further manipulations of the role of working memory came from Mayr (2010) who used 2:1 response mappings[32] (a cue-task mapping – two possible cues could signify one task) and concluded that use of memorised task representations mirrored the cue switch cost found with exogenous explicit cues. A significant portion of RT costs were due to the need to switch between memorised cue labels rather than switching between actual tasks. However, a recent review (Vandierendonck, 2012) has shown that in some instances there is no interaction between memory load and costs. Undoubtedly there is a significant reliance on verbal working memory during task switching, as seen from the role of verbalisation (Goschke, 2000; Monsell, 2005) and the disruptive effects of concurrent articulatory suppression (Baddeley, Chincotta & Adlam, 2001). Other studies (e.g. Saeki & Sato, 2004; Liefooghe, Vandierendonck, Muyllaert,

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[32] Mayr notes Altmann’s (2006) objection to the use of 2:1 mappings as introducing an erroneous additional level of processing to the task, stating that just such a retrieval based cost is implicit but masked in 1:1 mapped tasks.

Verbruggen & Vanneste, 2005) have demonstrated that taxing the phonological loop results in slower and more error prone switching.

Conversely, other evidence has shown little link between WM and switching. Logan's (2004) task-span was compared to memory span – task-span reflected the number of tasks carried out in the correct order and memory span the number of task *names* remembered in the correct order. Logan found no trade off between storage and task switching, suggesting that storage processes were separate from task performance processes. Switching involved processes outside of WM and the results were taken to support theories positing multiple executive processes. Other work, looking at switching performance in individuals with high and low WM span (Kane, Conway, Hambrick & Engle, 2007) has found that while a high span is linked to faster, more accurate switching, a low span is not linked to *higher* switch costs. Vandierendonck (2012) suggests a model containing components of declarative (examples of current problems) and executive (task set and rules) WM would account for both sides of this debate. Differences are related to the time available to rehearse - limited time results in detriment for recall (e.g. Liefooghe, Barrouillet, Vandierendonck & Camos, 2008) and ample time means that recall does not depend on difficulty (e.g. Logan, 2004). Thus WM is potentially implicated in switching even when the results from studies suggest there is no link. However, the onus is still on declarative WM (which equates to the phonological loop/ visuospatial sketchpad) to maintain serial information about task order. While this model might seem readily applicable to the Continuous Series II, with seemingly ample rehearsal time, it should be remembered that the Continuous Series II elicits no additional activation in areas linked to verbal WM (Gurd et al., 2002). In this respect the role of WM in Continuous Series II is still unclear and warrants further investigation.

Previously in this thesis it has been noted that detrimental effects for switch cost of articulatory suppression in the absence of environmental cues emphasises the role of verbalisation in task switching. In an uncued switching task such as the Continuous Series II, presumably heavily reliant on inner-speech as a self cuing device, it would be of import to determine the relationship between memory span and switch cost. As such all experiments contained in this thesis assess the correlation between digit span measures and switch cost, partialling out any effects found. It must be assumed that involvement of the phonological loop (or its equivalent as presented by Vandierendonck, 2012) to the degree suggested by Saeki & Sato (2004) (and thus reliance, in the uncued paradigm, on WM) would consistently present as reduced switch costs for those individuals with greater memory span, in line with Kane etal. (2007). However, memory span has not been found to account consistently for switch cost when accounted for on statistical analyses of the Continuous Series II. A further way to account for the effects of WM on switch cost in an uncued paradigm would be to introduce cues which must necessarily reduce the requirement to hold a sequence of up to four tasks in WM. Rehearsal in the Continuous Series II is twofold, for both tasks and task items. As such it cannot be assumed that models such as Vandierendonck's could fully account for potential costs. Although verbal WM is not thought to be overly implicated in the task (Gurd et al., 2002) that is not to say that other aspects of WM might not be. Experiment 6 in Chapter 8 addresses this directly, introducing continuously present cues of either low or high semantic content (used previously by Logan and Bundesen, 2004). WM load for task order is reduced, thus freeing up capacity for item rehearsal, presumably resulting in lower costs, fewer between category (task) errors and within category (item) errors.

Working memory is thus still a pertinent question as regards the Continuous Series II, but what of its role in reconfiguration accounts? If WM is implicit in the Continuous Series II is this evidence for reconfiguration or inhibition based accounts? Both inevitably lay claim to the involvement of WM. Working memory must be involved in reconfiguration and maintenance – for example, Vandierendonck (2012) suggests an executive aspect of WM which deals with task set and rules. It has been suggested by others (e.g. Rubinstein et al., 2001) that only one task set can be present in WM (presumably addressed for Vandierendonck by the declarative aspect) – switching therefore necessitates executively mediated LTM retrieval of further task sets. Working memory therefore interacts with executive reconfiguration processes. Further evidence comes from Baddeley, Chincotta & Adlam (2001) who used articulatory suppression to interfere with switching processes, using a suppressive task akin to 2-category switching in the Continuous Series II. Greater interference occurred for switching rather than repeat conditions – the secondary tasks involved executive control processes and so these were not available for reconfiguration. It should be noted however that Rogers & Monsell (1995) themselves highlighted that WM processes are separate to switching. This was the basis of their criticism of Jersild's (1927) assessment of switching in blocks as there was a disparate WM load between switching and repeat blocks. Further, there is also evidence that WM is *not* involved in the maintenance of task sets. Some studies have proposed that it is activated LTM rather than WM that holds things like response representations (e.g. Rubin & Meiran, 2005; Meiran & Kessler, 2008). It has also been proposed that when the alternating runs (AABBAA...) paradigm is executed with a long RSI (response-to-stimulus interval) there is the potential for the task set to be lost from WM, necessitating further retrieval from LTM (Vandierendonck, Liefooghe & Verbruggen, 2010). Such re-retrieval acts like retrieval of a *new* task set and so can add to costs in a way that might appear asymmetric. Working memory would seem to be an implicit co-process in a reconfiguration account by virtue of how many task sets can be maintained (or lost), although some would say this can be supplanted by active LTM[33], which may be less limited in capacity.

As far as inhibition and priming accounts are concerned (Allport, Styles & Hsieh, 1994; Allport & Wylie, 2000), priming occurs through associations between stimuli and responses and also by repetition of instructions that indicate the upcoming task (e.g. Arrington & Logan, 2004b; Schneider & Logan, 2005). As such this would involve the phonological loop for rehearsal of instructions. Task set inertia involves the passive transient decay of the previous task set (or stimulus response set) in WM – this is why effects are locally confined and do not build up over time. Increasing the interval between stimuli *decreases* the inertial effect (Witt & Stevens, 2012), thereby reflecting memory decay. Although earlier studies using the Jersild (1927) switch/ repeat list approach (specifically Allport, Styles & Hsieh, 1994), potentially included the WM confound noted by Rogers & Monsell (1995), later studies that looked at priming effects (Waszak, Hommel & Allport, 2003) modified the design to address these issues. Thus the involvement of WM in inhibition and priming accounts is confined to the passive decay of items it contains. Whereas during reconfiguration items are actively moved to (and rehearsed in) WM stores, inhibition accounts make no claims about active movement of items, being more passive and stimulus led. The reality is that WM acts as a supportive process to reconfiguration, allowing for rehearsal of task order (Monsell, 2005) and maintenance of the current task set, with decay of that set contributing to passive carryover effects. As previously noted, many accounts of task switching allow for both processes to act in concert (e.g. Meiran, 1996; Yeung & Monsell, 2003) and WM would seem one setting in which they interact.

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[33] Representations activated for relevant associated task sets within LTM as oppose to a peripheral portion of WM (Cowan, 1988).

Given that the Continuous Series II does not show additional activation of areas associated with verbal working memory (Gurd et al., 2002), it is possible that the load on WM is not greater than that accrued in any other task switching paradigm, given what we know about verbalisation for the upcoming task (Goshcke, 2000; Monsell, 2005), even when explicit cues are used. However, as the Continuous Series II gives a measure of general (whole task) switch cost it inevitably captures a range of contributory processes. It would therefore be pertinent to ascertain exactly how much of this cost is memory based. Additionally, there is the contribution of recalling instructional cues from LTM. It has been noted that increasing the number of items to be maintained does not always increase switch cost (Liefooghe et al., 2008) so holding up to four items in WM may not inflate cost. Conversely though, the same study shows that task switching itself does impair the *maintenance* of items. Other work (Liefooghe, Barrouillet, Vandierendonck & Camos, 2008) confirms that the act of switching introduces a cost to WM functioning. Thus there may be a circuitous increase in cost as the act of switching will impair the maintenance of the four items, which obviously is more difficult than maintaining the usual two tasks associated with most traditional studies. Working memory and task difficulty have been shown to doubly dissociate functionally (Barch et al., 1997) so WM would be an additive contributor to cost in these circumstances. Attempting to alleviate WM load (and LTM instructional retrieval) would therefore further refine general cost in the Continuous Series II and would give an important indication of just how much of this cost is switch related.

11.3 Calculation of switch cost during continuous verbal task switching

As well as the unusual pattern of non-visuo-spatial parietal activity and the greater reliance on (although undetermined contribution of) WM, there are other features relating to the structure and administration of the Continuous Series II that make it unusual in the literature and are worthy of comment. One of these is the calculation of general (whole-task) cost, rather than local per-switch cost. Unlike most of the work mentioned thus far, performance in the verbal switching task is measured continuously rather than on a trial by trial basis, lending itself to calculation of a *general* switch cost for completing all component tasks together. Switch cost is calculated over the whole time course of the task rather than for individual switches or repeats within the whole task, as was also the case for Jersild (1927), Allport, Styles & Hseieh (1994) and Rubinstein, Meyer & Evans (2001). In the Continuous Series II speech rate in the switching condition is compared to non-switching speech rate for the same categories. For example, if switching is between ‘numbers’ and ‘days’ then the non-switching speech rate for each of those categories is added together and divided by two (the number of categories being switched between). It has been noted that the emphasis on measuring switch cost only over local task transitions disregards the inevitable influence of “... the global representational structures in which individual tasks are embedded” (Kleinsorge, Heuer & Schmidtke (2004), p.32). Mixing costs (identified by Fagot (1994) as the time disadvantage for repetitions occurring in a switch block instead of a single task block) additionally implicate the influence of task proximity as well as task transition on costs (although see Monsell (2003) for a critique).

During the calculation of general costs, it has been found that there is evidence for distinct phases of executive volition in instigating tasks and inhibition requirements to overcome previous tasks (Rubinstein et al., 2001). Clearly general switch cost is a suitable tool to assess contributory processes in task switching (see also Goffaux, Phillips, Sinai & Pushkar, 2006). Asymmetries have also been found in general as well as specific costs (Ellefson, Shapiro & Chater, 2006). This type of cost is an indicator of executive function and reflects the need to maintain and select between task sets (Kray & Linedenberger, 2000; Kray, Li & Lindenberger, 2002; Reimers & Maylor, 2005). As such it may be particularly sensitive to measuring proactive control as proposed in the dual mechanism model of cognitive control proposed by Braver, Gray & Burgess (2007), comprising of sustained proactive control and transient reactive control. General costs reflect the selection processes that prepare the cognitive system for the upcoming switch (Kray, Li & Lindenberger, 2002). As such they must reflect preparation and have potential to shed light on reconfiguration processes. Although general (per block) and specific (per trial) switch costs are dissociable (Kray & Lindenberger, 2000) they do still fall under the auspices of the same proposed control mechanisms. Blocked designs generating general switch cost have been used to present more widely applicable theories of task switch cost, perhaps most prominently by Allport, Styles & Hsieh (1994) in proposing their TSI hypothesis.

One of very few studies looking at continuous switching performance is offered by Verhaegen and Hoyer (2007), allowing investigation of what they term ‘focus switching cost’. This is defined as the contribution of switching between task sets held in the focused and unfocused portions of Cowan’s hierarchical model of working memory (see Cowan, 2001). The focused zone of WM in this model accommodates the momentary focus of attention and holds approximately four items. The unfocused zone draws on LTM but is limited in practical terms by the effects of interference and decay. According to Verhaegen and Hoyer operations on the current task set occur within focused WM and so do not require retrieval. The non-current task set has to be retrieved from unfocused WM – what they term ‘focus switching cost’ reflects this unfocused retrieval. They cite tasks of serial attention, such as the Continuous Series II in which participants must keep track of several items, as being well suited to accounting for such retrieval costs.

However, it should be noted that, while the contribution of costs related to whole task representation and execution are central to the current work, they are not necessarily attributed wholly to working memory (such questions are considered in more detail in the section ‘memory load during verbal switching’ on page 82). The fundamental issue here is that trial by trial analysis of task switching has gleaned much information about trial by trial *switching processes*, that is to say processes which are implicated in a single transition from one task response to another. There has been criticism (e.g. Monsell, 2003) of Jersild’s (1927) original subtractive list comparison approach (comparing performance on a single task list to an alternating task list) on the basis that it obscures the distinction between mixing and switching costs, that is the costs of performing two tasks in proximity to each other and of switching between them. Nevertheless, deconstructing task switching to a trial by trial basis inevitably loses the contribution of this ‘global representation’ of tasks over time. The effects of previous task switches, of the awareness of subsequent task switches and the need to maintain task sets as available all contribute to this global representation and may not be captured in a single trial transition.

While some studies have examined the effect of the broader switching environment on the ability to switch (for example Arbuthnott (2008) looking at the effect of task location and type on backward inhibition), very few offer an alternative to discrete trial based measures of switch cost. Both Altmann & Trafton (2004) and Kleinsorge & Kajewski (2008) have warned against the limitations imposed by such an approach. As a caveat Gurd & Oliveira (1996) conceded that, when calculating continuous holistic whole-task costs, the contribution of switching to time costs may be difficult to fully discriminate from other sources of interference, such as ‘proactive inhibition’ (Allport, 1992). However, the role of inhibition in task switching has been found not to be so widespread throughout the task and is focussed at the level of stimulus attribute and response processing in a recent review of the role of inhibition in task switching (Koch et al., 2010).

11.4 Switching between four tasks: The contribution of global task difficulty to switch cost

As well as the way switch cost is calculated, another unusual feature of the Continuous Series II is that it facilitates switching between up to four tasks. True ‘multi-tasking’, switching between *multiple* tasks, is not common experimentally. Notable areas of exception are studies of backward inhibition using three tasks (e.g. Mayr & Keele, 2000: Arbuthnott & Frank, 2000; Arbuthnott, 2008) and those that use a factorial combination of two response choices and two S-R mappings (e.g. Allport, Styles & Hsieh, 1994 (Experiment 1); Rogers & Monsell, 1995 (Experiment 6); Kleinsorge, 2004; Kleinsorge, Heuer & Schmidtke, 2004). The rarity of multiple task switching in the literature was noted by Buchler, Hoyer and Cerella (2008), who used up to four equivalent arithmetical tasks (addition, subtraction, magnitude – smallest, magnitude – largest). However, as the tasks had no fixed order the appropriate task was indicated by the colour of the stimuli. This arbitrary mapping introduced another level of processing (see Logan & Schneider, 2006b) not required in the Continuous Series II. Buchler and colleagues concluded that only the current task was held in active awareness and the others were equally accessible, regardless of number, but that response latencies were weakened as the number of tasks increased, perhaps due to a ‘dilution’ of overall resources. A degree of general cost for the Continuous Series II may therefore be associated with maintenance of multiple tasks as oppose to switching between multiple tasks; calculation of per-task as oppose to general costs may be illustrative in this regard. Assessing tasks with no content, that is arbitrary load free tasks (repeating the same word) that act as a ‘place holder’ instead of more complex overlearned sequences, would also help determine the contribution of maintaining four tasks per se. Experiment 5 in Chapter 7 addressees this issue, using a constant range of four tasks at every switching level instead of increasing up from two tasks. The ratio of ‘place holder’ (repeating colour names) and overlearned sequence tasks is changed at each switching level, increasing the more complex content of the tasks but keeping them at a constant four. Thus the contribution of keeping four tasks active can be assessed separately from maintaining the task content for the overlearned sequences.

11.5 The use of verbal responses

Although not as unusual as the inclusion of four tasks or calculation of general costs, the Continuous Series II does deviate from the norm within the literature somewhat by using verbal responses. Other studies have used verbal responses (e.g. Arbuthnott & Frank, 2000;) but most studies use button presses in response to stimulus decisions. Monsell (2005) says language supports ongoing control of task switching and reconfiguration of task set by means of verbal self-instruction (this is particularly noted in older adults, who rely on the facility more in lieu of deficits in executive functioning e.g. Kray, Eber & Lindenberger, 2004). Monsell (2005) also notes that participants sometimes mutter task rules to themselves – this has been noted extensively for the Continuous Series II (Essig, 2004a), specifically stating the goal “The next one is days...”, the previous response across tasks “Days then months...”, the previous response within a task “*Monday,* Tuesday...” or seemingly unrelated ‘filler’ utterances “What comes next?”. Concurrent articulation is generally found to increase switch costs when it is at odds with this internal verbalisation (e.g. Baddeley, Chicotta & Adlam, 2001; Emerson & Miyake, 2003). Goschke (2000) found *irrelevant* concurrent word production eliminated the practice advantage but uttering the task name did not. The role of speech *per se* in task switching is evident – switch costs have been shown to be higher for patients with left hemisphere damage compared to right and particularly so for those with language disorders[34] (Mecklinger, von Cramon, Springer & Matthes-von Cramon, 1999), further suggesting that reconfiguration is reliant on language functioning. The question is whether the verbal responses in the Continuous Series II are relevant or irrelevant to the inevitable internal verbalisation. It is possible that the use of a verbal response disrupts the use of inner speech as a supportive device, removing any beneficial effects of internal verbalisation (Holland & Low, 2010). If internal rehearsal is for task order (as would seem most likely from Monsell, 2005) then a verbal response of a task item might be supposed to interfere with that. For example, responding with the word ‘Tuesday’ might interfere with rehearsal of task order ‘numbers, days, months…’ However, as evidenced above sometimes rehearsal is for the category item in which case rehearsal would be supported. The additional analysis for Experiment 2 in Chapter 4 addresses the issue of whether the type of verbalisation produced has any differential effect on the subsequent responses made. By categorising both non-target utterances of the type already reviewed above and subsequent responses it is possible to determine whether rehearsal, regardless of its nature, has a beneficial effect for completion of the task.

11.6 Classification of errors in the Continuous Series II

One final area of difference within the verbal switching paradigm is the way that errors are classified. This leads directly on from the relevance of verbal responses, as it is just

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[34] Interestingly previous work using the Continuous Series II (Essig, Gurd & Kischka, 2005) indicated no correlation between normal speech rate and switch cost in a sample of healthy controls. None of the experiments presented in the current work show significant correlations between normal speech rate and switch cost at any level.

these responses that allow different types of errors to be identified. Rogers and Monsell (1995) determined that errors were more common during switching trials, decreased with practice for some tasks (e.g. digit but not letter decisions, their Experiment 1) and could be almost extinguished with sufficient preparation time (1200 msec, their Experiment 3). Errors were seen to contribute to time switch costs through post-error slowing and to justify the requirement for an exogenous controller through the commission of ‘capture errors’ (as stimuli evoke concomitant task execution). Capture errors are analogous in healthy controls to perseverative errors in frontal patients (often seen in the Wisconsin Card Sorting Test, Grant & Berg, 1948) attributed to “absentmindedly perform[ing] an action habitually associated with the context instead of the action intended” (Rogers & Monsell, 1995, p. 209). Such errors during switching can be permanent or temporary, signifying a loss of endogenous control and an evocation of task set by the stimuli – task sets become *exogenously* controlled. Task set is automatically assumed by a process of contention scheduling. Errors in the Continuous Series II constitute more than capture errors – perseverative errors[35] could be classed as such but within-category sequencing errors, where items are produced from the correct category on each iteration but in the wrong order, do not lend themselves to this interpretation.

In the original Continuous Series study (Gurd, 1995) errors were classified as WM errors (sequencing errors), contention scheduling errors (repetitions or perseverations) or schema errors (‘wild card’ items from unrelated categories). Clearly there is agreement at least partially with Rogers & Monsell’s (1995) perseverative capture errors. However, the only other verbal response study to differentiate between different error types is that of

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[35] Perseveration in the Continuous Series II can occur within a single category, repeating the same response over several iterations (‘Tuesday, Tuesday, Tuesday’ instead of ‘Tuesday, Wednesday, Thursday’) or across categories, repeating items from the same category instead of switching to the subsequent ones (‘Tuesday, Wednesday, Thursday’ instead of ‘Tuesday, April, L’)

Arbuthnott & Frank (2000). They defined errors as either *wrong task* errors (selecting the wrong task to carry out) or *decision* errors (selecting the wrong response within the correct task). Arbuthnott proposed decision errors to reflect task-specific processes and task errors relate to executive control. Earlier, Gurd (1995) had related sequencing errors to working memory and repetitions (perseverations) to executive control though had not made the distinction of whether these occurred within or between tasks. Errors as reported by Rogers and Monsell (1995) did not allow for such a distinction as they were ambiguous due to the manual response mode. Commonly, other studies report only task errors for this reason (e.g. Woodward et al., 2003; Meiran & Daichman, 2005). Errors occurred too infrequently for analysis in the original TSI study (Allport, Styles & Hsieh, 1994). Allport and Wylie (2000) and Wylie and Allport (2000) report the same general error count but comment on it only in respect of its elevation during Stroop switching.

It would seem plausible to use this distinction of wrong task (executive) and decision (working memory) to define errors in the Continuous Series II. Errors can either occur between categories/ tasks (choosing the wrong task or omitting a task) or within tasks (choosing the correct task but making a sequencing error). However, this is limiting in the scope of errors that can be made. In the Continuous Series II, perseveration can occur both between tasks (e.g. ‘Monday, *Tuesday*, A’ instead of ‘Monday, January, A’) and within tasks (e.g. ‘Monday, January, A, *Monday*, February, B’). Within category errors are clearly not limited to failure of WM. The type of error is relevant to defining the theoretical description of the task. It is not necessarily the case that errors are caused solely by forgetting or that they reflect WM or other memory faculties – they may not be derived from tasks that extensively rely on WM (Gurd et al., 2003). Instead this thesis will use a novel approach to defining error source, relating to Daniel Kahneman’s two-system approach to judgement and choice

(Kahneman, 2011). System 1 results in fast, automatic, subconscious thinking, System 2 results in slow, effortful, conscious thinking. Kahneman defines System 1 as adept in detecting simple differences automatically (e.g. the changing state of a single attribute such as the overlearned sequence days of the week). System 2 is more deliberate and is able to follow rules – a crucial function of this system is the adoption of task sets. Effortful deliberate switching is the domain of System 2 and automatic minimal effort updating is the domain of System 1. The fundamental difference is automatic reaction and intentional control. The first is naturally faster than the second so additionally this would predict that updating within a task (Monday, Tuesday…) contributes less to general costs than switching between tasks (numbers, days…).

Adopting Kahneman's dual-system definition for decision making in defining Continuous Series II errors avoids the need to recount to WM as a basis for error production. Such a definition limits the usefulness of error data in defining models of processing. While WM does undoubtedly have links to attentive and executive processes it does not need to be the sole descriptor of faulty response production. To say that errors are just a case of forgetting is to ignore the nuances of information they can give about the way a task is completed. Within-category errors are indicative of a failure to correctly execute an automatic process – between-category errors are more systematic and are indicative of a failure to disengage or activate a task set. It could of course be argued that this *is* in fact a failure of memory in keeping track of the correct task order – Experiment 6 addresses this issue by introducing task cues to remove this memory requirement. If between-category errors are in fact nothing more than a case of forgetting (and it is the contention of this thesis that this is not the case) then cues will significantly reduce, if not eradicate, such errors. Interestingly none of the experiments contained within this work show a correlation between within and between category errors, further suggesting that the two have a different basis – if an individual were forgetful of item order it would be highly likely that they would be forgetful of task order as well. Being forgetful is not selective.

12 Theoretical accounts of task switching and the verbal switching paradigm

Evidently a number of features set the Continuous Series II somewhat apart methodologically from more traditional measures of task switching. But do these features extend to separating the Continuous Series II from theoretical accounts of task switching – for example, can the verbal paradigm be explained in terms of passive carryover or active reconfiguration? Certainly drawing conclusions between alternating tasks, alternating runs and explicit cued/ uncued designs should be done cautiously if at all. The autonomous continuous nature of the verbal task and the calculation of general rather than local switch cost for the Continuous Series II do perhaps limit the interpretations that can be made based on previous research. Aspects of switching such as residual switch cost (the persistent cost left after ample practice) and manipulations of RSI (response to stimulus interval) are not immediately accessible using the verbal paradigm. Localised interference accounts based on asymmetry (Allport, Styles & Hsieh, 1994) require alternating tasks to be of disparate difficulty. Exogenously triggered completion accounts (Rogers & Monsell, 1995) relying on the calculation of residual cost from alternating require presentation of external stimuli and manipulation of the gap between response and presentation of the next stimulus. Neither account offers a direct ‘off the peg’ explanation for the accumulation of switch cost in Continuous Series II.

12.1 Verbal switching and the task-set inertia (TSI) hypothesis

Stroop-style tasks (Allport, Styles & Hsieh, 1994; Woodward et al., 2003; Gilbert & Shallice, 2002) require a switch between cognitive and perceptual domains (word reading and colour identification). Finding asymmetry when switching between such conditions may therefore be an inflated representation, reflecting the need to change domains rather than being *task* switch related. Much has already been said about the potential for the asymmetry in Stroop-style switching as an artefact of the task itself. The Continuous Series II is entirely cognitive, offering multiple tasks within a single cognitive domain. Gurd et al. (2003) were particularly critical of tasks which cross this boundary; Jersild (1927) said tasks encompassed by a single task set (such as language) were more efficient. However, in its current form the verbal task does not allow for assessment of asymmetry due to the comparability of task difficulty between overlearned sequences (as per the component tasks used by Rogers & Monsell, 1995) and so the applicability of localised interference is difficult to assess[36].

However, this issue is addressed in Experiment 3 (Chapter 5) which introduces a design entirely within the cognitive domain that has component tasks of differing difficulty. The Mixed Category II task involves switching alternately between producing items from semantic categories (e.g. fruit, vehicles) and overlearned sequences (e.g. months, days). The task is introduced in an earlier form in Experiments 1 and 2 but it is in Experiment 3 that it is extended to switching between four categories (the same as the Continuous Series II) and that asymmetry is assessed. During a practice session Gurd et al. (2002) found semantic category production to be more error prone than overlearned sequence production, thus suggesting it is

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[36] Previous work (Essig, 2004, see page 145) combined the Continuous Series II and semantic category switching into a task that alternated between overlearned sequences and semantic categories – while tasks in this instance were of varying levels of difficulty, asymmetry between constituent tasks was not assessed as switch cost was calculated globally for the whole task.

more difficult. Additionally when producing items from semantic categories, search and retrieval are more effortful and there is the requirement to inhibit past responses (Kellett, Stevenson & Gernsbacher, 2011). This task allows the novel situation of assessing asymmetry in the absence of bivalency (cueing of two possible tasks by one stimulus). Bivalency slows all trials within a block, even if only *some* of the stimuli are bivalent and the rest are univalent (cueing one task) (e.g. Meier, Woodward, Ray-Mermet & Graf, 2009). Avoiding bivalent stimuli avoids this additional source of slowing, which is of particular importance when calculating whole-task cost over the time-course of the task as for the Continuous Series II. There would be a problem for traditional explanations of asymmetry (e.g. Allport, Styles & Hsieh, 1994) as univalent stimuli do not afford the need to inhibit competing responses, suggesting an absence of inhibition (Lien, Ruthruff & Kuhns, 2006). However, there are computational models of task switching that give an explanation of asymmetry in relation to relative differences in task activation rather than inhibition of the easy task (Yeung & Monsell, 2003) – these depend on a threshold of activation being reached between the two tasks (see page 29). As such it is legitimate to look for non-bivalent asymmetry, based solely on the relative difference of difficulty level between the tasks.

The Continuous Series II places minimal demands on response selection as the task and responses made to it are, in the words of Hunt and Klein[37] (2002) “hyper-compatible”, yet switch costs don’t seem to be extinguishable (sensory and perceptual processing requirements are also removed). Further to this, the extensive predictability of switches in the verbal task does not extinguish switch cost (although it really equates to maximal preparation

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[37] Hunt and Klein purportedly extinguished residual switch cost by using saccade rather than manual responses, terming their response method “hyper-compatible” with the stimuli. The task was cued for the saccade to move towards or away from the stimulus. They believed residual cost to be an artefact of response selection rather than switch related, hence their resilience to adequate practice time. Regardless of the plausibility of this view the notion of hyper-compatible (and indeed incompatible) responses and stimuli is a useful one.

time), although it may extinguish that part of it which leads to the switch cost reduction in predictable alternating runs tasks. Despite remaining entirely predictable the increasing number of switches does result in increasing switch cost. There must therefore be an additional source of switch cost in verbal task switching which is not thus far accounted for.

12.2 Verbal task switching and the task-set reconfiguration (TSR) hypothesis

The TSR hypothesis states that switch cost reflects intentional control and is reliant on top-down processing. There was a practice-resistant portion of switch cost (the residual cost) that could not be extinguished despite extending the RSI (response to stimulus interval) to upwards of one second. Residual cost is confined to the first trial of a run (AABB…) and is attributed to an exogenously controlled part of reconfiguration. The arrival of the stimulus triggers completion of the process and it cannot complete until this occurs. Whether residual costs are represented in the Continuous Series II is debatable – typically the first trial of a run is faster with switch cost building up over the first few iterations and reaching a plateau for the rest of the task[38] (Essig, 2004b). Arrival of the stimulus is moot as no externally presented stimuli are presented during the verbal task. One could argue that the retrieval of the next task in the sequence from memory constitutes arrival of the stimulus although of course this would be subject to individual differences and so would be more approximate than in the alternating runs paradigm. Nevertheless, there would be a period between making a response (e.g. Tuesday) and retrieving the next task (e.g. months) that could constitute an equivalent, albeit non-controllable, to RSI. This would give a localised practice period – both alternating runs and the Continuous Series II are fully predictable so both offer the long term benefits of this.

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[38] Unpublished data relating to the sample for Experiment 1 (healthy controls and neurological patients) was plotted to show cumulative switch cost at 10 second intervals over the time course of the task.

It can therefore be assumed that general cost for the Continuous Series II has the potential to reflect at least in part practice resistant cost. This may reflect retrieval processes relating to the upcoming task in a similar way to waiting for the arrival of the upcoming stimulus in the alternating runs paradigm. Mayr & Kliegl (2003) suggest that the preparation period always represents this memory retrieval, even in the presence of externally represented stimuli (Altmann & Gray (2008) also define preparation as the retrieval of task codes within WM). Clearly there is practice resistant cost in the Continuous Series II but not, it would seem, confined to the first trial of a run. Lack of localised measures of cost and the continuous nature of the task cloud this issue. It is plausible that there is ‘stimulus’ cued completion of reconfiguration, as suggested by Rogers & Monsell (1995). Switching performance is known to improve with adequate preparation time but an unknown factor in this uncontrolled scenario is whether the preparation time is adequate. As the task is self-paced one would assume that individuals take full advantage of the preparation period but this is an unknown quantity – general cost could reflect inadequate preparation as well as residual-type cost and this could certainly vary between individuals. The way switch cost builds up over the time course of the verbal task is reminiscent of the associative interference account of Wylie & Allport (2000) although that of course relied on bivalent Stroop stimuli which offered a degree of interference not seen in the Continuous Series II. While there might be a degree of perseveration, a ‘day’ response can only afford days – there would not be the same overlap of S-R mappings.

So what might be the explanation for increasing cost over the time course of the task and the absence of first trial confinement? At the beginning of the Continuous Series II there is no requirement to temper responses against those that have gone before – this would result in faster response times as no switching occurs ‘within’ the component tasks (there is no or little updating at the beginning). This could easily mask a first trial effect between tasks and contribute to the increasing and levelling of the general switch cost. Therefore an explanation based on reconfiguration could apply to the Continuous Series II, although extrapolation of residual cost would seem problematic. It is possible that each iteration of the task (each occurrence of, for example, the three category run of numbers, days and months) could give an occurrence of something similar to the first trial of a run in the alternating runs paradigm, although embedded within the continuous cycle of the overall task. If switching is represented as a continuous repeat of a three category run then it is possible that residual costs could be extracted by calculating local per-category (rather than per switch) costs, thus giving a measure of first trial costs within the framework of general switch costs.

12.3 Verbal task switching and the failure to engage (FTE) hypothesis

A further point that is worth returning to, related to the use of localised preparation time between the commission of a response and the retrieval of the subsequent task, is whether this preparation time is taken advantage of? It has already been considered that preparation time might not always be adequate (both within and between individuals) but there is also the possibility that the time is adequate but not used. This reflects the failure to engage hypothesis of De Jong (2000) (see page 40 of this document). It is entirely feasible that, if we accept retrieval of the upcoming task is akin to arrival of a stimulus (at least in terms of triggering access to the relevant task set) then the interval from the preceding response constitutes localised preparation time for the next task. It is proposed (De Jong, 2000) that there needs to be an additional and specific intention to use this preparation time to actively change task set. De Jong suggests that it is failure to do this that results in residual switch cost. In his model there is a cue-action pairing (with the action being making use of the preparation time) that retrieves the intention, with the suggestion being that sometimes these pairings are not made. A further reason given for the failure to engage is that activation level of the cue-action pairing is too low for it to effectively act as a trigger for advance preparation. This could relate to low subjective utility of the benefits or limited WM capacity for maintaining the intention.

Evidently there is no cue in the Continuous Series II to make such a pairing. In De Jong's model the cue triggers the knowledge of what to prepare for during the interim period. Indeed, Nieuwenhuis & Monsell (2002) have proposed that it is the explicitness of these cues that accounts for the finding that residual cost can be entirely extinguished when engagement is actioned. It is however still possible that there is a lack of appreciation of benefits of advance preparation, something De Jong highlights as intrinsic to the effect. It is possible that the gap between response and retrieval of the next task is not fully used to prepare for that switch, resulting in further delay in producing the correct task item. Again there is not the control over the duration of the preparation time that would allow us to definitively whether it is being utilised or not, but the possibility remains that it is not being fully accessed in all instances. Once again this would vary between individuals, particularly as it is likely that the *duration* of the preparation time varies in such a way. However, this may actually benefit performance. As preparation times are likely to vary *within* participants, according to Altmann (2004) individuals will take advantage of longer preparation periods. When no variation in preparation times is given Altmann found that there was a persistent failure to engage. Variations could occur for a number of reasons, including proficiency at each individual task. Although all sequences are overlearned and therefore produced automatically, examination of individual baseline rates for the separate categories in all experiments reveals variation in aptitude at producing category items. While a degree of this will be relate to item length (e.g. months as opposed to letters) the variation appears not to be systematic with individuals being more proficient in one or other category. It would seem that, although lacking the pairing with an associated cue, there remains a possibility that the preparation period within the task may not always be utilised again both within and between individuals. A failure to engage would be more difficult to extrapolate from the data, given the self-paced nature of the task and the embedded nature of the preparation period, but it should be considered as a possible contributor to general cost for the task.

12.4 Verbal task switching and dual mechanisms accounts of switch cost

As previously noted, it is evident that no one account of task switch cost can readily fit the behavioural measures seen in the Continuous Series II. It may perhaps be the case that a dual mechanism approach may be more suited to explaining cost and error measures in the verbal task. As already noted, Kahneman's (2011) dual system of attention has already been employed to account for the different types of error produced during the task. Recently this approach has also been adopted to inform theorising about costs seen using the Continuous Series II task (Gurd & Cowell, 2013). This system lends itself to automatic processing of overlearned word sequences (Kahneman's System 1) and effortful switching between categories (System 2). More generally such dual system accounts allow for both passive and active processes to work in concert, negating the need for an all-or-nothing approach to task switch cost. This allows a fractionated approach to task maintenance and task reconfiguration – as seen earlier (section *'Neural activation during task switching'* on page 75) these features of task switching are known to be functionally distinct. Some models do not fit the Continuous Series II so well, such as Goschke's (2000) suggestion of a modular 'control panel' for switching. Implicit to this are stimulus evoked bivalent error responses, taken as evidence of passive carryover of previous task set activation. Evidently the lack of stimuli *per se* and the lack of bivalency in the Continuous Series II would make this interpretation problematic.

Other dual-mechanisms accounts lend themselves at least partially to interpretation of the Continuous Series II. The account proposed by Braver, Reynolds and Donaldson (2003, page 64 of this thesis) combines sustained, proactive control that oversees fast switching over time with transient, reactive control that relates to reconfiguration and S-R mappings with cues. Both types of control have been shown to be functionally distinct, with a third separate process related to maintenance and representation of task set also identified. Thus there are two distinct types of switching control, neither of which has to devote any processing to the holding of tasks and task sets in WM. The Braver study uses both block comparisons (as does the Continuous Series II) allowing for calculation of general switch cost and single trial comparisons within blocks giving rise to local costs[39]. It is noted that general (block comparison) switch costs are informative of the contribution of transient control, relating to internalised reconfiguration or updating of goals. This would equate to between-task switching in the Continuous Series II and to the more effortful System 2 in Kahneman’s model. In the Braver model, local costs (individual switches within a mixed task block) are said to inform questions of sustained or proactive control, relating to “…increased active maintenance demands associated with keeping multiple task sets at a relatively high level of activation…” (Braver, Reynolds & Donaldson, 2003, p.714). This does not initially appear to carry out the same function as Kahneman’s System 1, automatic retrieval of overlearned

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[39] Confusingly, but not uniquely, the paper refers to block comparisons as switching cost and local comparisons within switching blocks as mixing costs. As noted previously, this thesis takes the definition of mixing costs to be the additional cost of *repeating* a task within a mixed block compared to single task repeat blocks – not the cost of *switching* within a mixed block.

sequences. However, there is the need in the Continuous Series II to keep component tasks at a high state of readiness. Whether this state of readiness is comparable for highly overlearned word sequences would be a matter for further debate. It could be that the spatial representation of such sequences (Gevers, Reynvoet & Fias 2003, 2004; Eagleman, 2009) would result in differential representation in WM[40], perhaps leading to an easier route to readiness as there would not be as much competition with task rehearsal (numbers, days, months). Task readiness therefore might not need the same degree of control (or it might be implicated in a different way) as in the Braver study. Additionally it should be noted that Braver and colleagues used explicit cues (e.g. ‘large/ small’ for a size classification task), something also under the management of sustained control. Thus involvement of sustained control would again be at a different level for the Continuous Series II.

While the Continuous Series II has resonance at some level with Rogers & Monsell’s (1995) task-set reconfiguration (TSR) account and some of the dual-mechanisms models, it is apparent that thus far no model would appear to be a complete fit for the verbal switching paradigm. This is due in part to the previously discussed methodological issues which set the task apart within the literature. The lack of cues and lack of external stimuli mean that further work must be done before any one model can be taken to account for switching costs and error production within the task. Some of the proposed experiments will directly address theoretical issues, such as Experiment 3 looking at the potential for task-set inertia (TSI) type carryover of task sets. It is envisaged that the pattern of switch costs and errors gained from the set of experiments as a whole will further inform debates over the most suitable theoretical account.

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[40] Differential from the usual verbal rehearsal noted by Goschke (2000) and Monsell (2005) as being implicit in task representation

13 Real world relevance of verbal task switching: *Media multitasking*

Finally some credence should be given to the real world relevance of the Continuous Series II. Most task switching studies require participants to make isolated judgements about single letters or digits, shapes, or locations of objects. Some tasks use more real world judgments, for example Braver, Reynolds & Donaldson (2003) asking whether an item is large or small (e.g. a truck or a carrot), but just about all use isolated decisions. The Continuous Series II is quite different in using language and in asking participants to keep track of the changing state of a task over time. In this respect the task the task is more akin to the type of switching we do in our everyday lives, keeping track of language-based activities. Altmann is most vociferous about the lack of ecological validity in the "tasks" (his quotation marks, Altman & Trafton, 2004) which make up the body of task switching literature, expressing the need for 'higher-level' tasks and real time switch costs.

Switching between several tasks within a verbal cognitive domain has strong resonance with this aim. Additionally, it lends itself very well to the burgeoning field of media multitasking. In today's world there is an increasing need for individuals to carry out several language based tasks at once. In work and home environments it is not unusual to find someone switching rapidly between sending an email, working on a word processed document and conducting a text conversation with music or a TV program on in the background, as in this example from a 14 year-old teenager from Los Angeles: "I usually finish my homework at school... but if not I pop an open book on my lap, and while the computer is loading, I'll do a problem or write a sentence. Then, while mail is loading, I do more..." (Wallis, Cole, Steptoe & Dale, 2006, p.48). As noted, traditional switching tasks do not consider error in greater depth than count relating to switching or repetitions; recognition of, and recovery from, errors are sources of interruption which the Continuous Series II absorbs into calculation of real-time switch cost. Czerwinski, Horvitz and Wilhite (2004) report on a real time analysis of the nature of task interruptions commonly experienced by information workers switching between a number of complex language and media based tasks (see also Altmann & Trafton (2004; 2007) for a consideration of the role of task interruptions). In real-life observations people tend to work in several ‘spheres’ or clusters of thematically related tasks (González & Mark, 2004), in effect a gross externalised manifestation of switching within and between cognitive sets as specified by Gurd et al. (2003). Further evidence from observational studies of information workers (Iqbal & Horvitz, 2007) identifies conversational interruptions (analogous with non-target utterances during verbal switching such as “I’m not sure where I should be – I’ve lost it” (Essig, 2004 and Experiment 2, this thesis)). These non-target utterances may be interruptive rather than supportive in the Continuous Series II; interpretation of results from the verbal switching paradigm may have a high degree of relevance for real world language based multitasking behaviour.

14 Conclusion

Reservations about the efficacy of the Continuous Series II to give entirely switch-related measures of cost within a multi-task environment (e.g. Ragland et al., 2008) are rightly acknowledged. However, they are deemed to be acceptable given that the task offers a stimulus-free representation-dependent measure of switching in real time and within a single cognitive domain. The calculation of general costs for the task relate to executive control and have been associated with the need to maintain and select between tasks sets (Kray &

Lindenberger, 2000) as well as internalised reconfiguration and updating of goals (Braver, Reynolds & Donaldson, 2003). That classic TSI and exogenous-control accounts do not seem to immediately fit the verbal task, coupled with the paucity of verbal-style switching in the literature, attests to the need for a wider range of tasks and ensuing explanations.

> *"Until now, the vast majority of task-switching studies deal with situations in which participants are provided with perfectly reliable information in a just-in-time manner. In addition, in most cases all information needed to perform the actual task is perceptually available when the execution of the task is actually required, allowing participants to perform the tasks in a largely stimulus-driven mode. This may have biased theories of task switching to focus predominantly on stimulus-related factors and to neglect the contribution of factors related to internal representations."*
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> *Kleinsorge & Gajewski (2008, p.513)*

The usefulness of semantic switching in clinical evaluation is acknowledged (Birn et al., 2010). Indeed, the ability of individuals with PD (Gurd & Oliveira, 1996) and those post-stroke or with severe brain trauma (see Experiment 1, Chapter 3) to complete the Continuous Series II confirms that working memory load is not beyond acceptable levels, Monsell's (Rogers & Monsell, 1995) assertion that un-cued sequences may excessively load working memory seemingly notwithstanding[41]. The Continuous Series II offers a novel way to assess

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[41] Rubinstein et al. (2001) noted very small time costs associated with signed (+/ -) addition and subtraction switching and suggested "…the rules for solving signed addition problems— like the rules for reading familiar printed words—are permanently enabled in procedural long-term memory, thereby requiring the rule-activation stage of executive control to take little or no extra time for fully enabling them." (Rubinstein et al., 2001, p.784).

complex switching over time in a variety of populations – as such it may require a novel explanation of switch cost.

14.1 Thesis aims

The purpose of this thesis is to explore the usefulness and reliability of the Continuous Series II and the verbal task switching paradigm under various conditions as a measure of task switching behaviour and to interpret such behaviour against existing models of task switch cost, determining the most suitable theoretical explanation of verbal task switching.

The need for multiple types of task within the wider task switching paradigm is accepted (Ravizza & Carter, 2008). It is further noted that "...different switching tasks involve different processes and are, thus, likely to involve different brain mechanisms and relate to different processes. In particular, switching within working memory is separable from switching in perception" (Wager, Jonides & Smith, 2006, p.1742). Other than a few instances, switching between continuous verbal tasks has not been well researched – Gurd (1995) and Gurd and Oliveira (1996) administered the task to PD patients with relatively modest healthy control samples of around twenty, Gurd et al. (2002) tested eleven healthy participants (Gurd et al. (2003) further analysed the same data) and Ragland et al. (2008) tested individuals with schizophrenia with a control sample of thirteen, using only part of the Continuous Series II task.

Theories may also be biased towards stimulus-related factors (Kliensorge & Gajewski, 2008), as explicitly presented by Rogers and Monsell (1995). Sohn and Carlson

(2000) showed a separable stimulus-based component of cost, although Verbruggen et al. (2007) posited that such costs may be cue rather than stimulus related. The Continuous Series II utilises neither external stimuli nor cues and so avoids having to account for such costs. Although the verbal task is more reliant on working memory representation the constituent tasks are implicit (and considered a special class of verbal category – see Pariyadath, Churchill and Eagleman, 2008) and require no visual or interpretive processes which might add to overall time costs (e.g. Grange & Houghton, 2010). Whether, however, the representational presence of the verbal category within the switching process can be aligned to the arrival of an external stimulus remains to be determined. The cue-free nature of the paradigm makes assumptions about the task based on cue-based theories of cost difficulty (see Altmann, 2007) – factors such as cue processing (Logan & Bundesen, 2003, 2004) make for a very different model of switch cost composition.

Only one previous study (Arbuthnott & Frank, 2008) has been noted as differentiating between errors that occur within a task and errors that occur between tasks, by virtue of recording verbal responses. They cite errors between tasks ('wrong-task errors') as denoting switch-related failure in executive control and errors within tasks ('decision errors') as being specific to that particular task rather than switch related. The pattern of errors recorded for a particular switching scenario can therefore be interpreted much more accurately in terms of their relationship to executive and task related factors.

The aims of this thesis are thus to explore the limits of the Continuous Series II with a view to aligning it to one of the existing theoretical models of task switching or adapting one of those models to best suit the action of the task. Additionally artefacts of the task design will be explored to see if these impact on the theoretical model. With a view to this the following things will be explored: Do the number of tasks being switched between (Experiment 5) or the order in which the tasks are presented (Experiment 4) have an impact on the degree to which the measure of general switch cost purely measures switching behaviour? Does the dissociation between overlearned and overlearned plus semantic versions of the task (Experiment 1) indicate any difference in processing between these different types of verbal category? Further to this, Experiment 1 will consider the introduction of a task where there are categories of disparate difficulty (addressing the TSI hypothesis through error rates). To what degree is working memory load and rehearsal of task order a contributor to general switch cost (Experiments 5 & 6) and how does this relate to theoretical interpretation of the task? Further interpretation of the theoretical model most suited to the task will ascertained from Experiment 3 where a further version of the task will be used to determine whether non-bivalent asymmetry is in evidence for tasks of disparate difficulty. Experiment 2 will consider the introduction of self-generated verbal cues as an aid to subsequent item production, contrasted to the lack of usefulness of externally provided written cues in Experiment 6.

CHAPTER TWO: GENERAL METHOD

1Introduction

Much of the procedural detail for the verbal switching task is common to all versions. The following chapter details participant recruitment, choice and administration of background measures, and the basic method for the Continuous Series II. There is also an indication of the types of measures taken during the task and common statistical procedures used. Any variations to the stimuli or method peculiar to specific versions of the verbal switching task are detailed in the appropriate chapters.

2 Participants

2.1 Recruitment

All participants were healthy individuals aged 18-65 years old and were recruited either from the University of Hertfordshire or from the wider community[42]. Recruitment at the University of Hertfordshire was largely conducted using the School of Psychology participant pool; students on undergraduate and taught postgraduate psychology are required to take part in academic research in return for course credit. Non-psychology students were also recruited via leaflets distributed at the College Lane campus of the University of Hertfordshire (see Appendix B). Participants from outside the university were recruited via word of mouth or personal contact. All those recruited from outside the School of Psychology

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[42] Recruitment of neurological patients for the initial presentation of the Continuous Series II and Mixed Category task are outlined in chapter 3.

were entered into a draw to win a prize of £20, in lieu of the incentive of course credit. Informed consent was gained from all participants (see Appendices C and D for information sheet & consent form).

2.2 Screening criteria

All participants were right handed[43] (self-reported) native English speakers with normal or corrected to normal vision and normal hearing. They were further screened to exclude any factors which could have extraneously affected language production, general processing speed or task switching performance. These included: history of drug or alcohol abuse; neurological or psychiatric diagnosis; known problems processing or producing speech or language, including (but not exclusively) dyslexia and a stutter; history of a closed head injury; regular use of anti-depressants, anti-psychotics, benzodiazepines or tranquilisers.

2.3 Demographics

Age, gender, total number of years spent in education since the age of 5, current employment classification and the highest educational or professional qualification attained were recorded for all participants. Age (along with background measures detailed below) was considered as a potential covariates to factors of interest, and were accounted for using a GLM-ANCOVA procedure where indicated.

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[43] The prevalence of atypical language lateralisation in left-handers has been estimated (in non-clinical populations) at as much as 22%, around four times that found in right-handers (Szaflarski et al., 2002). Although it is acknowledged that such atypical distribution may not present as atypical functionality (e.g. Knecht et al. (2001) found no significant effect of atypical lateralisation on verbal fluency or linguistic processing speed), the current work adheres to the convention of excluding left-handers, due to the nature of the tasks used and sparse availability of data to suggest otherwise.

Little work has been carried out to specifically test the effects of gender on switching abilities; despite this, the consensus within the literature favours gender differences as not being significant, contrary to the popularly held belief that women out-perform men when multitasking[44]. At the time of writing, there is an indication from a single study that women are better able to strategically plan in a multitasking environment (Stoet, O'Connor, Connor & Laws, 2013). Specific switch cost for a diagrammatic search planning task was lower for females; specific switch cost for all other tasks showed no gender difference. An earlier large-scale study (Reimers & Maylor, 2005)[45] found general switch cost to be *faster* for males but no gender differences for specific switch costs for component tasks. Such differences are likely to be strategic rather than functional; for example, males and females show remarkably similar neural activity during executive control tasks (Haut & Barch, 2006) and appear to be task specific. There is evidence that gender differences, as varied as they may be, fluctuate across the lifespan (see Reimers & Maylor, 2005 or Tun & Lachman, 2008)[38]. Credence must also be given to gender differences in reaction time *per se*; females have been found to perform slower (but more accurately) and with more variability on simple and multi-choice RT tasks (Der & Deary, 2006)[38]. Consequently, whilst SToet et al. (2013) propose task-specific gender differences in switching is acknowledged, the variable (and non- executive) factors which may contribute to this difference and the entrenched nature of the stimuli used in the current study suggest that gender need not be considered as a source of variation in this instance.

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[44] It should be noted that, while there a well-established gender effect in verbal *cluster* switching (as found in the FAS verbal fluency task e.g. Weiss et al., 2006), this does not equate to either general switching abilities or the type of verbal switching employed in the Continuous Series II.

[45] Reimers and Maylor (2005) $N = 6381$; Der and Deary (2006) $N = 7130$; Tun & Lacman (2008) $N = 3616$.

3 Background measures

3.1 National Adult Reading Test-2 (NART-2)

The National Adult Reading Test-2 (NART-2) (Nelson & Willison, 1991) offers a reliable estimation of IQ for the purposes of comparison. It consists of 50 irregular words of increasing difficulty e.g. ‘psalm’, ‘aeon’, ‘puerperal’, which were presented to participants printed on two sides (items 1-25 and 25-50) of an A4 card. Participants are scored according to the number of errors made[46]; this is used to predict full scale, verbal or performance IQ from the Wechsler Adult Intelligence Scale – Revised (WAIS-R) (Wechsler, 1981). The irregular nature of the words does not allow their pronunciation to be guessed phonetically, successful performance relying on prior knowledge (Strauss, Sherman & Spreen, 2006). This method of estimating IQ was used in previous studies of the Continuous Series II on both clinical samples and single case series (Gurd & Oliveira, 1996; Gurd et al., 2002; Essig, 2004) and healthy populations (Gurd et al., 2002) and was retained over other predictive measures of IQ to preserve continuity for the purposes of comparison across these studies.

3.2 Wechsler Adult Intelligence Scale – Revised (WAIS-R) vocabulary subtest

During an earlier study using the Continuous Series II (Essig, 2004) there was an indication of some type of bias for younger participants (<24 years) completing the NART, manifesting as a marked unwillingness rather than inability to pronounce words, particularly those in the second half of the list. Demographic effects on NART scores have previously been studied (Crawford et al., 1988), highlighting an age-NART score correlation which was dependent upon years in education and social class.

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[46] The task has an optional discontinuation threshold (14 errors in 15 correct responses) which was not applied in this instance.

To accommodate this, the vocabulary subtest of the WAIS-R was included in the background test battery as a supplementary measure to the NART. This task requires participants to describe the meanings for a list of 35 words, presented printed on one side of A4 card and read out concurrently by the experimenter. The words are of increasing difficulty e.g. ‘breakfast’, ‘tranquil’, ‘tangible’ and responses are scored 2, 1 or 0 according to accuracy. The test is discontinued after 6 consecutive scores of zero. Raw scores are then converted to an overall subtest age-scaled score. The advantage of this test is that it allows the participant to give a usage example or synonym of the word being described; the experimenter may also ask individuals to clarify their answers. The vocabulary subtest has the highest correlation with full scale IQ (Wechsler, 1981) and has been indicated as a useful measure of IQ in normal or non-language impaired populations[47] (Vanderploeg & Schinka, 1995).

3.3 Digit Span (forward and backward)

The digit span test from the Wechsler memory and intelligence scales (e.g. Wechsler 1955; 1987; 1997) measures immediate verbal recall. The forward digit span primarily relates to the attentional aspect of recall, with any score of 5+ considered within normal ranges (Miller, 1956; Lezak et al., 2004). It requires individuals to recite back random digit sequences of increasing length, in this instance from 3 to 9 digits. The digits are read out at a rate of one per second and in a monotone, thus avoiding any opportunity for the participant to ‘chunk’ digits (Miller, 1956). There are two versions of each sequence, allowing for a second attempt after a fail. For example, an individual failing to recite the 5-digit span correctly is able to make a second attempt with a new set of digits. Success at this length would allow

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[47] It has been included in most short form versions of the WAIS-R (see Crawford, Allan & Jack (1992) and is indicated as a reasonable standalone estimate of premorbid IQ in clinical populations (e.g. Russell et al., 2000).

them to go on to attempt 6-digits; failure at that stage would mean their maximum span is recorded as five.

The backward digit span follows the same format, with the requirement that digits are repeated in reverse order (1-2-3 repeated as 3-2-1). This measure is more reflective of active working memory, specifically central executive involvement in the manipulation of the digit sequence (Baddeley, 1986). Sequences range from 3 to 8 digits in length. Backward span scores of 4+ would be considered normal in healthy individuals[48] (Lezak et al., 2004).

Digit span performance was recorded as a raw score of longest span correctly repeated in each condition (forward and backward) and was not combined into a single score as per the Wechsler scoring scale. This was to preserve the differential information they provide regarding attention and recall span (forward) and active working memory (backward) (Ramsay & Reynolds, 1995). Digit span is particularly well suited for participant screening and analytical purposes with the Continuous Series II, given that task's requirements for sustained attention and mental manipulation of verbal information.

3.4 Conversational speech rate

The Continuous Series II uses overlearned sequences as being representative of automatic speech. There is clear evidence for the 'special nature' of ordinal verbal categories; distinct right hemisphere neural pathways (Pariyadath, Churchill and Eagleman, 2008), abstract linear spatial representation (Gevers, 2004; Eagleman, 2009), and preservation of

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[48] Scores of 3 are also considered within normal limits dependent upon educational background (Lezak et al., 2004).

ordinal sequences in cases of semantic dementia (Cappelletti, Butterworth & Kopelman, 2001) support this. However, we cannot say for certain to what degree these ordinal categories are produced automatically; speech is intentional and therefore subject to control in its own right (Fodor, 1983). Levelt (1983) surmises at least marginal forms of control are evident during regular fluent speech, so we must concede to the possibility that ordinal sequence production brings an additional need for cognitive control to the verbal task switching paradigm.

In an attempt to account for this, a measure of normal conversational speech rate was taken before the experimental task. Participants were asked to talk about their last holiday for one minute, with one minute to prepare. The number of words produced was divided by sixty to give a words-per-second speech rate, which was considered for use as a potential covariate where appropriate. Speech rate was given additional consideration in light of the relationship between various verbal rate measures and memory span (e.g. positive relationship between span and ‘sub-vocalisation rate’ (Standing et al., 1980), speeded reading, story reading and digit span (Naveh-Benjamin & Ayres, 1986), inner speech for normal prose and digit span (Standing & Curtis, 1989)).

4 Basic Method for Verbal Task Switching: Continuous Series II

4.1 Overview

The Continuous Series II (Gurd, 1995) task requires participants to produce items incrementally and alternately from increasing numbers of verbal categories. This version of the task (and most subsequent versions[49]) uses overlearned sequences (OS), categories with a predetermined and well established order; these are numbers, days of the week, months of the year, and letters of the alphabet. The words per second (w/sec) rate during switching is compared to a preliminary non-switching condition using the same categories. The difference in word production rate between these two conditions is the switch cost – a reaction time evidenced processing cost for reciting the categories in combination. Number and type of errors are also recorded.

4.2 Non-Switching Condition

Participants are initially required to recite each category individually and repeatedly (the number sequence is truncated at 20 for this purpose) as fast as they can for a period of 15 seconds, giving a w/sec rate for each category. These individual rates are then used to calculate the average w/sec rate for each combination of word categories used in the switching (S) conditions. For example, the non-switching (NS) rate for 'numbers' and 'days' would be calculated:

$$\mathit{Rate}^{\boldsymbol{A}}\text{ (numbers)} + \mathit{Rate}^{\boldsymbol{B}}\text{ (days) / 2} = \mathit{Rate}^{\textbf{2-cat NS}}\text{ (numbers/days non-switching)}$$

4.3 Switching Conditions

Participants are then required to alternately produce items from two of the previously recited categories, keeping each in its correct order e.g. 'One', 'Monday', 'two', 'Tuesday'. The categories have predetermined non-canonical start points and the task continues for a set number of iterations, as given in Table 2. They are required to do this as fast and as

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[49] The Mixed Category version of the task (see Chapter 3) alternates overlearned sequences with semantic categories such as animals and fruit. The dummy categories task (see Chapter 5) includes arbitrary low-load categories consisting of a single repeated word, in this instance colour names (blue, red etc.).

accurately as possible, avoiding any extraneous utterances. There is no feedback during the task (participants are informed of this). Reaction time is measured from the beginning of the first response uttered to the end of the last. The same procedure is carried out for switching over two and three categories.

Table 2 Start Points and Task Length for Switching Conditions in the Continuous Series II

Switching condition	Start point	Number of iterations
2 categories	6 – Tuesday	23
3 categories	4 – Friday – October	21
4 categories	9 – Wednesday – February – H	20

4.3.1 Calculation of Switch Cost

The w/sec rate for each switching condition is calculated by dividing the number of words produced by the time (in seconds, to 2dp.) taken to complete the task. The switch cost is the difference between the switching rate and the appropriate non-switching rate, expressed as a percentage w/sec increase. This is calculated by subtracting switching rate from non-switching rate, dividing this by the non-switching rate and multiplying by 100, as shown below:

$$Rate_{\boldsymbol{NS}}\ \text{(w/sec)} - Rate_{\boldsymbol{S}}\ \text{(w/sec)}\ /\ Rate_{\boldsymbol{NS}}\ \text{(w/sec)} \times 100 = Switch\ cost\ (\%)$$

5 Procedure

All testing took place in a quiet room either at the University of Hertfordshire or the participant’s own home and took approximately half an hour (the repetition study sessions took approximately one hour). Participants were given a written and verbal explanation of the rationale and requirements of the task and asked to provide written consent to take part in the testing session and for the session to be audio recorded (declining to be recorded did not exclude participants from taking part). Anonymity and the right to withdraw unchallenged were assured. After noting demographic information, background tests were administered in the order: NART; WAIS-R vocabulary subtest; WAIS-R digit spans and conversational speech rate measure. Participants were then asked to recite each of the component categories repeatedly and at speed, one at a time, for the baseline non-switching phase of the Continuous Series II. For the switching phase they were asked to produce items alternately and sequentially from two named categories as per the previous task description (see Appendix A for standardised task instructions). They used given starting points for each category and were asked to complete the task as fast and as accurately as possible, continuing until told to stop. The same switching procedure was applied using three and then four categories. Debriefing was carried out according to a predetermined schedule (see Appendix E).

6 Data Collection

6.1 Audio recording & timing

All testing sessions were audio recorded as mp3 files, to allow for accurate timing and transcription of responses. Separate consent was obtained from all participants for recording to take place. Response timings were recorded using a hand held non-beeping digital stopwatch. Task duration typically lasted from approximately 30 seconds for 2-category switching to several minutes for 4-category switching, so the level of accuracy from this method was well within acceptable limits. The stopwatch was non-beeping to ensure that it wasn't misinterpreted as a cue to start the task[50].

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[50] During piloting it had been noted that several participants interpreted the beep or click from the stopwatch as a cue to start, causing them to falter at the beginning of the task or stop and question whether they should wait

6.2 Criteria for exclusion from analysis

6.2.1 Scores outside normal range on background test battery

Individuals showing an impaired level of performance on the NART-2/ WAIS-R vocabulary subtest or the digit span were excluded from the final analysis, although it is acknowledged that such results in a normal population may be indicative of false-positive impaired scores (Axelrod & Wall, 2007). In practice, most of those showing impairment on the background battery also showed unusual performance on the verbal switching task. For example, very low score on the backward digit span coupled with consistently very high switch cost on all levels of the switching task, suggesting an inability to manipulate information in working memory. Numbers excluded on these grounds are indicated in individual chapters.

6.2.2 Poor performance on task baseline measures

Participants were excluded from the final analysis if they completed the baseline part of the task in a manner that suggested they were not entirely fluent with overlearned sequence categories. Examples of this included repeatedly mixing up or missing out particular category items, such as reciting months January to November or missing out ‘Y’ from the alphabet.

6.2.3 Completion

Type and number of errors are intrinsic to the interpretation of behaviour during the verbal switching task. While switch cost is generally stable at a much lower level of

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for the beep. One of the prominent features of the Continuous Series II is that it does not require any external prompts or cues to guide performance.

completion[51], such performance may not give a definitive portrayal of accuracy. Therefore any participant not completing at least 70% of the predetermined length of the task at every stage (switching over 2-categories = 23 iterations; 3-categoires = 21 iterations; 4-categories = 20 iterations) had their entire set of scores excluded from the final analysis.

6.3 Additional measures recorded

6.3.1 Error types

Errors are counted as any response that does not adhere to the predetermined category order or the correct sequence of items within those categories; they are recorded as total number per error type for each level of the task. Figure 1 shows an excerpt from a composite response sheet for switching between three categories, with examples of the various possible types of error. The verbal switching tasks allow a greater level of error analysis than the more usual visuo-spatial switching tasks, which only indicate errors occurring between stimuli judgements, showing misapplication of task set[52]. Verbal switching allows errors both between categories and within categories to be recorded. Errors are classified as follows:

> **Within category errors –** an item is produced in the correct category, but not in the correct sequence for that category. The categories are kept in the correct order but a participant may produce e.g. days in the wrong order.

(i) *Within category repetition error* (WR) – the previous item produced in that category is repeated (see WR in Figure 1). For example, "one/ Monday/ **one**/

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[51] Previous presentations of the Continuous Series II have included calculation of switch cost at 30 seconds into the time course of the task. This was to account for possible early discontinuation by neurological patients. No significant difference was found between 'short' and full task switch cost for healthy controls.

[52] It has previously been noted (Gurd 2003; Essig, 2004; Essig, Gurd & Kischka, 2005) that many studies on task switching fail to make the distinction between tasks that switch within or between a *cognitive* set. Here the reference is to differing rules for separate stimuli judgements, which may or may not be within the same cognitive set.

Tuesday…" Two or more repetition errors in succession constitute a perseverative error.

(ii) *Within category sequencing error* (WS) – an item from the correct category is produced but out of sequence. For example, "one/ Monday/ **seven**/ Tuesday…" (see WS in Figure 1)

Between category errors – an item is produced in the wrong category position. In this situation the order of the categories is incorrect; items within a category e.g. days, may or may not be in the correct order.

(i) *Between category repetition error* (BR) – the last category is repeated in the next category slot. For example, "one/ Monday/ two/ Tuesday/ three/ **four**…" (see see BR in Figure 1)

(ii) *Between category sequencing error* (BS/ BSS) – a category is produced out of the prescribed sequence (but not as a repetition of the last category produced) (see BS in Figure 1). Between-category sequencing errors can occur either alone or in conjunction with *within*-category sequencing errors.

   i. *BS example* – the categories are produced in the wrong order but the items within them remain correctly sequential. For example (switching over 3-categories), "one/ Monday/ January// two/ **February**/ **Tuesday//** three/ March[53]/ Wednesday…"

   ii. *BSS example* – the category order is wrong *and* the items within them are no longer correctly sequential. For example (switching

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[53] Note that although subsequent responses are out of sequence with the original task order, they are not counted as further errors as they carry on correctly from the last response and 'new' category order.

over 3-categories), “one/ Monday/ January/ two/ **February**/ **Thursday/** three/ March/ Friday…”

(iii) *Deletion error* (BD) – the category is completely missed out of the sequence.

It should be noted that, with the exception of deletion errors, one occurrence of a between-category error must necessarily be followed by another as swapping the position of two categories means that both are in the wrong place and both constitute an error.

Numbers	Days	Months
4 No response BD	Fri ✓	Oct ✓
5 4 W	Sat ✓	Nov ✓
6 5	Sun December BS	Dec Sunday BS
7 6	Mon January	Jan Monday
8 12 WS	Tue February	Feb Monday WR
9 13	Wed Saturday B	Mar Tuesday
10 Wednesday BR	Thu Sunday	Apr Wednesday

Figure 1 Sample section of response sheet for Continuous Series II showing target responses (black), actual responses (blue), errors (circled red) and classification of error as within-category (W) or between-category (B). Note it would be unusual to see this group of error types from a healthy normal participant.

6.3.2 Self corrections

Self-corrections occur when individuals perceive (correctly or otherwise) that they had made a mistake; they are again recorded as total number per type of correction for each level of the task. All responses are classed as either (i) Positive corrections ($SC_{\mathbf{pos}}$), where participants have correctly indentified and resolved an error, or (ii) Negative corrections ($SC_{\mathbf{neg}}$), where a correction has been made but the result is an incorrect response. These can be of two types:

(i) *Single negative* ($SC_{\mathbf{neg1}}$) – an error is correctly identified but is changed to an incorrect response. For example, where the target response is ‘one’, ‘Monday’... the actual response might be “one, **Tuesday**... no, **Wednesday**...”

(ii) *Double negative* ($SC_{\mathbf{neg2}}$) – a correct response is erroneously identified as an error and changed an incorrect response. For example, where the target response is ‘one’, ‘Monday’... the actual response might be “one, Monday... no, **Tuesday**...”

7 Data Analysis

7.1 Overview

This section details common procedures for analysing switch cost. Changes to the analysis because of differing task structure or additional data being recorded are dealt with in individual chapters. All analyses were carried out using IBM SPSS Statistics for Windows 17.0; data was routinely screened for missing and incorrect entries. Unless otherwise stated, statistical significance was set at the level α = .05. Effect sizes were interpreted according to Cohen (1988); .20 = a minimal effect, .50 = medium, .80 – large.

7.2 General Linear Model (GLM) Analysis of Variance/ Covariance (ANOVA/ ANCOVA)

The GLM repeated measures procedure was used to analyse all multi-factorial designs, due to the constant repeated measures factor of ‘Number of Switching Categories’. A number of background measures known or suspected to have an effect on task switching performance were considered as potential covariates: age (switch costs are known to be increased in older adults, in relation to a number of aspects of the switching process – see Kray & Lindenberger, 2000; Kray & Eppinger, 2006; Meiran & Gotler, 2001), digit span (as a measure of working memory capacity) and conversational speech rate (due to the nature and number of tasks). Binomial correlation analyses were carried out to determine whether there was a significant relationship between these variables and the main dependent measures of switch cost and task speech rate. Covariates entered into the analysis shared no common correlation; a number of measures were known to have this type of relationship. Both digit span measures correlated with each other as scores in the normal range tend to remain within 2 points of each other (Black & Strub, 1978); NART is known to correlate highly with age and years spent in education (Crawford et al., 1988). Where applicable (for studies with several groups: order effects (Chapter 4) and cue effects (Chapter 6)), groups were matched for scores on these variables (Miller & Chapman, 2001).

Inclusion of covariates with repeated measures factors results in what can be interpreted as an overcautious reduction in power for those measures (Thomas et al., 2009). Scores on the covariates do not differ between measurements of the dependent variables at different levels of the repeated measure, particularly in the current context where measures are temporally adjacent[54] i.e. age is the same whether measuring switch cost over 2, 3 or 4 switching categories. Main effects for repeated measures were therefore reported separately using a GLM ANOVA; covariate interactions were then reported using the GLM ANCOVA procedure (see Annaz et al. (2009) for a presentation of this approach).

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[54] Unlike more typical repeated measures studies using treatment trials or other longitudinal measures of a single group.

CHAPTER THREE: USING VERBAL TASKS OF VARYING DIFFICULTY

1 Introduction

This chapter describes a study carried out using three versions of the verbal switching task: the Continuous Series II, Verbal Fluency switching and the Mixed Category task (Essig, 2004). Verbal Fluency switching involves switching between producing words from different semantic categories and the Mixed Category task involves alternating between increasing numbers of overlearned sequences and semantic categories in turn. The study aimed to reanalyse data from a single case series of neurological patients (taken from Essig, 2004) using a suitably age matched replacement control sample (the original sample was not age matched). The aim of comparing performance on these three tasks was to assess whether switching between tasks of differing difficulty in the absence of both bivalency (one task having two possible responses) and Stroop-like interference between responses would result in increased switch cost. Additionally verbal fluency alternation is known to be more complex than overlearned sequence alternation in that it requires formations of sub-groups (clusters) of responses (e.g. farm animals, zoo animals) and switching between these clusters.

1.2 Summary of previous research

The premise for the current thesis is based upon the results of previous work (Essig, 2004; Essig, Kischka & Gurd, 2005), which are summarised here[55]. Performance on the Continuous Series II was compared with a Verbal Fluency switching task (producing items from alternating semantic categories), and the novel Mixed Category task, which alternated overlearned sequence categories with semantic categories. The three-task comparison was carried out with a sample of $N = 30$ healthy controls (age $M = 39.23$, $SD = 11.37$) and a single case series of seven neurological patients (age $M = 51.29$, $SD = 11.62$) with disparate diagnoses (See Table 4). It was predicted in the original study that Mixed Category task switch cost would *not* be significantly slower for 3-categories than 2-categories, due to the 2:1 semantic category (SC) to overlearned sequence (OS) switch requirement as the task triplet repeated (SC-OS-SC/SC-OS-SC/SC-OS-SC…). Over a continuous run of three categories two semantic categories occurred next to each other (categories 3 and one of the repeating triplet). This resulted in fewer second-order reconfigurations; task *type* (OS or SC production) changed less often than *task* (production from flowers, days or sports). A second prediction was that Mixed Category task switch cost would be slower than either Continuous Series II or Verbal Fluency switching due to the 'double' switching requirements (switching not only between tasks but between *types* of task, OS or SC). A final prediction was that neurological patients would be impaired on both switch cost and error rate, particularly producing more between-category executive based errors. The Mixed Category task was found to be slower than the Continuous Series II and patients were impaired in terms of both cost and error rate.

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[55] The section 'Summary of previous research' refers to work previously presented for the award of Master of Science at the University of Hertfordshire (2004). Any further presentation outside of that chapter section of statistical analyses, discussion of background theory or methodology relating to that data is additional work carried out after the submission of the MSc thesis.

1.3 Combining tasks of varying difficulty

The Mixed Category task introduces a difference in difficulty level between alternate component tasks, determined by the differing level of semantic and syntactic complexity between semantic categories and overlearned sequences (noted by Bookheimer et al. (2000) and Ragland et al. (2008)). Variance in task difficulty is not entirely comparable to that present in Stroop-style tasks (as used by Allport and others), which rely on suppression of the stimulus-activated easier more dominant task of word reading in the more difficult colour naming condition. As such, any difference in time costs between semantic categories and overlearned sequences (be that costlier switching to the easier task or vice versa) may not be attributable to the same processes posited as causing Stroop asymmetry. Allport, Styles and Hsieh (1994) accredited asymmetry to a carryover of interference from the preceding harder task (see page 27), later framing this as long term associative interference (Allport & Wylie, 2000). A threshold for interference was advocated by Monsell, Yeung and Azuma (2000) (see page 29 of this document), thus accounting for the dominance of either task relative to the other and allowing for the finding of reverse asymmetry (easier to switch to the easier task). This ‘relative-dominance’ view may better account for any such differential costs found in the Mixed Category task given the combination of component task completion and the additional switch between verbal domain as well as task, as illustrated in Figure 2. While the additional level of switching (between task *type* as well as task) in the Mixed Category task may account for greater time costs it may serve to more completely disengage the previous task set and so result in fewer between-category errors.

1.4 Comparing overlearned sequences and semantic categories

A second feature of the Mixed Category task is that the two component tasks, semantic category and overlearned sequence production, are controlled by different frontal processes rather than one unitary process. To fully comprehend the relevance of comparing different classes of word between and within tasks it is necessary to revisit the original basis for the Continuous Series II task. Gurd (1995) looked for a correlation between the Continuous Series task (alternating between increasing numbers of overlearned sequences) and semantic verbal fluency (producing items from different semantic categories). Verbal fluency was assessed in both single category and alternating forms. The Continuous Series and verbal fluency production are both frontal tasks – a lack of correlation between the two could be indicative of fractionated frontal functions rather than a common frontal basis. No significant correlation was found. Gurd therefore concluded that the frontal processes involved in these two tasks were separate from each other and took this as evidence for a fractionated SAS. As such we can assume that switching between different verbal tasks (overlearned sequence or semantic production) will tap into different frontal executive functions. Comparison of time-related switch costs and errors for such tasks will allow us to determine whether there is a generalised switching function (at least for all types of verbal task) or whether the underlying processes differ according to the task being carried out. This ties in also with the additional level of switching (between task *type* as well as task) as participants may be switching control process as well as task.

Additionally semantic category production involves a more subtle level of switching that is not seen in the Continuous Series II. Even single-category verbal fluency requires a degree of switching between search strategies for items, resulting in clustering of items as items are produced from first one sub-category and then another. Clustering and switching are two separate established features of verbal fluency production (Troyer, Moscovitch & Winocur, 1997). Search within and between clusters requires more abstract processing when alternating between two different categories. The Verbal Fluency task will therefore assess switching between overt categories (e.g. animals and furniture) and implicit clusters (e.g. zoo animals and farm animals), with the alternating requirement (particularly at three categories) assessing the role in complex switching of more abstract processing. In comparing Verbal Fluency switching to Continuous Series II it would be predicted that switch cost would be greater due to the need to switch between clusters within each task and would also be implicit in the Mixed task, adding to varying task difficulty. This could be evidence for different task-controlling processes, one that required control for continual state updating (the Continuous Series II) and one that required control for cluster switching (Verbal Fluency).

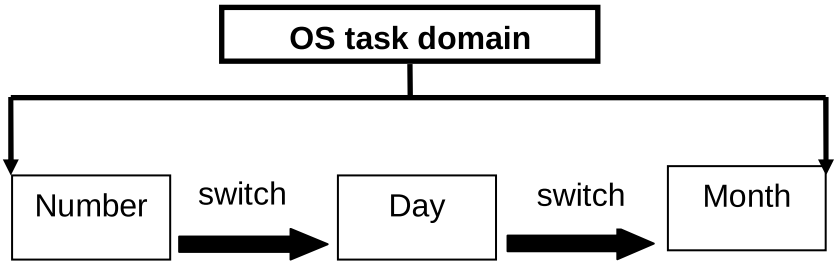
Switching between different verbal tasks (overlearned sequences and semantic categories) should also make a difference in the type of errors produced. Within-category errors for the Continuous Series II are determined to be automatic updating errors (according to Kahneman’s (2011) System 1). Within category errors for semantic categories are likely to reflect a different process at work. Semantic category production involves searching the category rather than automatically updating and recalling whether the response has already been made. As such within category errors reflect a more complex process for semantic categories. Within category errors could also reflect carryover of activation of the easier or harder task to the subsequent task, interfering with update of the next task. To determine this would necessitate a more fine grain analysis than just a count of within-category errors. If the task set from, for example, the category animals is still active when trying to select a response for the sequence days then the response for the sequence days would fail to update . A perseverative error *within* the category (e.g. cat, Thursday, dog, *Thursday*…) would be indicative of this. By comparing within-category repetition and within-category sequencing (item out of sequence but not repeating – e.g. cat, Thursday, dog, *Saturday*…) errors it should be possible to determine whether such an occurrence is more common in the Mixed Category task, suggesting TSI-like effects (Allport, Style & Hsieh, 19954) in the absence of bivalency and relying only on difference in task difficulty.

1.5 Neuropathology and task switching

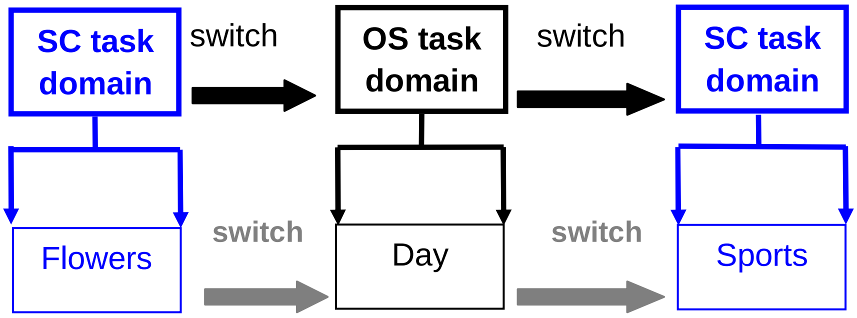
Both traumatic brain injury (TBI) and stroke are associated with reduced performance during task switching. Loss of functionality in task switching after TBI has been documented (e.g. Mecklinger et al., 1999). While time costs are greater than those of healthy controls, patients are able to complete tasks and seemingly to take advantage of preparation time to improve costs (Schmitter-Edgcombe & Langill, 2006). Switch costs are confined to the first trial of a run (in the alternating runs paradigm) so it would seem that executive processes are completed before this first trial. Reduced functionality is therefore possibly due to increased mental effort rather than fundamental impairment of underlying processes (Azouvi et al., 2004). Chronic TBI patients have been found to recruit more areas of the brain at low levels of switching difficulty (LaRoux, 2010), exhibiting healthy-like behaviour but facilitated in a different way.

During Stroop-style switching TBI has been associated with greater error rates (Perlstein, Larson, Dotson & Kelly, 2005) and greater error-rate interference (Sozda, Larson, Kaufman, Schmalfuss & Perlstein, 2011) than for healthy controls. Error-rate interference was calculated as the increase in error rates in the incongruent over congruent Stroop condition, much as switch cost is calculated. This increased error-rate interference was matched by Sozda and colleagues with increased ACC activity (already noted as implicit in conflict resolution during switching (Brown, Braver & Reynolds, 2007)). In less severe cases patients are thought to be proficient in monitoring but not adapting to conflict during switching (Larson, Farrer & Clayson, 2011). Given the contribution of post-error slowing to switch costs (Rogers & Monsell, 1995) this lack of adaptation must also feed into the increased time costs seen in TBI. It has been found that stroke patients exhibit a pattern of reduced accuracy but similar response times to healthy controls, particularly for uncued endogenously controlled alternating tasks (Pohl et al., 2007). It is suggested that stroke patients cannot maintain the combination of accuracy and speed i.e. they would be more accurate if they were not aiming to respond as fast as possible.

The ability to differentiate between executive ‘wrong-task’ errors (producing Days instead of Months) and task-specific decision errors (selecting a Day out of sequence) in the Continuous Series II will allow for specific identification of executive failure where it occurs rather than general reference to accuracy as a secondary unspecified source of cost as is the case in the wider literature. The current study uses an ultra-cognitive neuropsychological perspective (as termed by Shallice, 1988), based on the principle that any non-normal functioning (regardless of its source) will inform the determination of underlying processes in normal functioning. By administering the Continuous Series II to patients with TBI and stroke the evidence of executive failure in the task will be more apparent than with a healthy control sample. It will thus be possible to infer implicit processes in verbal task switching by putting the behaviour ‘under the spotlight’ of non-normal functioning. If between-category errors are indeed indicative of executive failure then they will be more widespread in the patients.



A: Continuous Series II



B: Mixed Category task

Figure 2 Example of a single iteration of switching between three verbal categories for (A) Continuous Series II overlearned sequences (OS) and (B) Mixed Category task OS + semantic categories (SC). Switching on the Continuous Series II task occurs between different categories but within a single task set, that of overlearned sequences. Switching on the Mixed Category task occurs both between the categories and between task domains (semantic search and overlearned sequences).

In summary, comparison of the Continuous Series II with the Mixed Category task will allow investigation of tasks of differing difficulty in a verbal paradigm. Proactive interference, of the type proposed by Allport, Styles & Hsieh (1994) in their task-set inertia (TSI) hypothesis (transient interference from the previous task set interferes with establishing the current task set) would present in the Continuous Series II as slowed RT on the second and subsequent tasks and failure to establish the task (an error in the subsequent task). As between-category error are proposed to be executive and therefore not open to effects from non-executive processes, it is proposed that any evidence of carryover effects would result in increased within-category errors, specifically perseverative within category errors (repeating the last item e.g. Monday, February, *Monday,* March...). As switch cost in the verbal switching paradigm is measured for the whole task it is not possible to assess the effect on costs but it is possible to assess the effect on within-category errors. By comparing the Continuous Series II with a Mixed Category task comprising of (harder) semantic categories and (easier) overlearned sequences we are in effect replicating the harder-to-easier task structure that showed asymmetry in the Allport study, within a verbal paradigm. There is no Stroop-like interference or bivalency and so the harder-to-easier aspect of the task can be studied in isolation.

2 Hypotheses

1. In line with previous work (Essig, 2004) performance on all indices will deteriorate as the number of switching categories increases.
2. It is predicted that the Mixed Category task will result in greater switch cost than the Continuous Series II, due to the contribution of switching between an easier and more difficult task as opposed to just easier tasks and the need to switch between tasks under fractionated rather than unitary frontal control (Gurd, 1995).

3. There are expected to be fewer between category errors for the Mixed Category task than the Continuous Series II, reflecting the disengagement from both the previous task and the previous task domain. The double switch in the Mixed Category task emphasises the ‘cognitive gear change’ (Monsell, 2003) implicit in the task set reconfiguration (TSR) (Rogers & Monsell, 1995) account. Between-category errors, which indicate a breakdown in System 2 (Kahneman, 2011) reflect such effortful top-down processing. The need to, in effect, doubly switch will result in slower (as previously predicted) but more complete switching.
4. There will be a difference in the *type* of within-category errors found in both the Continuous Series II and the Mixed Category task, although at present it is unclear how the difference will present. Specifically, if there are more repetition (e.g. Wednesday, *Wednesday*) than sequencing (e.g. Wednesday, *Saturday*) errors found in the Mixed Category task, which has tasks of differing difficulty, this will indicate evidence of carryover effects interfering with establishment of subsequent tasks. The *type* of within-category errors will act as a secondary measure of the prevalence of TSI.
5. It is predicted that the Verbal Fluency task will result in greater switch cost than the Continuous Series II due to switching solely being between ‘difficult’ tasks. Additionally there is the need to switch between sub-groups within categories. Although there will not be the contribution (in either direction, asymmetric or reverse asymmetric) of switching between easier and harder tasks, it is predicted that the more difficult task will be more time consuming overall.
6. There will be a difference in switch cost between the Verbal Fluency task and the Mixed Category task. It is unclear which combination will be more costly, differing task difficulty/ different frontal control processes for the Mixed Category task or

harder task/ switching between both categories and sub-groups for the Verbal Fluency task.

3 *EXPERIMENT ONE*

3.1 Method

3.1.1 Design

Healthy control data was analysed throughout as a repeated measures design, measuring Speech Rate (w/sec), Switch Cost (% w/sec increase) and Error Type (within or between categories) as detailed in Chapter 2. Due to the Verbal Fluency (VF) and Mixed Category (MX) tasks being truncated at 3-categories, Continuous Series II (CS) data was initially analysed on its own across all three levels of difficulty. The three tasks (CS, VF & MX) were then compared as a repeated measures 3 x 2 design (Task Type (CS, VF, MX) x Difficulty Level (2, 3, 4 categories)) for analysis of Task Speech Rate and Switch Cost. Error types were analysed using two or three levels of a single factor (either Task Type or Number of Categories) as appropriate. The neurological patients were treated as a series of single case studies. Raw scores were converted into *z*-scores[56] ; the criterion for impaired performance was set at 2*SD* below the control mean. Positive and negative *z*-scores for Switch Cost were reversed as a higher score would indicate slower (and therefore impaired) performance.

3.1.2 Single case series approach

The single case series design adopted what Shallice (1988) termed a strong or ultra-cognitive approach, seeking to establish the processes underlying *normal* cognitive functioning (in this case, the ability to switch between verbal tasks) by studying the

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[56] Patient raw score minus control *M* divided by control *SD*

performance of people with known *abnormal* cognitive functioning, not to ascribe any relationship between specific brain processes and such functions (Coltheart, 2004). Although viewed by some as too extreme (e.g. Shallice, 1988) in the extent of its exclusion of physiological cause, this approach lends itself very well to the current aim of establishing the limitations of the verbal switching paradigm. No inference regarding implementation of the task is made (or required) at this stage of theorising (c.f. Marr & Poggio, 1976). Further, the approach can be considered more robust as predictions are tested repeatedly against a number of individual cases, in much the same way as using a number of separate groups, by means of z-scores calculated against the results from a healthy control group (with an appropriately sized control sample c.f. Crawford & Howell, 1998; Crawford & Garthwaite, 2002).

3.1.3 Participants

A new sample of healthy controls ($n = 28$) was used for the reanalysis of data from Essig (2004); they were a mix of postgraduate psychology students and staff from the University of Hertfordshire and individuals from the wider community, recruited by word of mouth. Six neurological patients[57] from the original study were included in the analysis (see Table 4 for details of individual diagnoses); patient 5 (a 57-year old female, two-months post left hemisphere stroke) was removed from the analysis as she did not complete the Mixed Category task or either of the speech rate measures. All participants carried out the same core background measures as detailed in Chapter 2; neurological patients did not complete the WAIS-R vocabulary sub-test so as to avoid fatigue. The short NART (Beardsall & Brayne, 1990) which uses only the first 25 words from the full version was used with Patient 3 as he appeared to have difficulty with reading (Crawford et al., 1991 confirm reliability of the short

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[57] Patients for the original study had been recruited from the Oxford Centre for Enablement and had been referred by their consultant neurologist.

version in predicting full scale IQ when compared to full NART). The neurological patients carried out a picture description task (using a scene of people playing on a beach) at the end of the session, to give a second w/sec measure of speech rate. The intention was to compare this to the initial conversational speech measure to assess possible fatigue effects on speech rate and to end the test session with a positive activity. Two of the patients were unable to complete the first conversational activity as they could not think of a topic to talk about[58]. A paired sample T-test carried out on the remaining four patients showed no significant difference between conversational rate (*M* 2.63, *SD* .21) and picture description rate (*M* 2.44, *SD* .52), *t*(3) = .78, *p* = .49. The picture description measure was therefore used for the purpose of speech rate comparison with the control group. A series of independent samples *t*-tests showed that speech rate was the only measure showing a significant difference[59] between healthy controls (*M* 2.58, *SD* .42) and patients (*M* 1.98, *SD* .82), *t*(32) = 2.64, *p* = .13.

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[58] The neurological patients were offered the choice of talking about a favourite or recently completed hobby or pastime (they all took part in occupational and art therapy sessions) as this was felt to be a more emotionally neutral and easily recalled alternative to a holiday.

[59] This did not adversely affect task performance measures as Switch Cost is calculated individually against each participant's speaking rate.

Table 3 Descriptive Statistics of Background Test Battery (NART Predicted Full Scale IQ, WAIS-R Vocabulary Sub-Test, Forward and Backward Digit Span, Conversational Speech Rate and Picture Description Speech Rate) For Healthy Controls (N = 28) and Neurological Patients (N = 6)

Group	Age	NART	WAIS-R vocab.	Digit span Forw.	Backw.	Conv. speech (w/sec)	Picture desc. (w/sec)
Controls							
Mean	47.25	113.04	12.5	6.57	4.93	2.58	*
SD	*12.38*	*7.26*	*3.38*	*1.17*	*1.39*	*0.42*	
Patients							
Raw scores							
1	43	118	*	7	4	2.73	2.03
2	57	102	*	4	2	**	1.16
3	65	87	*	7	2	**	0.93
4	38	112	*	6	4	2.33	2.28
6	37	94	*	8	4	2.80	3.20
7	61	124	*	8	6	2.65	2.26
Patients							
Mean	51.60	106.17	*	6.67	3.67	2.63	1.98
SD	*13.18*	*14.32*		*1.51*	*1.51*	*0.21*	*0.82*

* Task not administered; ** Did not complete task

Table 4 Clinical Details (Injury, Treatment and Time elapsed before Testing) for Neurological Patients (n = 6).

Injury and any invasive treatment	Time between injury & testing	Neuropsychological assessment at admission
Patient 1 (female, 43 yrs) Right total anterior circulation stroke	2 mths	Mild visual problems (especially re: locating objects in space) Problems with visual memory & IP speed (although good verbal recall) Slight executive problems (planning unstructured & novel tasks)
Patient 2 (male, 57 yrs) TBI resulting in large fronto-temporo-parietal contusion & subsequent right parieto-temporal craniotomy and partial right frontal & temporal lobectomy	7 mths	Geographical disorientation (believed he was in London, not Oxford) Significant impairment of verbal and visuospatial recall and recognition; very slow thinking speed Significant executive impairment, showing perseveration, set shifting problems, confused & disorganised performance and lack of insight
Patient 3 (male, 65 yrs) Left hemisphere stroke to the middle cerebral artery (investigated for same side TIAs 9 months prior to this)	2 mths	Significant reduction in IP speed Significant problems with planning and construction Difficulty learning new unstructured verbal material (structured verbal and visual recall good) Possible executive problems
Patient 4 (female, 38 yrs) Left hemisphere intra cerebral haemorrhage; left craniotomy, evacuation of haematoma and embolisation of discovered AVM	2 mths	No significant cognitive difficulties found Difficulties recalling numbers strings, though possibly due to long term recall problems
Patient 6 (male, 37 yrs) Closed head injury (fall from height onto a hard surface). Left frontal & right cerebellar contusions	4 mths	Mild cognitive impairment Retrograde amnesia regarding accident
Patient 7 (male, 61 yrs) Right fronto-parietal intracerebral haemorrhage (TIA/ left occipital lobe ischaemic infarct 9 months prior to this)	6 wks	No noted cognitive impairments, although slight tendency towards impulsivity

IP = information processing; **TBI** = traumatic brain injury; **TIA** = transient ischemic attack; **AVM** = arterio-venous malformation

3.1.4 Stimuli

The study used the Continuous Series II (CS; full description in Chapter 2), a Verbal Fluency switching task (VF) requiring participants to switch between increasing numbers of semantic categories and the Mixed Category task (MX), which required switching between increasing numbers of alternating overlearned sequences and semantic categories. Categories and start points used for each task are presented below; start points were pre-set and non-canonical for overlearned sequences and free for semantic categories.

Table 5 Categories and Start Points used in Continuous Series II, Verbal Fluency and Mixed Category Tasks.

Task & Number of Categories		Categories	Start points
Continuous Series II	*2*	Numbers – Days	6 – Tuesday
	3	Numbers – Days – Months	4 – Friday – October
	4	Numbers – Days – Months – Letters	9 – Wednesday – February - H
Verbal fluency	*2*	Vehicles – Clothing	*Free start points*
	3	Occupations – Animals – Fruit	*Free start points*
Mixed Category task	*2*	Furniture – Months	*Free* – July
	3	Flowers – Days – Sports	*Free* – Saturday – *Free*

Number of sequence iterations: 2-cats. = 23 3-cats. = 21 4-cats. = 20

Semantic category norms were taken from Hampton & Gardiner (1983). Several categories were excluded[60] due to possible ambiguity or restricted set size for the neurological patients (such difficulties are extensively documented by Lezak et al, 2004). The reduced number of suitable categories resulted in the Verbal Fluency and Mixed Category tasks being truncated to 3-category switching.

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[60] The excluded categories were: birds; fish; food flavourings; insects; vegetables; weapons

3.2 Procedure

After completing background measures, healthy controls completed tasks in the order Continuous Series II, Verbal Fluency and Mixed Category task; full procedural details for verbal switching are described in Chapter 2. Neurological patients completed the Continuous Series II and Mixed Category tasks only, to reduce any possible effects of fatigue. Task order was fixed to ensure that neurological patients carried out what was perceived to be the most unfamiliar first, thus avoiding undue stress and fatigue during the session. While the Mixed Task was felt to be harder per se, patients were more likely to be familiar with semantic search and so this task was felt the most appropriate one to finish on.

3.3 Data Analysis

3.3.1 Data distribution

Normality for all variables was assessed using the Shapiro-Wilk's test with significance set at .01; where appropriate skewness and kurtosis were considered using a *z* limit of + 2.71, equivalent to an α level of .01 (Field, 2009). Both digit span measures were found to have a non-normal distribution: forward digit span $W(28) = 0.89$, $p = .008$, with a leptokurtic cluster scoring at 7; reverse digit span $W(28) = 0.90$, $p = .010$.

Continuous Series II rate and switch cost for 4-category switching were non-normal, $CS4_{\mathbf{rate}}$ $W(28) = 0.90$, $p = .009$, $CS4_{\mathbf{cost}}$ $W(28) = 0.86$, $p = .002$, this time with skewness just reaching significance at the .01 level for switch cost only. Closer investigation revealed $CS4_{\mathbf{rate}}$ to have a peak at 0.40 w.sec and $CS4_{\mathbf{cost}}$ to peak at 90%. The degree of these peaks beyond the normal curve and the number of participants contributing to them, as well as the observed normality of the rest of the sample and normal distribution of other rate and switch cost variables, indicated that transformation of the data was not justified (particularly given the intrinsic change to the nature comparisons this would entail – see Field, 2009) and that parametric analyses could reasonably be applied.

Rate and switch cost measures for 3-category Verbal Fluency switching exhibited a significantly non-normal distribution, $VF3_{\mathbf{rate}}$ $W(28) = 0.85$, $p = .001$, $VF3_{\mathbf{cost}}$ $W(28) = 0.84$, $p = .001$. Although statistically non-normal, observation of a histogramatic representation of the data indicated that the majority of the sample presented a normal distribution, with $VF3_{\mathbf{rate}}$ showing a peak at around 0.20 w/sec and a single high score of 0.37 and $VF3_{\mathbf{cost}}$ peaking less noticeably between 68-78%, with a single low (fast) score of 50%. As expected, all error measures for all three tasks (with the exception of $CS4_{\mathbf{within}}$) showed significantly (in excess of $\alpha = .01$) non-normal distributions. Additionally all measures of *different* within-category error type (repeat or sequencing), which were used to address hypothesis 4, were non-normally distributed with the exception of CS4 sequencing errors.

3.3.2 Statistical tests

Continuous Series II rate and switch cost were analysed over 2, 3 and 4 switching categories using GLM repeated measures ANOVA, IV1 = Number of Categories (2, 3, 4). Rate and switch cost for all three verbal switching tests (CS, VF and MX) were then compared over 2 and 3 switching categories using a GLM repeated measures 3 x 2 ANOVA, IV1 = Task Type (CS, VF, MX), IV2 = Number of Categories (2, 3). Post-hoc contrasts were carried out using t-tests or GLM repeated contrasts as appropriate, depending on whether scores could reasonably be expected to be incremental across levels. A bivariate correlation was used to identify any potential covariates from the baseline measures, which were incorporated into ANCOVA analyses where appropriate (see note in Chapter 2, page 124 regarding the use of covariates with repeated measures factors (Thomas et al., 2009)). In all instances of the GLM ANOVA/ ANCOVA multivariate results are reported using Wilk's lambda Λ, which is more robust to violations of sphericity. Effect sizes are reported using partial η^2, interpreted as .01 = small, .06 = medium and .14 = large (Cohen, 1988). Error rates (within and between category errors) were analysed using the non-parametric Friedman's ANOVA and Wilcoxon signed-ranks test, with effect size reported as *r*, interpreted as .10 = small, .30 = medium and .50 = large (Cohen, 1988).

Significance levels for post-hoc contrasts made using t-tests or Wilcoxon signed ranks tests were determined using Holm's sequential Bonferroni adjustment throughout (Holm, 1979). All non-parametric significance levels are exact measures; for Wilcoxon signed ranks tests this is indicated in the text as one or two-tailed as appropriate. Effect size *r* was calculated in the following ways (Field, 2009): t-tests, $\sqrt{}\ ((t^2 \div (t^2 + df))$; Wilcoxon signed ranks, test statistic $Z \div \sqrt{}$ number of observations.

3.4 Results: Healthy Controls

3.4.1 Descriptive and preliminary statistics

All tasks showed the predicted increase of Switch Cost and Errors, and decrease in Task Speech rate (see Tables 4 and 5), as the Number of Categories increased. Task Speech Rate and Switch Cost for the three tasks were not inversely matched as difficulty increased. Rate was slowest for VF (M = 0.25), then MX (M = 0.37), then CS (M = 0.96); cost was greatest for MX (M = 75.36), then CS (M = 69.71), then VF (M = 67.59). Rate was at a comparable level for VF2 (*M* = 0.29) and MX3 (*M* = 0.28), but for the same two tasks cost was comparable between VF3 (*M* = 72.20) and MX2 (*M* = 71.23).

Switch Cost measures showed more variation than Task Speech Rate, reducing in all instances as the Number of Categories increased. Conversely, variance *increased* in line with Number of categories for both Error Type measures.

No correlation was evident between age and predicted NART IQ. Forward digit span correlated significantly with reverse digit span, $r = .51$, p (all significance values two-tailed) $= .006$, normal speech rate $r = .38$, $p = .049$ and all three speech rate measures for the Continuous Series II, $CS2_{\textbf{rate}}$ $r = .42$, $p = .025$, $CS3_{\textbf{rate}}$ $r = .60$, $p = .001$, $CS4_{\textbf{rate}}$ $r = .55$, $p = .003$. Similarly, reverse digit span correlated with all Continuous Series II rate measures, $CS2_{\textbf{rate}}$ $r = .46$, $p = .015$, $CS3_{\textbf{rate}}$ $r = .63$, $p = .0001$, $CS4_{\textbf{rate}}$ $r = .65$, $p = .0001$ and also with $CS4_{\textbf{cost}}$ $r = -.46$, $p = .014$ and $MX2_{\textbf{rate}}$ $r = .42$, $p = .026$. Finally, normal speech rate also correlated with $CS2_{\textbf{rate}}$ $r = .38$, $p = .049$. The relationship between normal speech rate and forward digit span/ $CS2_{\textbf{rate}}$ very likely reflected the ability to speak at a normal or near to normal rate during those two activities, rather than indicating any attributable share of the variance. Reverse digit span was deemed the most suitable of the two span measures to use as a covariate, given its relationship with all three tasks and some of the more complex switching indices, but was excluded due to its non-normal distribution.

3.4.2 Task speech rate

A one-way GLM ANOVA indicated that for the Continuous Series II the Number of Categories (see Table 6 for means) being switched between had a highly significant effect on speech rate during the task, $\Lambda = .06$, $F(2, 26) = 224.53$, $p = .0001$, $\eta_p^2 = .95$, with rate increased significantly in line with the number of categories CS2 to CS3 $F(1, 27) = 291.02$, $p = .0001$, $\eta_p^2 = .92$, CS3 to CS4 $F(1, 27) = 134.12$, $p = .0001$, $\eta_p^2 = .83$.

For the cross-task comparison a two-way GLM ANOVA revealed a highly significant main effect of task type (see Table 6 for means), $\Lambda = .06$, $F(2, 26) = 197.87$, $p = .0001$, $\eta_p^2 = .94$, and of number of categories (2-cats *M* = 0.67, 3-cats *M* = 0.38), $\Lambda = .06$, $F(1, 27) = 394.43$, $p = .0001$, $\eta_p^2 = .94$, as well as a highly significant interaction (see Figure 3) manifesting as a greater effect of Number of Categories for the CS task, $\Lambda = .09$, $F(2, 26) = 137.10$, $p = .0001$, $\eta_p^2 = .91$.

Table 6 Descriptive Statistics (M, SD, Range and Confidence Interval) for Healthy Controls (n = 28) on Task Speech Rate (w/sec) and Switch Cost (% increase).

	Continuous Series II			**Verbal Fluency**		**Mixed Category**	
	2-cats	**3-cats**	**4-cats**	**2-cats**	**3-cats**	**2-cats**	**3-cats**
Task Speech rate (w/sec)							
Mean	1.26	0.66	0.43	0.29	0.21	0.47	0.28
SD	0.21	0.20	0.18	0.08	0.05	0.11	0.07
Switch cost (% increase)							
Mean	61.21	78.22	87.46	62.99	72.20	71.23	79.49
SD	9.36	8.22	5.47	7.77	5.33	7.71	6.53

CS rate: M = 0.96, SE = 0.03
VF rate: M = 0.25, SE = 0.01
MX rate: M = 0.37, SE = 0.01
2-cat rate: M = 0.67, SE = 0.02
3-cat rate: M = 0.38, SE = 0.01

CS cost: M = 69.71, SE = 1.55
VF cost: M = 67.59, SE = 1.08
MX cost: M = 75.36, SE = 1.16
2-cat cost: M = 65.14, SE = 1.18
3-cat cost: M = 76.64, SE = 0.92

3.4.3 Switch cost

A one-way GLM ANOVA indicated that for the Continuous Series II the Number of Categories (see Table 6) being switched between had a highly significant effect on switch cost during the task, $\Lambda = .08$, $F(2, 26) = 143.63$, $p = .0001$, $\eta_p^2 = .92$, again increasing significantly in line with categories, CS2 to CS3 $F(1, 27) = 190.18$, $p = .0001$, $\eta_p^2 = .88$, CS3 to CS4 = $F(1, 27) = 127.06$, $p = .0001$, $\eta_p^2 = .83$.

A two-way GLM ANOVA revealed a highly significant main effect of Task Type (see Table 6), $\Lambda = .40$, $F(2, 26) = 19.73$, $p = .0001$, $\eta_p^2 = .60$, and of Number of Categories (2-cats $M = 69.71$, 3-cats $M = 67.59$, 4-cats $M = 75.36$), $\Lambda = .12$, $F(1, 27) = 206.14$, $p = .0001$, $\eta_p^2 = .88$, as well as a highly significant interaction again caused by the effect of categories for task CS, $\Lambda = .46$, $F(2, 26) = 15.08$, $p = .0001$, $\eta_p^2 = .54$; the difference between 2-cats and 3-cats was significant for task CS compared to VF, $F(1, 27) = 27.12$, $p = .0001$, $\eta_p^2 = .50$, but not for VF compared to MX, $F(1, 27) = 24.70$, $p = .610$, $\eta_p^2 = .01$. Figure 4 very clearly illustrates the lack of interaction between VF and MX, with the particularly low cost produced by CS2 causing the interaction.

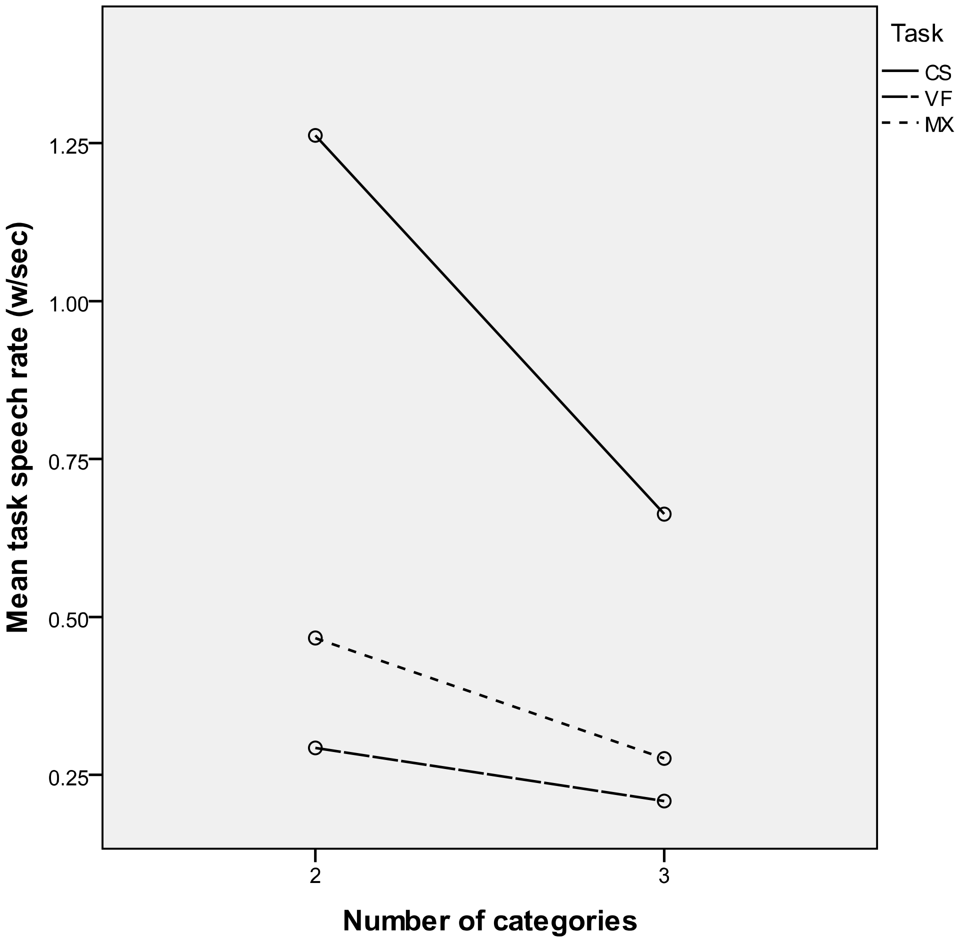

Figure 3 Task speech rate (w/sec) for Continuous Series II, Verbal Fluency and Mixed Category tasks over two and three switching categories.

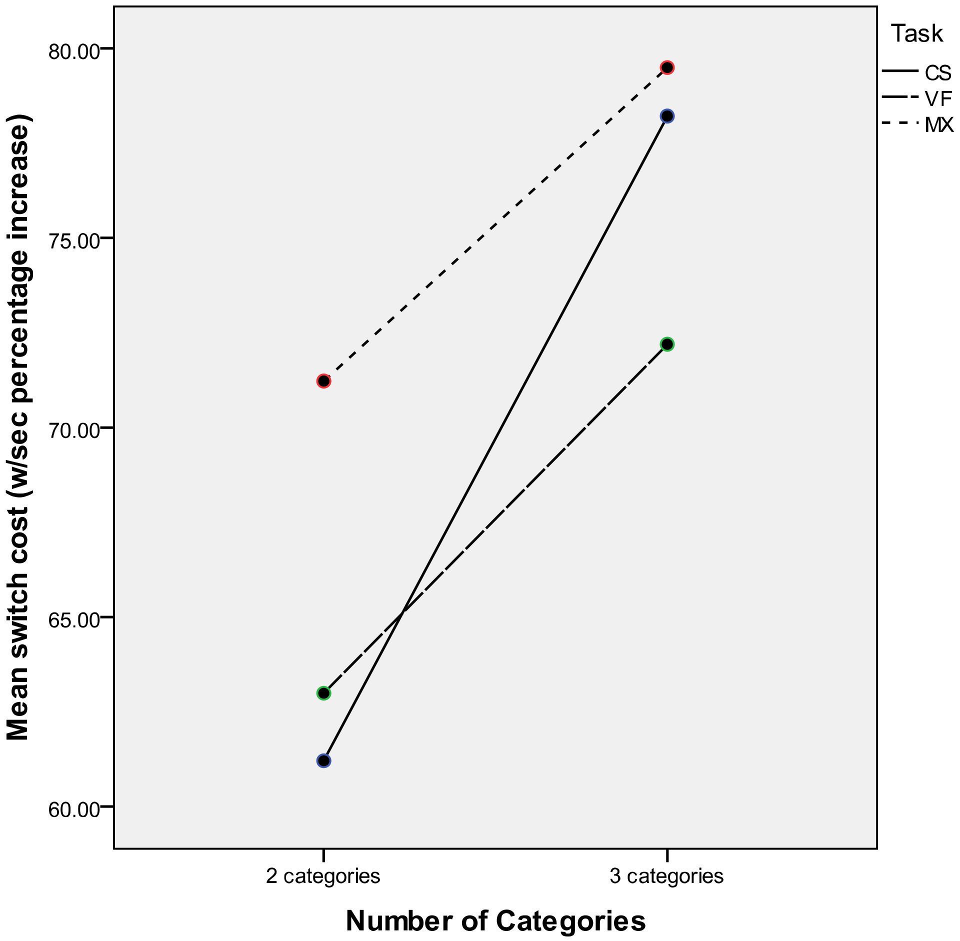

Figure 4 Switch cost (w/sec percentage increase) for Continuous Series II, Verbal Fluency and Mixed Category tasks over two and three switching categories.

Table 7 Descriptive Statistics (Sum, N producing errors, M, SD, Range and Confidence Interval) for Healthy Controls (n = 28) on Error Types (Count).

		Continuous Series II			**Verbal Fluency**		**Mixed Category**	
		2-cats	**3-cats**	**4-cats**	**2-cats**	**3-cats**	**2-cats**	**3-cats**
Error type (number)								
Within	Sum	7	92	270	22	42	61	167
	N	4	23	25	13	16	14	22
	Mean	0.25	3.29	9.64	0.79	1.50	2.18	5.96
	SD	0.7	3.23	6.90	1.07	2.42	3.40	6.90
Between	Sum	0	5	24	8	21	0	7
	N	-	3	6	2	6	-	3
	Mean	-	0.18	0.86	0.29	0.75	-	0.25
	SD	-	0.61	1.74	1.18	1.82	-	0.84

3.4.4 Within category errors

A Friedman's ANOVA revealed that for the Continuous Series II (CS) the increase in within-category errors as a factor of Number of Categories was significant, χ^2 (2) = 42.27, *p* = .0001. Follow up Wilcoxon signed ranks tests revealed this to be uniformly significant, CS2 to CS3, *T* = 0, *p* = .0001, r^2 = -0.54, CS3 to CS4, *T* = 13, *p* = .0001, r^2 = -0.55. During 4-category switching for the Continuous Series II 68.7% of within-category errors were perseverative (repeating he last response made within the category) and 31.3% were sequencing errors.

A Wilcoxon signed-ranks test revealed that for the Semantic Category task there was no significant difference between the number of errors produced when switching between two and three categories, *T* = 65.50, *p* = .37. There was a highly significant increase in the number of within-errors produced from two to three categories for the Mixed Category task, *T* = 4, *p* = .0001, r^2 = -0.52.

Errors produced when switching over 3-categories were compared between all three tasks using a Freidman's ANOVA; two category switching was less informative for this purpose due to the paucity of errors at CS2. A significance difference was indicated, χ^2 (2) = 11.42, p = .003. Follow up Wilcoxon signed ranks tests compared the tasks in ascending order of number of errors – VF, CS, MX (as shown in Table 7) and showed the increase to only be significant from comparing the smallest (VF) with the largest (MX) number of errors, VF to CS, VF3 to CS3, T = 52, p = .035, VF3 to MX3, T = 47, p = .001, r^2 = -0.42, CS3 to MX4, T = 90.50, p = .05.

Types of within-category errors, either repeats (e.g. 9, Wednesday, 10, *Wednesday*…) or sequencing errors (e.g. 9, Wednesday, 10, *Saturday*…) were looked at overall for the two tasks and between category types for the Mixed Category task. Using Wilcoxon signed ranks tests, the number of repetition and sequencing errors were found not to significantly differ for the first two difficulty levels of the Continuous Series II, $CS2_{rep}$ & $CS2_{seq}$, T = -1.13, p = .257, $CS3_{rep}$ & $CS3_{seq}$, T = -0.19, p = .847. The most difficult level of the Continuous Series II showed a significant difference with twice as many repeats as sequencing errors (see Tables 8 & 9), T = -2.57, p = .010. For the Mixed Category task there were significantly more sequencing errors than repeats at both levels of difficulty (see Tables 8 & 9), $MX2_{rep}$ & $MX2_{seq}$, T = -3.20, p = .001, $MX3_{rep}$ & $MX3_{seq}$, T = -2.23, p = .026.

Looking at the categories of the Mixed Category task in detail, to see if there was a difference in repetition errors (signifying TSI in the easier overlearned sequences) for the two types of task, it was found that for 2-category switching there was no significant difference (see Table 9) , T = -1.41, p = .157. However, for 3-category switching there were significantly more repeats for the overlearned sequence categories compared to the semantic categories, $T = -3.75$, $p < .0001$.

Table 8 Descriptive Statistics for the Within-Category Repeat and Sequencing Errors for the Continuous Series II and Mixed Category Task.

	Continuous Series II						**Mixed Category task**			
	CS2$_{rep}$	**CS2$_{seq}$**	**CS3$_{rep}$**	**CS3$_{seq}$**	**CS4$_{rep}$**	**CS4$_{seq}$**	**MX2$_{rep}$**	**MX2$_{seq}$**	**MX3$_{rep}$**	**MX3$_{seq}$**
Mean	0.04	0.21	1.57	1.64	6.29	3.14	0.11	2.14	1.57	4.36
SD	0.19	0.79	2.33	1.77	5.84	2.46	032	3.40	1.60	6.11

CS = Continuous Series II MX = Mixed Category task rep = repeat seq = sequencing

Table 9 Descriptive Statistics for Within-Category Repeat Errors only, comparing Rates for Semantic Categories and Overlearned Sequences at each Level of Difficulty.

	Mixed Category task			
	2-categories		**3-categories**	
	Repetition $_{sem}$	**Repetition $_{OS}$**	**Repetition $_{sem}$**	**Repetition $_{OS}$**
Mean	0	0.07	0.04	1.61
SD	0	0.26	0.19	1.52

Sem = semantic category OS = overlearned sequence

3.4.5 Between category errors

As no between-category errors were produced over two categories, Continuous Series II errors of this type were compared for three and four categories using a Wilcoxon signed-ranks test, showing a significant increase with categories $T = 4$, $p = .03$, $r^2 = -0.26$. When switching over 4-categories of the Continuous Series II there were no perseverative errors (repeating the last task); 64.29% were found to be sequencing errors and 35.71% were found to be errors of omission.

Between-category errors were compared for all three tasks over 3- categories (MX also producing none over 2-categories) using a Freidman's ANOVA, but revealed no significant difference, χ^2 (2) = 2.18, $p = .337$.

3.5 Results: Neurological Patients

Like the healthy controls, patients show a reduction in task speech rate as the tasks get harder (see Table 10), although this is much less pronounced for the Mixed Category task. Switch cost also follows the pattern of increasing with task difficulty, for many starting higher and increasing less for the Mixed Category task. Of note is P3 who maintained the same task speech rate for both difficulty levels of the Mixed Category task, although this was likely due to premature cessation over 3-categories. Patient 2 showed both reduced task speech rate and, unusually, switch cost as the Mixed Category task became more difficult, again due to premature cessation.

A number of patients were impaired on task speech rate – for the Continuous Series II P3 and P4 were impaired over 2-categories, P3 also over 3-categories and none over 4-

categories. For the Mixed Category task P1, P3 and P4 over 2-categories, P1 and P3 over 3-categories. No patients showed any notable dissociation between the two tasks for task speech rate. There was only one impaired switch cost score, P3 on the Continuous Series II over 2-categories. Again no dissociations of note were evident.

Generally number of errors increased as tasks became more difficult, although a decrease was seen from 2-categories to 3-cateogrories for within-category errors in the Continuous Series II for P2, possibly again due to premature cessation and in the Mixed Category task for P1on between-category errors, P2 on within-category errors and P6 on within-category errors.

A dissociation for between-category errors over 3-categories on the two tasks is noted for P6 and P7 (see Table 11); these fall in opposite directions with P6 being impaired on the Continuous Series II and above control performance for the Mixed Category task and P7 showing impairment on Mixed Category task and improved performance on the Continuous Series II. However, the positive performance is not comparable to the level of impairment (positive scores for both patients are zero); due to the opposing hemisphere damage it is possible that the scores of P6 and P7 are indicative of a doubly dissociative trend (both patients completed the full task). Patient 2 shows a broader dissociation between within-category errors over 3-categories (lower than controls for Continuous Series II, much higher on Mixed Category task) but the lower score here falls just short of the impaired level. Patient 3 also shows a mild dissociative pattern over 2-categories (Continuous Series II lower, Mixed Category task higher) but again the lower score is not at the impaired level.

When looking at the type of errors produced during 4-category Continuous Series II switching, for within-category errors patients were found to produce 44.83% perseverative errors (P1, P2, P3 and P4) and 55.17% sequencing errors (P1, P2, P3 and P4). For between-category errors they produced 17.39% perseverative errors (P1, P2 and P3), 43.48% sequencing errors (P1, P2, P3 and P7) and 52.94% omission errors (P2 and P3).

Table 10 Raw scores and z-scores for Neurological Patients (n = 6) on Speech Rate (w/sec) and Switch Cost (% increase).

		Continuous Series II			**Mixed Category**	
		2-cats	**3-cats**	**4-cats**	**2-cats**	**3-cats**
Task Speech rate (w/sec)						
Patients						
1	Raw score	0.91	0.30	0.18	0.21	0.14
z-score		-1.67	-1.80	-1.39	*** -2.36**	*** -2.00**
2	Raw score	1.31	0.46	0.33	0.27	0.25
z-score		+0.24	-1.00	-0.56	-1.82	-0.43
3	Raw score	0.29	0.21	0.22	0.12	0.12
z-score		*** -4.62**	*** -2.25**	-1.17	*** -3.18**	*** -2.29**
4	Raw score	0.77	0.42	0.08	0.25	0.18
z-score		*** -2.33**	-1.20	-1.94	*** -2.00**	-1.43
6	Raw score	1.10	0.73	†	0.34	0.30
z-score		+0.76	+0.35		-1.18	+0.29
7	Raw score	1.68	0.91	0.40	0.49	0.28
z-score		+2.00	+1.25	-0.17	+0.18	0.00
Switch cost (% increase)**						
Patients						
1	Raw score	49.44	83.33	90.16	80.37	83.72
z-score		+1.26	-0.62	-0.49	-1.19	-0.65
2	Raw score	58.68	85.40	89.91	81.63	66.66
z-score		+0.27	-0.87	-0.45	-1.35	+1.97
3	Raw score	84.15	88.00	89.91	81.81	82.35
z-score		*** -2.45**	-1.19	-0.45	-1.37	-0.44
4	Raw score	77.35	86.79	97.75	81.75	86.05
z-score		-1.72	-1.04	-1.88	-1.36	-1.00
6	Raw score	54.16	69.58	†	73.82	72.97
z-score		+0.75	+1.05		-0.34	+1.00
7	Raw score	49.09	70.74	88.17	71.68	78.63
z-score		+1.29	+0.91	-0.13	-0.06	+0.13

***** = impaired at < 2*SD* below control *M*
****** = *z*-score reversed from positive to negative
† = did not complete

Table 11 Raw scores and z-scores for Neurological Patients (n = 6) on Error Types (Count).

			Continuous Series II			Mixed Category	
			2-cats	**3-cats**	**4-cats**	**2-cats**	**3-cats**
	Error type (count)*						
1	Within	Raw score	1	2	14	0	4
	z-score		-1.07	+0.40	-0.63	+0.64	+0.28
	Between	Raw score	0	0	4	2	0
		z-score	‡	+0.30	-1.80	‡	+0.30
2	Within	Raw score	1	9	4	8	1
	z-score		-1.07	-1.77	+0.82	-1.71	+7.19
	Between	Raw score	0	4	9	0	2
	z-score		‡	* **-6.27**	* **-4.68**	‡	* **-2.89**
3	Within	Raw score	1	2	6	2	3
	z-score		-1.07	+0.40	+0.53	+0.05	+0.43
	Between	Raw score	0	1	1	6	4
	z-score		‡	-1.34	-0.08	‡	* **-4.46**
4	Within	Raw score	0	1	11	2	6
	z-score		+0.36	+0.71	-0.20	+0.05	-0.01
	Between	Raw score	0	0	0	0	0
	z-score		‡	+0.30	+0.49	‡	+0.30
6	Within	Raw score	0	2	†	2	1
	z-score		+0.36	+0.40		+0.05	+0.72
	Between	Raw score	0	2	†	0	0
	z-score		‡	* **-2.98**		‡	+0.30
7	Within	Raw score	5	2	4	1	2
	z-score		* **-6.79**	+0.40	+0.82	+0.35	+0.57
	Between	Raw score	0	0	4	0	2
	z-score		‡	+0.30	-1.80	‡	* **-2.08**

* = impaired at < 2*SD* below control *M*

** = *z*-score reversed from positive to negative

† = did not complete

‡ = *z*-score not computable due to control score of zero

4 Discussion

All tasks followed general patterns predicted for the increase in task difficulty for both healthy controls and neurological patients[61]. For the healthy controls, degradation in performance in line with difficulty was much more pronounced for the Continuous Series II, for both rate and cost measures, than for the other two tasks (see Table 6). Verbal fluency switching was the slowest in terms of task speech rate but as predicted the Mixed Category II task was the costliest when compared to baseline speech rate. That verbal fluency switching results in the slowest task speech rate is to be expected, given the slower baseline production rate for categories (as evidenced by baseline rates for the mixed task in Experiment 3, see Table 25). Semantic category production involves semantic search and review of which responses have previously been made. Task speech rate results are entirely predictable from examination of baseline rates for the component task categories.

Greater cost for the healthy controls on the Mixed Category II task overall is attributed to the combination of semantic category rate and the ‘double’ switch requirement of changing not only to the next task but to a different verbal domain (Gurd et al., 2003). During 3-category switching, switch cost for the Mixed Category II and Continuous Series II tasks converges (see Figure 4), though a large proportion of this convergence would appear to be due to the benefit seen in 2-category switching for the Continuous Series II. Lack of errors (and consequent time costly error recovery) would seem to account in part for this benefit. Verbal fluency switching produced three times as many within-category errors at this difficulty level and the Mixed Category II task produced almost nine times as many (Ragland et al. (2008), using only the 2-category component of the Continuous Series II, also found

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[61] There were some exceptions for neurological patients but these were largely attributed to early cessation of the task.

minimal errors[62]). However, errors produced at the 3-category level are almost twice as prevalent for the Mixed Category task as for the Continuous Series II (see Table 7), while switch costs for this difficulty level are almost identical (see Table 6). Within-category errors at the 3-category difficulty level evidently contribute far less to cost for the Mixed Category task. Another explanation would be that an additional source of cost is encroaching for the Continuous Series II.

Although the Mixed Category task is slower overall than the Continuous Series II, presumably because of the fractionated control processes needed for the differing tasks, this cost difference is not evident over 3-category switching. While costs converge at this level of difficulty the cause would seem to differ for the two tasks, indicated by the variation in within-category errors. For the Mixed Category task there is no significant difference between errors produced in semantic categories and errors produced in overlearned sequences, although there are about 50% more semantic than overlearned errors. If recovery from semantic errors is faster than overlearned sequence errors this could be a contributor. Three-category switching involves two semantic categories in the sequence – clarity over the role of differing errors types would only become clear if the task extended to 4-categories, as is the case in Experiment 3, Chapter 5. In addition these two categories in effect appear next to each other, reducing the number of times the double switch (task and task type) needs to be made. For example, "flowers – days – *sports* – *flowers* – days…" It is only in Experiment 5 that the full extent of this double switch effect can be seen. Another potential contributor to this convergence could be the rate of increase between task levels for the Continuous Series II i.e. increasing difficulty might have more of an effect for this task.

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[62] In healthy controls and individuals with schizophrenia

Anecdotally there is a great difference in participant awareness of errors which may also account for the differing effect of such errors. Errors in overlearned sequences appear to be noticed much more regularly than errors in semantic categories. Very often an overlearned sequence error will be followed by gaps or slowing in responses as awareness of an error is gained, followed by comment on the commission of the error such as "…no, wait, that was not right…" (Experiment 2 in Chapter 4 looks in detail at the nature of these non-target utterances). Awareness of the error would seem to be greater due to the comparative context of the response – returning the response 'Wednesday' is set against the previous response 'Tuesday', giving some context to check the suitability of the response against. A breakdown in this checking results in uncertainty over the response and backtracking to try and correct or acknowledge the error. Conversely errors in semantic categories are very often made with no indication of awareness at all. Quite often an item from the beginning of the task will be repeated near the end of the task so awareness of the repetition appears to be limited.

Comparison of the two tasks at this truncated level of 3-category switching is therefore of limited value in determining the difference between the two tasks and their differing levels of involvement of top-down control, which must be returned to in more length in Chapter 5. However, the Mixed Category task does allow for assessment of the verbal switching paradigm in relation to Allport's task-switch inertia (TSI) hypothesis, whereby enduring activation of the previous more difficult task set carries over and interferes with establishment of the following easier task set. Semantic categories, with their need to search and check, are deemed more difficult to produce items from than the automatic overlearned sequences. If TSI was in evidence (albeit in the absence of bivalency) then there would be a greater number of repetition errors compared to sequencing errors, particularly when comparing the two types of task. Repetition errors would be more in evidence in the overlearned sequences as carryover would prevent updating of the task item. There were in fact significantly more sequencing than repetition errors for both difficulty levels of the Mixed Category task (see Table 8). Looking in detail at the Mixed Category task there was no difference in repetition errors between the two types of task for 2-category switching and significantly more repetition errors for overlearned sequences in 3-category switching. This is particularly relevant given there are more component semantic categories than overlearned sequences at this difficulty level. The Mixed Category task therefore does not offer any evidence thus far for carryover when comparing tasks of differing difficulty[63].

Although affordance of two tasks from one set of stimuli (bivalency) is noted as relevant to the outcome of carryover effects (Monsell, Yeung & Azuma, 2000), emphasis is also placed on the differing level of difficulty between tasks. There is no need to suppose that carryover of inhibition would *only* occur for bivalent tasks, particularly if the strength of disparity between the two tasks were sufficient. Production of the two types of word again reflects Kahneman’s (2011) two-system model, automatic and fast for overlearned sequences and effortful and slower for semantic categories. Monsell et al. (2000) note that inhibition of the type posited by Allport, Styles & Hsieh (1994) may be switch-specific rather than just prolonging some process that occurs when the task is carried out in a non-switching condition (such as response selection). Thus the carryover of inhibition would not necessarily be tied to the bivalent nature of the task but instead be related to the switching process and to the need to overcome the level of control required for the previous harder task. Continuous presentation of the same stimuli triggering the now erroneous task set (as in Stroop) would of course make the effect stronger but part of the carryover effect comes from the differing levels of difficulty and differing strength of activation for each task set.

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[63] Issues of switch cost for the competing tasks are addressed in Experiment 3, Chapter 5.

Patients were generally slower than controls on Continuous Series II task speech rate, something which became more pronounced as the task became more difficult. This was more in evidence and showed more impaired performance for the Mixed Category task. Given that the patients were deemed to be impaired in terms of executive control and the Mixed Category task is proposed to involve two fractionated types of control for the component tasks, the level of impairment would seem to support this proposition. One patient (P3) had reported dysarthria and delivered impaired performance over 2 and 3-categories of both tasks – the lack of impairment over 4-categories was attributed to early cessation of the task at that level. Slower speech rate was expected given the range of pathologies (Pimm, 1997; Wang, Kent, Duffy & Thomas, 2005). However, impairment was seen more widely during the Mixed Category task, possibly again in relation to the double nature of switching between component tasks – patients would be expected to have greater word finding difficulties for the semantic categories.

More than half the patients produced a *faster* switch cost than the controls for 2-category Continuous Series II switching – only one, P3, was impaired. This phenomenon would appear to be related to the 2-category switch cost advantage (when compared to the other two tasks) for the healthy controls, compounded by a ceiling effect imposed by the slower nature of baseline non-switching speech rate for the patients. This advantage was not seen at greater difficulty levels for the task. The Mixed Category task saw some performance higher than controls at the 3-category level; two of the patients here ended the task one-third in, thus not affording the chance to accrue general cost contributors. Generally early ending of the task appeared to occur when mental effort (noted by Azouvi et al. (2004) to be the source of reduced switching functionality during switching for TBI patients) became overwhelming, accompanied by comments such as “I can’t think” or “It’s too difficult to think". On the Mixed Category task patients frequently commented they had "…run out of words…" suggesting that semantic search may similarly have been too effortful. Cessation of the task often followed a run of errors, highlighting the greater interference felt from errors in such patients (Perlstein et al., 2005; Pohl et al., 2007; Larson et al., in press). Both these phenomena highlight issues previously raised in relation to the Mixed Category task, the likeness to Kahneman's 2-system model and the contribution of error recovery to cost. System 2 requires effort and is under conscious control, evidenced by the types of comments and early cessation seen in the Mixed Category task. This would suggest that in the Mixed Category task there is greater need for System 2, with both switching *per se* and one of the component tasks being under its control. Automatic production of overlearned sequences has been noted as intact in populations such as PD patients (Gurd, 1995) where there is impairment to the System 2 switching process. Patients appear to be largely intact in System 1 but not so in System 2. It is therefore possible to complete switching to an extent using System 1 but deficits in System 2 limit the execution of the task. Between category errors are also widespread amongst the patients, which would further implicate a deficit of System 2. Other two-system models of control specifically during task switching would also fit this interpretation. One example is the dual-route model of motor task switching proposed by Imamizu, Kuroda, Yoshioka and Kawato (2004). Switching can occur through the parietal based parallel MOSAIC route or the frontally based serial Mixture of Experts route. Switching can be completed by a single route in the absence of the other, though with some detriment[64]. Finally, that cessation often followed a run of errors gives insight to the contribution errors make to switch cost for all participants. Clearly recovery from errors takes time (as in the interruption resumption lag noted by Altmann & Trafton, 2007) – this

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[64] The MOSAIC (Modular Selection And Identification for Control, Haruno, Wolpert & Kawato, 1999) is a parallel modular architecture combining multiple pairs of inverse and feed forward models which control and predict motor behaviour respectively, the act of switching being governed largely by the fit of the two internal models themselves. The Mixture of Experts (Jacobs & Jordan, 1991) uses a separate switching module to, referred to as a 'gating network', being more analogous with a typical executive function.

recovery period is magnified in patients who have less resilience to interruption of the switching process (governed in Kahneman’s model by System 2 which appears to be deficient in such a population) due to less control over that process.

Patient errors followed the general overall pattern of detriment to performance as the task became more difficult. There is a notable double dissociation for 3-category between-category errors between the two tasks involving patients P6 and P7 (see Table 11). Patient 6 had suffered left frontal damage and was impaired on CS3 and performed favourably on MX3; P7 had right frontal damage and showed the opposite pattern of performance. Both patients were able and verbally competent and had performed well throughout the tasks (with the exception of P6 not attempting CS4). It is tempting to relate this to work mentioned in Chapter 4 concerning division of goal maintenance between the right and left APC (Charron & Koechlin, 2010) but there is no discernable functional basis for the dissociation as it stands. The PFC is involved in judging semantic acceptability (Dapretto & Bookheimer, 1999) and more generally in semantic response selection and retrieval (Thompson-Schill, Aguirre, D’Esposito & Farah, 1999). The left inferior frontal lobe is particularly involved in semantic processing (Bookhemier, 2002) – as such patient P6, who had left frontal damage, might be expected to be impaired on the Mixed Category task but in fact was not. The pre-frontal cortex (PFC) is associated with the System 2 abilities of detecting and resolving conflict (Evans, 1999) (associated in this work to between-category errors), whereas the ventral medial PFC is associated with the more intuitive automated System 1 responses. However, without more detailed background on the exact cite of damage it is difficult to determine the source of the dissociation. Overlearned sequences are associated with right temporal and parietal areas but do not relate to any frontal areas (Pariyadath et al., 2008); the double dissociation would therefore appear to be anomalous.

To continue in considering healthy controls, it is worth considering that Arbuthnott and Frank (2000) found almost 75% of their wrong–task errors (akin to between-category errors) to be perseverative in nature, with participants failing to switch from the previous task. In the current study (for Continuous Series II 4-category switching) this was found to account for none of the between-category errors with the majority being sequencing errors (participants switching *to* the wrong task but not repeating the previous one) and the rest were errors of omission. All of the sequencing errors involved the swapping over of two adjacent categories. Thus it would seem that the interpretation of such errors as System 2 failure would be more appropriate – this is associated with detecting and resolving conflict, which would be represented by mis-ordering of the tasks in this way. System 2 is rule based and judgements reflect a comparison of options, the breakdown of which would seem to be reflected by this type of failure. Perseverative between-category errors were seen in the patient results, accounting for almost one fifth of the total number of between-category errors (one third were sequencing and just over half omission). Even excluding the possibly inflated score of eight omission errors from one patient who omitted one category from the whole task, perseveration still only accounted for one third of all between-category errors. Unlike Arbuthnott and Frank’s (2000) sample, healthy participants here were always able to switch, albeit sometimes to the wrong task. Switching task *type* as well as task in the Mixed Category task is shown to be more time costly. The lack of perseverative between-category errors would appear to relate this to activation of the upcoming task rather than inhibition of the previous (Baddeley et al., 1998). In comparison at least to Arbuthnott and Frank’s (2000) data the verbal switching paradigm would seem to reflect the effect of preparatory processes more than inhibitory ones.

8 Conclusion

- In line with hypothesis 1 that cost would increase with difficulty, for all tasks and all participants switching became more taxing as the number of task being switched between increased (see Buchler et al., 2008).

- Cost is inevitably inflated by inclusion of error data in the general task cost calculation, although as stated earlier one of the aims of the current work is to account for the full effects of the global switching workspace (the costs incurred by the whole task including error production, self corrections, gaps etc.). The contribution of semantic category errors would seem to be less costly to recover from than overlearned sequence errors. Cost here is evidently related to switching rather than error contribution, supporting the double switch for the Mixed Category task mentioned in hypothesis 3 and negating the greater recovery time from semantic errors predicted in hypothesis 2. The latter would seem to be more noticeable to the participant and requires tracking back to the correct resumption point in the sequence whereas semantic category errors may go unnoticed.

- Combination of semantic and overlearned sequence categories has an increased combinatory effect on switch cost stemming from the need to switch not only task but verbal domain, resulting in a greater time taken to complete reconfiguration. Hypothesis 6 predicted a difference between tasks but not which would be more costly. This ‘double switch’ requirement however results in fewer between category errors as the disengagement from the previous task is more complete.

CHAPTER FOUR: VERBAL TASK SWITCHING IN A SAMPLE OF MONOZYGOTIC TWINS MIRRORED FOR HANDEDNESS

1 Introduction

This chapter describes a further study carried out using two versions of the verbal switching task, the Continuous Series II and the Mixed Category task (Essig, 2004). The sample for this study is a small group of left and right handed monozygotic twin pairs mirrored for handedness (MzTMH). They are assessed in an effort to determine whether control was differentially applied in accordance with disparate language lateralisation. Literature is discussed that suggests there is some basis for differential control for the component tasks (semantic category and overlearned sequence production) between individuals with left and right hemisphere lateralised language. Further, there is evidence that control for dual tasks can be split between the left and right hemispheres, suggesting that control of the Continuous Series II may present differently for the two groups in the sample. The chapter also includes some reference to post-hoc theorising, testing a hypothesis suggested by the data. For clarity background literature and a relevant hypothesis are included here, although the analysis was not determined at the start of the study. The hypothesis was suggested by the number of non-target utterances made during commission of the task with this sample, exploring the possibility that the type of utterance might affect the subsequent target response made.

1.1 Language lateralisation and verbal task switching

Monozygotic twins mirrored for handedness have been shown to have a higher than average incidence for similar mirroring of language lateralisation (Somner, Ramsey, Mandl & Kahn, 2002: Lux et al., 2008) and spatial lateralisation (Lux et al., 2008), with strong behavioural manifestations of such spatial differences (Gurd, Schulz, Cherkas & Ebers, 2006). There is also evidence of cerebellar asymmetry (Rosch, Ronan, Cherkas & Gurd, 2010). Given the implicit role of language in switching more generally (Monsell, 2005) and for the Continuous Series II in particular, such differences in lateralisation may have implications for the nature of control processes exerted during switching. Additionally, processing of ordinal sequences such as days and numbers have been located to the right hemisphere (Pariyadath et al., 2008) which may give a time advantage for those for whom this is the normal locus of language processing. The supposition that there is a right hemisphere temporal advantage is in line with the assumption that there is greater interplay within verbal and non-verbal abilities (and so enhancement of both) because they share a hemisphere (Springer & Deutsch, 1993).

There is evidence that the left and right hemispheres play a different role in task switching (Leite, Carvalho, Fregni, Boggio & Gonçalves, 2013). Transcranial direct current stimulation was used to affect performance of the left and right PFC. It was found that increasing LHEM activity and reducing RHEM activity resulted in decreased switch cost for a letter/ digit naming task. Switch cost was *increased* for a vowel-consonant parity task by the same pattern of stimulation, resulting in more time-impaired performance (but with greater accuracy). The parity task was seen as more cognitively demanding, suggesting that the more demanding task was in part under right hemisphere PFC control. Individuals with right-hemisphere language lateralisation would have an atypical relationship between language and attention (usually located in the right hemisphere but normally hemispherically dissociated from language) (Flöel, Buyx, Breitenstein, Lohmann & Knecht, 2004). This divergence of language lateralisation and attention into the right hemisphere for the left handers, in conjunction with the possible right hemisphere time advantage already noted, would further suggest that left handed twins would perform faster than left handed twins.

A number of other specific differences between left and right handers, some of which are switch related, also lend credence to the assumption that executive as well as language processing may be carried out differently. Related to the already mentioned right hemisphere advantage is the finding that mixed-handers are more effectively able to switch between clusters of category exemplars in a verbal fluency task (Sontam, Christman & Jasper, 2009). This is thought to be due to increased access to right hemisphere processing, which is said to be more diffuse (Chiarello, Burgess, Richards & Pollock, 1990). In an extensive sample of 399 mirrored twin pairs, left handers out performed right handers on Raven's Progressive Matrices (a test of reasoning) and the Peabody Picture Vocabulary Test (Carter-Saltzman, Scarr-Salapatek, Barker & Katz, 1976). In a Stroop test, handedness-related differences in the execution of executive control were observed (Beratis, Rabavilas, Papadimitriou & Papageorgiou, 2010); left handers exhibited less Stroop interference than right handers. In a separate task (based on the Hayling sentence completion task, a test of executive function) initiation and inhibition of sentence completion (providing a context-congruent or incongruent completion) was found to differ between left and right handers (Beratis et al., 2010). Left handers showed greater frontal activation during the initiation task and reduced activation during the inhibition task when compared to right handers. When interpreted with the Stroop findings (Beratis et al., 2010), this could point towards more efficient executive control during the Stroop task. Finally, in recent work looking at covert verbal fluency production, left-handed twins were found to have differential right frontal activation from right-handed twins but similar behavioural results. There is clearly a different structure-function relationship in achieving the task, which might well manifest behaviourally during switching.

In further tasks left handers were also more likely to show prowess in mathematical and verbal reasoning (Benbow, 1986) and cope better than right handers with new knowledge (O’Boyle, Benbow & Alexander, 1995). This affinity for novelty is also highlighted using the Cognitive Bias Task (a measure of context-dependent responding, involving multiple-choice responses in the face of ambiguity), which identifies a strong relationship between handedness and functional lateralisation of the frontal lobes (Goldberg, Harner, Lovell, Podell & Riggio, 1994). It is posited by Goldberg and colleagues that there may be qualitative differences in cognition between left and right handers rather than simply a mirroring of neural arrangement. They propose familiarity-seeking and novelty-seeking to be right and left handed traits respectively and link this to the high incidence of creativity in left handers (O’Boyle & Benbow, 1990).

Overall this builds up to a picture of advantageous processing, both linguistic and executive, for left handers. There may be evidence of a right hemisphere advantage – certainly there is less interference from the competing dominant task in the Stroop (Beratis et al., 2010) and evidence of differential involvement of the frontal lobes in executive tasks, both behavioural (Goldberg et al., 1994) and neurological (Beratis et al., 2009). More recently Gurd et al. (2013) have found very similar frontal differences between left and right handers to those indicated by Beratis et al. (2009). Evidence has also been provided by Charron and Koechlin (2010) that control of goals by the frontal lobes (specifically the medial and lateral frontal cortices) divide to simultaneously accommodate concurrent goals under dual-task conditions. This includes some overlap with areas identified as asymmetric[65] by Lux et al. (2008). Areas of the medial frontal cortex (particularly highlighted by Charron & Koechlin, 2010) have been identified as being involved in intentional reconfiguration during switching (Rushworth, Hadland, Paus & Sipila, 2002; Dove et al., 2000). The interaction of such divided control with differentially lateralised language function may well result in differential control for the verbal task. In conclusion, such functional and behavioural differences would suggest that handedness-related differences in RT and accuracy (particularly executive between-category errors) could be expected in the Continuous Series II.

While not directly informing theoretical accounts of task switching with which to interpret the Continuous Series II, investigation of individuals with atypical language lateralisation will be informative about the task itself, which was one of the main aims of the thesis. The two hemispheres are differentially recruited during task switching, seemingly related to the level of cognitive demand of the task. While the Continuous Series II utilises automatic speech production it is nonetheless more demanding than more usual measures of task switching. Overall it would seem there is a right hemisphere advantage for more demanding tasks and a propensity in left-handers for novel tasks. Given that there is a differential contribution of hemispheres to task switching and that production of overlearned sequences is a right hemisphere function it would be useful to know whether individuals with a right hemisphere processing bias would be better able to complete the task. Language

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[65] The inferior frontal gyrus, posterior and anterior middle frontal gyrus

processing is integral to task switching (Monsell, 2005) and particularly to the Continuous Series II – knowing whether the task is right hemisphere dominant (by virtue of the overlearned sequence processing) would be informative. It could be that right hemisphere dominance for language interacts not only with same-side lateralised attentional function but also the splitting of frontal goal control.

1.2 Externalisation of inner speech as a self-cuing device

Finally it is necessary to give theoretical background for some emergent data that arose while the current experiment was being analysed. Older adults (such as the current sample) find difficulty in switching between tasks compared to younger adults, possibly due to age-related deficits in executive functioning (Gratton, Wee, Rykhlevskaia, Leaver & Fabiani, 2009). The use of inner speech as a self-cuing device has been noted during task switching (Emerson & Miyake, 2003 – see page 60 of this document), particularly in older populations (Kray, Eber & Karbach, 2008). Disruption of inner speech during switching has been shown to increase mixing costs (e.g. Baddeley, Chincotta & Adlam, 2001) – mixing costs are the RT increase for performing a repeat of a task within a mixed (switching) block of trials as opposed to a single task block. Baddeley and colleagues noted that such costs are particularly large when the switching task does not use external cues and reliance on inner speech is increased. The Continuous Series II is just such a cue-free task. Although it is not subject to mixing costs (there is no task repeat during switching) reliance on inner speech does facilitate switching. There are anecdotal reports during task completion of participants rehearsing task and item order ‘in their heads’. Verbal labelling (naming the upcoming task in accordance with inner speech) is akin to this rehearsal and has been found to reduce age-related costs (Kray et al., 2008).

Further anecdotal evidence from the task in all experiments shows that sometimes task-related non-target utterances are made during completion of the task (see Appendix F for a sample of such utterances). These might be indicative of a rehearsal e.g. “Monday, Tuesday, Wednesday...” or of memory loss e.g. “What was the next category?” or be more general in nature e.g. “This is difficult, isn’t it?” Although participants are instructed not to say anything except the target responses, non-target utterances still occur. When reviewing the recordings for the twins sample it was apparent that such utterances were more frequent. It is hypothesised that this is related to the age of the sample (51 years, with a number of individuals in their later 50s or 60s) – utterances are an externalisation of the inner speech on which this age group more heavily rely. Older adults use reactive control according to the DMC model (dual-mechanisms of cognitive control framework) (Braver, Gray & Burgess, 2007; Czernochowski et al., 2010). Reactive control relates to reconfiguration and cue S-R mappings and is slower; proactive control oversees fast switching over time (Braver, Reynolds & Donaldson, 2003). Proactive control may be difficult for older adults (Braver et al., 2001). The DMC model suggests that older adults will instead rely on reactive control, which does not require maintenance over long periods of time (Rabbitt, 1979; Braver & West, 2008). Czernochowski predicts that older adults will particularly recruit reactive control at higher levels of difficulty. Utterances could therefore be indicative of reactive, reconfiguration-based control – indeed, their content does seem to signify this. It is proposed that utterances that reflect rehearsal (commonly the content of inner and overt speech in task switching, Monsell, 2005) will be more beneficial for subsequent responses in terms of whether an error is made as the utterance will reinforce inner speech.

2 Hypotheses

1. There will be a right-hemisphere advantage for switching between overlearned sequences in the Continuous Series II, such that left-handed twins (who are taken to have right hemisphere language lateralisation) will have a lower/ faster switch cost than right-handed twins on the Continuous Series II.
2. Similarly, because of more effective switching between clusters in semantic categories and greater access to more diffuse right-hemisphere processing for the harder task, the left-handed twins will have lower switch cost on the Mixed Category task than the right-handed twins.
3. Following on from the general advantage for left-handers, there will be a reduced level of both types of error.
4. Non-target utterances that reflect rehearsal will result in fewer subsequent errors than utterances that reflect memory loss or general comments.

3 EXPERIMENT TWO

3.1 Method

3.1.1 Design

The Continuous Series II was again initially assessed on its own (due to the truncated Mixed Category task) as a 2 x 3 (handedness x number of categories) mixed design measuring task speech rate (w/sec) and switch cost (% w/sec increase). Comparison between CS and MX was as a mixed 2 x 2 x 2 design (handedness x task x number of categories), again measuring task speech rate and switch cost. Error type (within or between) was assessed non-parametrically due to extreme non-normality of the data.

3.1.2 Participants

Thirteen pairs of monozygotic twins discordant for handedness (i.e. one left hander, one right) were tested. They had been recruited from the St. Thomas's UK Adult Twin Registry (Kings College London: Spector & McGregor, 2002) as part of an ongoing and separate research programme into spatial laterality and motor control and had all agreed to additionally take part in the current study; individuals were recruited via postal request and testing took place in the Neuropsychology Unit at the Radcliffe Infirmary in Oxford. Handedness had previously been assessed using a 16-item handedness assessment inventory comprised of items from both Briggs and Nebes (1975) and the Edinburgh Handedness Inventory (Oldfield, 1971). Although individual data was not available, inclusion on the St. Thomas's database was confirmation that participants satisfied this criterion. Full demographic data, as well as NART and digit span scores, is given in Table 9. Paired sample *t*-tests revealed no significant differences between left and right handed groups on NART, WAIS-R vocabulary or digit span measures. For Continuous Series II non-target utterances a smaller sample was used (*n* = 9, 6 right handed). For non-target utterances in the Mixed Category task a different sample was used (*n* = 14, 7 right handed) – demographics are given in Table 13.

3.1.3 Stimuli

The Twins study used the Continuous Series II and Mixed Category tasks in the same format as for Experiment One.

3.2 Procedure

Participants completed the NART, WAIS-R and forward and reverse digit spans as background measures; conversational speech rate was not included as testing sessions were strictly time limited, due to the constraints of the concurrent laterality study. Presentation order of the Continuous Series II and Mixed Category tasks was counterbalanced evenly between left and right handers.

3.3 Data distribution

Background measures and task speech rate/ switch cost measures were normally distributed for the whole group as indicated by Shapiro-Wilk test, with the exception of reverse digit span, $W(26) = 0.91$, $p = .007$, which had a leptokurtic (although not independently significant) peak at a score of 5. In comparing left and right handed participants no measures significantly violated normality at the α level of .01.

Table 12 Demographic and Baseline Measures for Twins Sample (n = 26).

						Digit span	
Twin pair	**Age**	**Gender**	**Handed-ness**	**NART IQ**	**WAIS-R vocab.**	**Forw.**	**Backw.**
1 – TW27	45	F	Right	114	8	7	6
2 – TW27	45	F	Left	109	8	6	4
3 – TW28	65	F	Right	96	8	9	4
4 – TW28	65	F	Left	108	10	7	5
5 – TW29	55	F	Right	111	11	6	4
6 – TW29	55	F	Left	114	10	7	5
7 – TW30	58	F	Right	116	12	6	3
8 – TW30	58	F	Left	107	11	6	3
9 – TW31	30	F	Right	111	8	7	5
10 – TW31	30	F	Left	113	10	7	7
11 – TW32	38	F	Right	108	11	6	3
12 – TW32	38	F	Left	110	11	5	3
13 – TW33	62	F	Right	125	15	8	6
14 – TW33	62	F	Left	126	15	8	5
15 – TW34	44	F	Right	111	12	5	5
16 – TW34	44	F	Left	110	11	5	3
17 – TW35	66	M	Right	121	15	9	5
18 – TW35	66	M	Left	122	17	8	5
19 – TW36	57	M	Right	106	12	8	5
20 – TW36	57	M	Left	111	15	8	5
21 – TW38	45	M	Right	116	14	5	3
22 – TW38	45	M	Left	117	18	7	7
23 – TW40	52	M	Right	95	8	7	5
24 – TW40	52	M	Left	97	11	5	5
25 – TW42	41	M	Right	113	11	8	8
26 – TW42	41	M	Left	115	13	8	8

Whole sample							
Mean	50.86			111.75	12.31	6.86	4.86
SD	10.48			7.54	3.04	1.24	1.43
L-handed							
Mean	50.62			112.23	12.31	6.69	5.00
SD	11.08			7.18	3.04	1.18	1.58
R-handed							
Mean	50.62			111.00	11.15	7.00	4.77
SD	11.08			8.53	2.58	1.35	1.42

Table 13 Demographics for Non-Target Utterances for the Continuous Series II and Mixed Category Task, showing Means and Standard Deviations in Parentheses.

	Age	**NART-IQ**	**WAIS-R**	**Digit forw.**	**Digit backw.**
Continuous Series II					
Whole sample (n = 9)	51.56 (12.63)	107.56 (6.58)	10.00 (1.23)	6.78 (1.20)	4.78 (1.39)
Mixed Category task					
Whole sample (n = 14)	54.07 (11.27)	111.64 (8.48)	11.14 (2.21)	6.57 (1.34)	4.57 (1.40)

All measures of non-target utterance (utterances and post-utterance responses) were found to be non-normally distributed with the exception of errors following a memory utterance and correct responses following a rehearsal utterance.

3.3.1 Statistical tests

Speech rate and switch cost for the tasks were analysed using mixed GLM ANOVAs, 2 x 3 for CS only and 2 x 2 x 2 for the CS and MX comparison, as detailed above. Covariates were identified using a bivariate correlation analysis; any such variables were stratified entered as independent factors in a second ANOVA to attribute covariance (see Experiment 1 and Chapter 2). Analysis of error types was carried out using the non-parametric Mann-Whitney test. Analysis of non-target utterances and subsequent responses was made using Friedman’s ANOVA, the Wilcoxon signed ranks test and the Mann-Whitney test. As for experiment 1, any multiple post-hoc comparisons made using t-tests used an appropriately adjusted α level; effect sizes were interpreted using $\eta_p{}^2$ (small = .01, medium = .06, large = .14) and *r* (small = .10, medium = .20, large = .30).

3.3.2 Descriptive and preliminary statistics

Task speech rate and switch cost for both tasks displayed slowing/ increase as difficulty increased. Mean scores for left and right handers were highly similar, the only difference being a slight increase in variance for the right handed group.

A number of correlations between background measures (and between background measures and factors) were indicated as follows: Age and forward digit *r* = .44, *p* (two-tailed) = .024; forward and reverse digit span, *r* = .53, *p* (two-tailed) = .005; forward digit span and $CS3_{\textbf{rate}}$, *r* = .72, *p* (two-tailed) = .0001; forward digit span and $CS4_{\textbf{rate}}$, *r* = .48, *p* (two-tailed) = .012; reverse digit span and $CS3_{\textbf{rate}}$, *r* = .63, *p* (two-tailed) = .001; reverse digit span and $CS4_{\textbf{rate}}$, *r* = .45, *p* (two-tailed) = .020. Reverse digit span was therefore considered as a potential covariate for task speech rate analyses only.

3.4 Results

3.4.1 Task speech rate

In the Continuous Series II task there was a significant effect of number of categories (see Table 14 for means), Λ = .07, *F*(2, 23) = 151.36, *p* = .0001, $\eta_p{}^2$ = .93 with rate reducing significantly across the task as the number of categories increased, $CS2_{\textbf{rate}}$ to $CS3_{\textbf{rate}}$, *t*(25) = 14.95, *p* = .0001, *r* = 0.95, 95% CI (0.54 – 0.71); $CS2_{\textbf{rate}}$ to $CS4_{\textbf{rate}}$, *t*(25) = 17.85, *p* = .0001, *r* = 0.96, 95% CI (0.73 – 0.92); $CS3_{\textbf{rate}}$ to $CS4_{\textbf{rate}}$, *t*(25) = 10.02, *p* = .0001, *r* = 0.89, 95% CI

(0.16 – 0.25). There was no indication of any independent effect of handedness (left & right $M = 0.78$) on task speech rate, $F(1, 24) = 0.001$, $p = .979$ ns, $\eta_p^2 = .0001$and predictably from such results no interaction with number of categories, $\Lambda = .97$, $F(2, 23) = 0.31$, $p = .738$ ns, $\eta_p^2 = .03$.

Table 14 Descriptive Statistics for Task Speech Rate (w/sec) on Continuous Series II and Mixed Category Tasks for Left and Right Handed Monozygotic Twins (group n = 26).

		Continuous Series II			**Mixed Category task**	
		2-cats	**3-cats**	**4-cats**	**2-cats**	**3-cats**
Task speech rate (w/sec)						
Left handed	*Mean*	1.27	0.65	0.43	0.47	0.28
	SD	0.16	0.14	0.15	0.12	0.07
Right handed	*Mean*	1.25	0.64	0.45	0.40	0.29
	SD	0.19	0.18	0.17	0.09	0.08

L-H rate: $M = 0.67$, $SE = 0.02$	R-H rate: $M = 0.65$, $SE = 0.02$
L-H CS rate: $M = 0.96$, $SE = 0.04$	R-H CS rate: $M = 0.95$, $SE = 0.04$
L-H MX rate: $M = 0.38$, $SE = 0.02$	R-H MX rate: $M = 0.35$, $SE = 0.02$
L-H 2-cat rate: $M = 0.87$, $SE = 0.03$	R-H 2-cat rate: $M = 0.83$, $SE = 0.03$
L-H 3-cat rate: $M = 0.46$, $SE = 0.03$	R-H 3-cat rate: $M = 0.47$, $SE = 0.03$

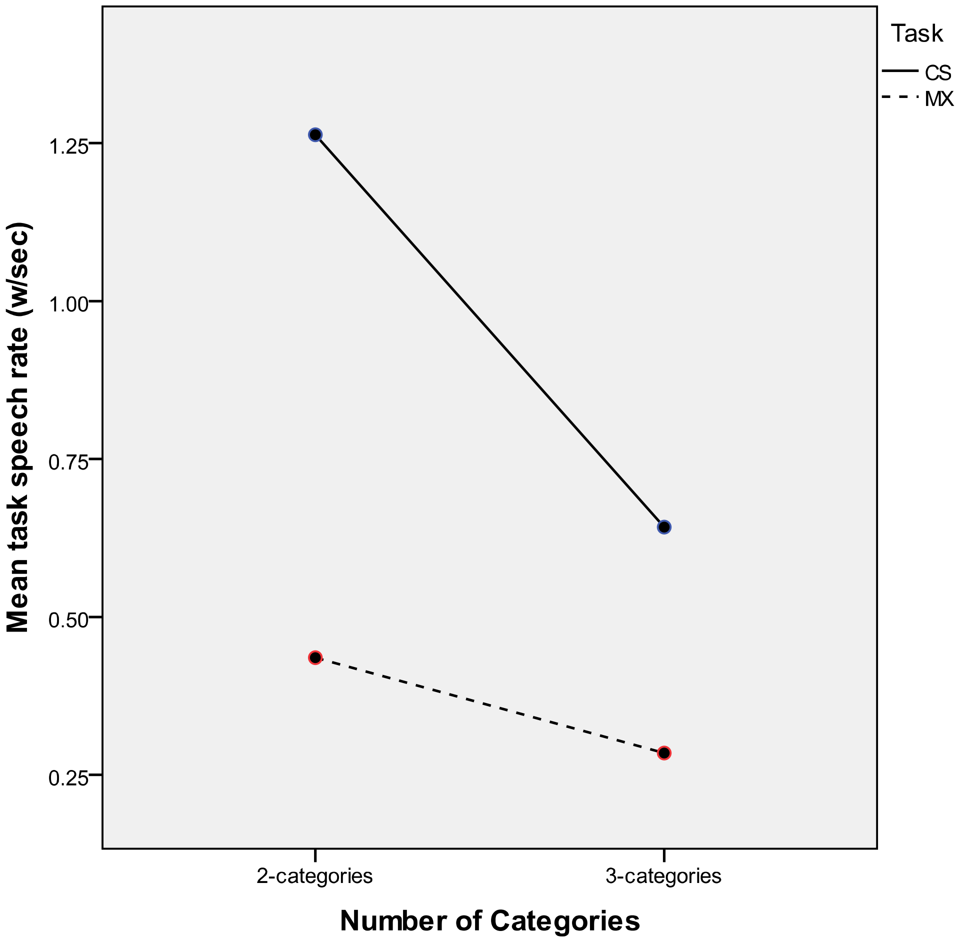

Figure 5 Task speech rate interaction of task type (Continuous Series II and Mixed Category task) and number of switching categories (2 and 3) for whole twins sample (N = 26)

The analysis of task speech rate for CS was re-run with the inclusion of reverse digit span as an independent factor (with similar cases grouped together) to determine the degree of covariance it accounted for in isolation from the repeated measures factor of Number of Categories. Scores were grouped as Low (scores of 3 or 4, $N = 9$, $M = 0.71$), Medium (scores of 5, $N = 11$, $M = 0.79$) and High (scores of 6, 7 or 8, $N = 6$, $M = 0.87$). Reverse digit span was found to have some independent effect on task speech rate, $F(2, 20) = 3.67$, $p = .044$, $\eta_p^2 = .27$, but did not differ significantly according to handedness $F(2, 20) = 0.23$, $p = .801$ ns, $\eta_p^2 = .02$, nor interact with Number of Categories $\Lambda = .77$, $F(4, 38) = 1.33$, $p = .276$ ns, $\eta_p^2 = .12$.

Comparing the two tasks confirmed that task speech rate was significantly slower for the mixed task, $\Lambda = .05$, $F(1, 24) = 440.41$, $p = .0001$, $\eta_p^2 = .95$, and that switching over 2-categories ($M = 0.85$) produced a faster rate than over 3-categories ($M = 0.46$), $\Lambda = .09$, $F(1, 24) = 255.93$, $p = .0001$, $\eta_p^2 = .91$. The two factors produced a significant interaction (see Figure 5) with an increase in switching categories causing a greater reduction of task speech rate for CS compared to MX, $\Lambda = .20$, $F(1, 24) = 98.64$, $p = .0001$, $\eta_p^2 = .80$.

Again handedness was not found to have a significant independent effect, $F(1, 24) = 0.48$, $p = .500$, $\eta_p^2 = .02$, nor significant interactions with task type $\Lambda = .99$, $F(1, 24) = 0.07$, $p = .798$ ns, $\eta_p^2 = .003$, number of categories $\Lambda = .96$, $F(1, 24) = 1.04$, $p = .318$ ns, $\eta_p^2 = .04$, nor did the previously identified interaction between these two factors differ according to handedness $\Lambda = .98$, $F(1, 24) = 0.58$, $p = .452$ ns, $\eta_p^2 = .02$.

Running the expanded analysis on the cross task comparison revealed that the potential covariate effect of reverse digit span (Small $M = 0.61$, Medium $M = 0.67$, High $M = 0.69$) was not realised independently $F(2, 20) = 2.30$, $p = .126$ ns, $\eta_p^2 = .19$ and this did not differ according to handedness $F(2, 20) = 0.83$, $p = .452$ ns, $\eta_p^2 = .08$. Additionally there was no interaction with Task Type $\Lambda = .77$, $F(2, 20) = 3.02$, $p = .072$ ns, $\eta_p^2 = .23$ or Number of Categories $\Lambda = .91$, $F(2, 20) = 1.04$, $p = .372$ ns, $\eta_p^2 = .09$; the interaction between these two repeated measures factors also remained the same regardless of digit span score $\Lambda = .89$, $F(2, 20) = 1.24$, $p = .311$ ns, $\eta_p^2 = .11$.

3.4.2 Switch cost

For the Continuous Series II task there was a significant effect of Number of Categories (see Table 15), on switch cost, Λ = .11, *F*(2, 23) = 97.29, *p* = .0001, η_p^2 = .89, confirmed as significant at all levels, CS2$_{\mathbf{cost}}$ to CS3$_{\mathbf{cost}}$, *t*(25) = -10.49, *p* = .0001, *r* = 0.90, 95% CI (-19.67 – -13.21); CS2$_{\mathbf{cost}}$ to CS4$_{\mathbf{cost}}$, *t*(25) = -14.46, *p* = .0001, *r* = 0.94, 95% CI (-29.30 – -21.99); CS3$_{\mathbf{cost}}$ to CS4$_{\mathbf{cost}}$, *t*(25) = -8.32, *p* = .0001, *r* = 0.85, 95% CI (-11.48 – -6.93).

Again there was no significant independent effect of handedness over the three levels of the Continuous Series II task, *F*(1, 24) = 0.004, *p* = .95 ns, η_p^2 = 0001, and no significant interaction with the Number of Categories, Λ = .92, *F*(2, 23) = 1.05, *p* = .365 ns, η_p^2 = .08.

Table 15 Descriptive Statistics for Switch Cost (% w/sec increase) on Continuous Series II and Mixed Category Tasks for Left and Right Handed Monozygotic Twins (group N = 26).

		Continuous Series II			**Mixed Category task**	
		2-cats	**3-cats**	**4-cats**	**2-cats**	**3-cats**
Switch cost (% increase)						
Left handed	*Mean*	62.00	77.12	87.76	71.41	79.37
	SD	6.74	6.70	4.40	8.12	5.20
Right handed	*Mean*	61.05	78.81	86.59	74.93	78.33
	SD	10.60	8.42	5.40	6.24	6.80

L-H cost: *M* = 72.48, *SE* = 1.48
L-H CS cost: *M* = 69.56, *SE* = 2.01
L-H MX cost: *M* = 75.39, *SE* = 1.52
L-H 2-cat cost: *M* = 66.71, *SE* = 1.82
L-H 3-cat cost: *M* = 78.25, *SE* = 1.57

R-H cost: *M* = 73.28, *SE* = 1.48
R-H CS cost: *M* = 69.93, *SE* = 2.01
R-H MX cost: *M* = 76.63, *SE* = 1.52
R-H 2-cat cost: *M* = 67.99, *SE* = 1.82
R-H 3-cat cost: *M* = 78.57, *SE* = 1.57

Cross task comparisons indicated switch cost to be significantly higher for the mixed task, $\Lambda = .55$, $F(1, 24) = 19.98$, $p = .0001$, $\eta_p^2 = .45$ and to increase in line with Number of Categories, $\Lambda = .22$, $F(1, 24) = 87.11$, $p = .0001$, $\eta_p^2 = .78$, with a significant interaction between the two presenting as a much greater effect of increasing the number of categories for CS, as seen in Figure 6, $\Lambda = .45$, $F(1, 24) = 29.98$, $p = .0001$, $\eta_p^2 = .56$.

Once again handedness failed to have a significant independent effect, $F(1, 24) = 0.15$, $p = .703$, $\eta_p^2 =.01$ and did not significantly interact with task type $\Lambda = .99$, $F(1, 24) = 0.10$, $p = .759$, $\eta_p^2 = .004$ or number of categories $\Lambda = .99$, $F(1, 24) = 0.17$, $p = .688$, $\eta_p^2 = .01$. The interaction between these last two factors did not differ for handedness $\Lambda = .88$, $F(1, 24) = 3.71$, $p = .079$, $\eta_p^2 = .12$.

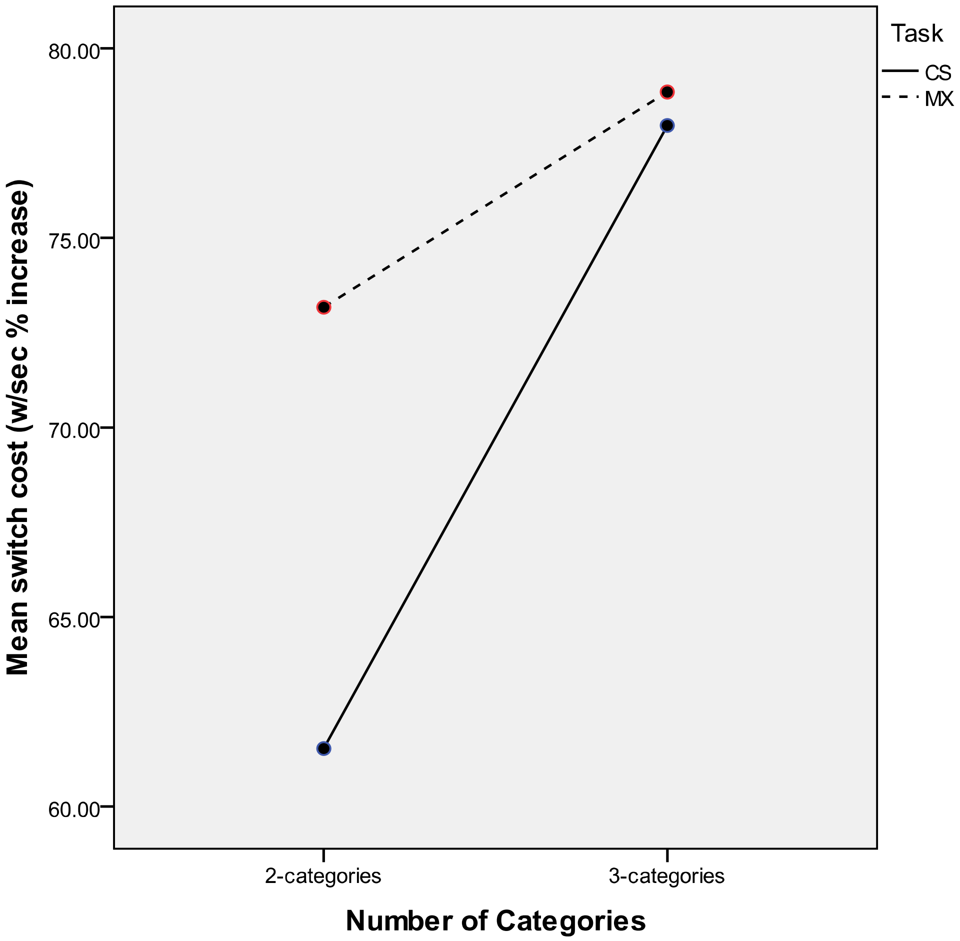

Figure 6 Switch cost interaction of task type (Continuous Series II and Mixed Category task) and number of switching categories (2 and 3) for whole twins sample (N = 26)

3.4.3 Within category errors

For Continuous Series II the number of within category errors (see Table 16) made when switching between 2-categories was significantly greater for right handed participants $U = 43.00$, $z = -2.6$, $p = .012$, $r = .51$, but there was no significant difference for handedness over 3-categories $U = 72.50$, $z = -0.62$, $p = .550$ ns or 4-categories $U = 80.50$, $z = -0.21$, $p = .849$ ns. Errors on the Mixed Category task did not differ according to handedness for either 2-categories $U = 62.50$, $z = -1.23$, $p = .230$ or 3-categories $U = 78.50$, $z = -0.31$, $p = .769$. Overall 62.71% of within-category errors were perseverative (65.31% right handers and

59.49% left handers) and 37.29% were sequencing (34.69% right handers and 40.51% left handers).

3.4.4 Between category errors

Left-handed participants made no between category errors during the Continuous Series II, with right handers producing errors over three and four categories. However, the difference between the two groups was found to be non-significant at both difficulty levels: 3-categories U = 78.00, z = -1.00, p .762; 4-categories U = 71.50, z = -1.44, p = .511. For 4-cateogory switching 66.66% of errors were sequencing and 33.34% errors of omission.

On the Mixed Category task, between category errors were observed to increase in line with Number of Categories for the left handed group but decreased for the right handed group; however, the number of errors made was not found to be significantly different between the two groups for either 2-categories U = 78.50, z = -0.56, p = .989 or for 3-categories U = 77.50, z = -0.65, p = .740.

Table 16 Within and Between Category Errors (Sum, N, Minimum and Maximum Scores) for Left and Right Handed Monozygotic Twins (Group N = 26).

		Continuous Series II			**Mixed Category task**	
		2	**3**	**4**	**2**	**3**
Within category errors						
Left	*Sum*	1	43	79	34	74
	N	1	9	11	8	11
	Mean	0.8	3.31	6.08	2.62	5.69
	SD	0.28	3.77	5.06	3.60	6.13
Right	*Sum*	16	54	100	23	87
	N	7	10	11	4	10
	Mean	1.23	4.15	7.69	1.78	6.69
	SD	1.48	4.12	7.91	3.40	8.06
Between category errors						
Left	*Sum*	-	-	-	2	5
	N	-	-	-	1	2
	Mean	-	-	-	0.15	0.38
	SD	-	-	-	0.56	1.12
Right	*Sum*	-	1	5	3	1
	N	-	1	2	2	1
	Mean		0.08	0.38	0.23	0.08
	SD		0.28	1.12	0.60	0.28

3.4.5 Analysis of non-target utterances

All test sessions for both tasks were transcribed and were initially analysed using content analysis. Non-target utterances were classified according to 4 pre-determined definitions – evidence of Memory Lapse (e.g. “I can’t remember what comes next”), evidence of Rehearsal (e.g. “Days come next”), evidence of a Correction (e.g. “No, I meant Tuesday”) and Other (e.g. “This is difficult”).

For the Continuous Series II initial comparison of the values for the four utterance types using a Friedman’s ANOVA showed that there was a significant difference between them, $\chi^2(3) = 11.03$, $p = .012$. Post-hoc comparisons using the Wilcoxon signed ranks test (with a Bonferroni adjusted α of .008) showed that none of the individual comparisons were significant at this more stringent significance level. As Correction utterances and Other utterances scored only 2 and 1 responses respectively it was decided to exclude these from any further analysis and concentrate instead on just Memory and Rehearsal utterances. A Wilcoxon signed ranks test comparing these showed the difference between these two not to be significant, *T* = 4.42, *p* = .624.

Responses following utterances for the Continuous Series II were classified as correct, self-corrections or errors. For memory and rehearsal utterances no self-corrections were returned. Comparison of Correct and Error responses for Memory utterances showed that there was no significant difference, *T* = 4.50, *p* = .157. Comparison of Correct and Error responses for Rehearsals showed that there was a significant difference, *T* = 4.50, *p* = .026, with far more correct subsequent responses than errors.

There was no significant difference for any measures when comparing between handedness for the Continuous Series II. Using Mann-Whitney tests there was no significant difference between memory utterances, *U* = 7.00, *p* = .480, no significant difference between rehearsal utterances, *U* = 5.00, *p* = .248, no significant difference between correct responses following a memory utterance, *U* = 9.00, *p* = .988, between errors following a memory utterance, *U* = 5.50, *p* = .317, between correct responses following a rehearsal, *U* = 6.00, *p* = .414 or errors following a rehearsal, *U* = 6.00, *p* = .157.

Table 17 Descriptive Statistics for Non-Target Utterances in the Continuous Series II.

	Utterances				**Post-utterance responses**			
	Mem	Reh	Corr	Other	Mem_{corr}	Mem_{err}	Reh_{corr}	Reh_{err}
Whole sample								
Mean	1.56	1.22	0.22	0.33	0.56	1.00	1.67	0.11
SD	1.13	1.48	0.44	1.00	0.73	0.71	1.32	0.33
Sum	14	11	2	3	5	9	15	1
N	9	4	2	1	4	6	6	1
Left handers								
Mean	2.00	2.00	0.67	0.00	0.67	1.33	2.00	0.33
SD	1.73	1.73	0.58	*	1.16	0.58	1.73	0.58
Sum	6	6	2	0	2	4	6	1
N	3	2	2	0	1	3	2	1
Right handers								
Mean	1.33	0.83	0.00	0.5	0.5	0.83	1.5	0.00
SD	0.82	1.33	*	1.23	0.55	0.75	1.23	*
Sum	8	5	0	3	3	5	9	0
N	6	2	0	1	3	4	4	0

Mem = memory Reh = rehearsal Corr = correction/ correct Err = error

* = non-calculable due to constancy

For the Mixed Category task initial comparison of the values for the three utterance types (no corrections were returned) using a Friedman’s ANOVA showed that there was a significant difference between them, $\chi^2(3) = 28.45$, $p < .0001$. Post-hoc comparisons using the Wilcoxon signed ranks test (with a Bonferroni adjusted α of .002) showed that there was a significant difference between Rehearsal and Memory, $T = 2.00$, $p = .002$ with there being more Rehearsal utterances than Memory and a significant difference between Other and Rehearsal $T = 7.58$, $p = .004$ with there again being significantly more Rehearsals.

Responses following utterances for the Mixed Category task were classified again as correct, self-corrections or errors. For memory and rehearsal utterances no self-corrections were returned. Comparison of Correct and Error responses for Memory utterances showed that there was no significant difference, $T = 4.80$, $p = .366$. Comparison of Correct and Error responses for Rehearsals showed that there was a significant difference, $T = 2.00$, $p = .003$, with far more correct subsequent responses than errors (see Table 18).

In comparing handedness there is only one significant difference, between errors following rehearsal utterances with left-handers scoring more errors than right handers, who scored zero (see Table 18), $U = 3.50$, $p = .004$. The rest of the comparisons are non-significant: memory utterances $U = 21.50$, $p = .674$, rehearsal utterances, $U = 18.00$, $p = .401$, correct responses following a memory utterance, $U = 23.00$, $p = .827$, errors following a memory utterance, $U = 17.50$, $p = .254$ and correct responses following a rehearsal, $U = 23.50$, $p = .895$.

Table 18 Descriptive Statistics for Non-Target Utterances in the Mixed Category Task.

	Utterances			**Post-utterance responses**			
	Mem	Reh	Other	Mem_{corr}	Mem_{err}	Reh_{corr}	Reh_{err}
Whole sample							
Mean	0.79	3.43	0.36	0.50	0.29	2.79	0.64
SD	0.70	2.03	0.84	0.65	0.47	1.72	1.08
Sum	11	48	5	7	4	39	9
N	9	13	3	6	4	13	6
Left handers							
Mean	0.71	3.86	0.29	0.57	0.14	2.57	1.29
SD	0.76	1.77	0.49	0.79	0.38	0.98	1.25
Sum	5	27	2	4	1	18	9
N	4	7	2	3	1	7	6
Right handers							
Mean	0.86	3.00	0.43	0.43	0.43	3.00	0
SD	0.69	2.31	1.13	0.54	0.54	2.31	*
Sum	6	21	3	3	3	21	0
N	5	6	1	3	3	6	0

Mem = memory Reh = rehearsal Corr = correction/ correct

4 Discussion

Task speech rate, switch cost and number of errors for both tasks followed the same pattern as for Experiment 1, in that performance deteriorated as the task became more difficult. The Mixed Category task produced slower task speech rate and greater switch cost than the Continuous Series II – there was greater disparity between 2-category and 3-category switching for the Continuous Series II on both measures, with the Continuous Series II exhibiting a seeming advantage for 2-category switching and cost measures for both tasks converging at the 3-category difficulty level, though this convergence must again owe something to the degree of advantage for the Continuous Series II over 2-categories. Comparative paucity of errors for the Continuous Series II was again noticeable over 2-categories (over three times fewer than for the Mixed Category task). Left and right handers did not display any significant difference for either rate or cost. Switch cost for the two tasks shows an almost identical pattern as seen in Experiment 1 with greater cost for the Mixed Category task again seemingly attributable to the additional domain switch (Gurd et al., 2003).

Right handers were more error prone in some conditions than left handers on the Continuous Series II. Within-category errors again followed the pattern of increasing with task difficulty for both tasks – right handed participants made significantly more within-category errors over 2-categories for the Continuous Series II. Number of errors again increased with difficulty for the Mixed Category task but with no significant difference between left and right handers. Although left-handed participants had the advantage in that the committed no between-category errors on the Continuous Series II, this difference was found to be non-significant. Between-category errors were found to increase with task difficulty for the left handers but decrease for the right handers during the Mixed Category task, although no significant difference was found between them at either difficulty level. On Continuous Series II 4-category switching most within category errors were perseverative, whereas just over a third were sequencing errors. Again no between-category errors were perseverative, with sequencing errors accounting for two thirds and the rest being omission errors. The lack of between-category perseveration again confirmed that participants were always able to switch task, unlike Arbuthnott and Frank (2000) where most errors of this type indicated a failure to switch. Clearly inhibition of the previous task is more successful in the verbal paradigm than for the two-choice decision tasks (made relating to letters, digits and symbols) in the Arbuthnott and Frank (2000) study. In the PDP model proposed by Gilbert and Shallice (2002) perseveration was avoided by ensuring each trial did not start with task demand units in the same state as the preceding trial; the continuous switching of tasks would seem to be an implementation of this facility. Each 'trial' in the PDP model can be equated to a switch from one task to the next in the verbal paradigm which must necessitate starting at a different point – the preceding task is never repeated and the upcoming one must always be different. Perseveration *within* a task can occur as memory for the last state of that item fails to update but this never translates to perseveration *between* tasks as a switch must occur at every response as each switch (trial) requires a different state to the one previously delivered. Each switch acts as a 'place holder' for a new task but the nature of the item produced within that task is subject to memory for the last item produced for that category.

There is a slight advantage for the left handed group in terms of errors in the Continuous Series II. That this advantage did not present itself during the Mixed Category task is surprising as studies which have identified asymmetric language lateralisation have used semantic categorisation tasks rather than tasks utilising overlearned sequences (e.g.

Sommer et al., 2002). However, the answer may relate to internal representation of the sequential overlearned sequence categories. All task ‘runs’ (although switching is continuous the sequence of 2, 3 or 4-categories has a beginning point which becomes embedded within the continuous cycle) begin with the category ‘numbers’, which are known to be represented spatially from left to right (Fias & Fischer, 2005) and are subject to the SNARC effect (Dehaene et al., 1993) whereby numbers and responses have parity leading to improved RT along a low-high/ left-right number line. There is evidence of the influence of handedness in the SNARC effect, with left handers showing the effect (in a number parity task) which was absent in right handers (Fischer, 2008); this study further found that finger tapping contributed to the spatial representation of numbers. ‘Tapping’ in mid air or counting using the fingers of one hand are common occurrences during the more difficult levels of the Continuous Series II. It may therefore be possible that left handers have an advantage in the numbers-led sequence of the Continuous Series II in that they are better able to ‘anchor’ the sequence. Experiment 4 in Chapter 6 looks in more detail at the effect of category order in determining switch cost and error rates.

Additionally, as previously noted, there is evidence that the frontal cortex can divide goal maintenance in dual task conditions (Charron & Koechlin, 2010). The areas involved in this (the medial and lateral frontal cortices) are particularly relevant for intentional reconfiguration; the left APC is also implicated in semantic encoding in language tasks (Posner et al., 1988). Language is known to be involved in switching outside of the verbal paradigm by means of self instruction which Monsell (2005) says supports reconfiguration. If language is right or bi-lateralised in the left handed twins then there may be a temporal advantage between right hemisphere processing of overlearned sequences (Pariyadath et al., 2008) and frontally-mediated reconfiguration, resulting in fewer within-category errors and no between-category errors for the left handed twins. That the advantage is seen in error production but not switch cost would tie in with task related semantic features rather than relating to switching; thus the left handed group have an advantage for task production but not switching. Work completed since the current study was carried out concurs with the finding of no behavioural Continuous Series II differences (rate or switch cost) for left and right handed twins (Gurd & Cowell, 2013). That study used a larger sample of 25 twin pairs, suggesting that the current findings are not simply due to a smaller sample size. The current study can confidently propose that there is no RT difference in task switching between left and right handed twins.

The change in within-category errors (between-category errors being rare in all instances) from 2 to 3-category switching is much steeper for the Continuous Series II with errors increasing almost six-fold – errors increase threefold for the Mixed Category task; this would undoubtedly account for some of the advantage at the 2-category level. However, the much faster task speech rate for Continuous Series II 2-category switching, around three times as fast as for the Mixed Category task, must reflect more than the difference of 40 in error production at this level and more than the double-switch ‘disadvantage’ for the Mixed Category task. Previous work (Gurd, 1995) used a rate measure of seconds per word rather than words per second, finding less of a pronounced difference from 2 to 3-category switching. Gurd and Oliveira (1996) using a words per second measure had results more on a par with the current study. It is possible that the configuration of the categories facilitated easier switching as several participants appended a date suffix to the numbers responses in the 2-cateogry switching condition, although when questioned none were conscious of having done this. If the sequence were being thought of in some way as a date this could have provided a more concrete implicit cue than the task sequence alone; implicit cues as presented by task sequence remain relatively unattended (Koch, 2008) and anything facilitating this affect could have reduced switch cost. Again, this phenomenon is further explored in Experiment 4, Chapter 6.

The question remains – why was there no advantage for left-handed twins when one was so strongly indicated? Clearly there is no right-hemisphere temporal advantage in having language lateralised to the same side as overlearned sequence processing. There is of course the possibility that not all left-handed twins were right-hemisphere lateralised for language. One study using fMRI, for example, shows only 10% of 50 left handed individuals tested to be fully right-hemisphere lateralised with a further 14% showing bilateral activation (Pujol, Deus, Losilla & Capdevila, 1999). While right lateralisation is more prevalent it is certainly not universal. It could be that the contribution of the left hemisphere is more implicit in task switching and so right-hemisphere language/ overlearned sequence lateralisation can only have a limited effect. Higher costs have been shown in left-PFC damaged than right-PFC damaged patients (Mecklinger et al., 1999) but it is not possible to extrapolate this from the contribution of impaired left-hemisphere language function. Other work has linked left frontal damage to impaired top-down control of task set and right frontal damage to impaired inhibition of the previous task set (Aron, Monsell, Sahakian & Robbins, 2004). If the Continuous Series II is under the control of active reconfiguration then left-frontal mediated top-down control would be implicit to the task. The concentration of processing in the right hemisphere may not be such an advantage as first foreseen as the task is not fully 'right-sided'.

Finally, there was again no effect of handedness when examining non-target utterances and their subsequent responses – the only difference found was that left-handed twins scored a total of 9 errors after a rehearsal whereas the right-handed twins scored no errors. If anything the advantage would have been predicted for the left handed twins, in line with the right-hemisphere advantage and general processing advantage outlined in the introduction. It is unclear why left-handed twins should commit more post-rehearsal errors, nor why this should be the only area of difference. Looking at the sample as a whole there are marked effects of the type of utterance made. For the Continuous Series II, while there was a general difference (although not identified pairwise) between the types of utterances made, there was a definite benefit of committing a rehearsal utterance – these were far more likely to be followed by a correct response. For the Mixed Category task there were significantly more rehearsal than memory lapse utterances and again these were far more likely to lead to a subsequent correct response. It would seem, therefore, that rehearsal utterances are reflecting and enhancing inner speech, which is used as a self-cueing device – according to Monsell (2005) such verbal self-instruction assists in reconfiguration of task set. Interfering with self-instruction has been shown to have a detrimental effect on switching (Goschke, 2000) but verbalisation concurrent to the task does not have such an effect. The current experiment looked at the effect on subsequent responses rather than switch cost (measures of general switch cost are not informative about subsequent time-based performance) but undoubtedly errors are more time consuming (particularly for the Continuous Series II, see ‘Discussion’ in Experiment 1). The time taken to make the utterance of course adds to general cost, but if this is in accordance with inner speech then is likely to be no more time consuming overall, being merely an external manifestation of preparation and reconfiguration processes. Overt verbal rehearsal would not be considered to relate to the task-set inertia (TSI) hypothesis (Allport, Styles & Hsieh, 1994) as overt rehearsal reflects the *updating* of a category or item rather than the endurance of the preceding one – it is an active progressive process. Thus the current findings would concur with Monsell (2055) that verbalisation reflects active reconfiguration and demonstrates that such processes can still have a beneficial effect when they occur spontaneously rather than as an instructed process. Although Monsell (2003) states that benefits from verbalisation would disappear with practice they would apply to the Continuous Series II as it is a very novel and unpractised task.

5 Conclusion

- Despite the small sample size and ensuing low power there is confidence in the findings due to the duplicate findings with a larger sample size from Gurd & Cowell (2013)
- The verbal switching tasks seem to offer a reliable method of measuring costs using continuous real time switching with increasing levels of difficulty; the Mixed Category task is costlier due to an additional switch between verbal domains as well as tasks.
- Inhibition of previous task, as evidenced by the absence of perseverative between-category errors, was consistently successful when switching between verbal tasks; the majority of errors are task related and so not indicative of switching processes.
- The sample may not be sufficiently right hemisphere lateralised for language or the left hemisphere may be more integral for top-down control, indicating the Continuous Series II is more related to a reconfiguration account of switching and there is no right hemisphere advantage. Consequently there is no support for hypotheses 1, 2 or 3

which all predicted an advantage for left-handed (right hemisphere dominant) participants.

- In support of hypothesis 4 (that rehearsal utterances would result in fewer subsequent errors), non-target utterances that reflect rehearsal for the task seem to mirror inner speech rehearsal and have a beneficial effect on subsequent responses. This is again indicative of reconfiguration processes.

CHAPTER FIVE: EXTENSION OF DIFFICULTY LEVELS FOR THE MIXED CATEGORY SWITCHING TASK AND ASSESSMENT OF ASYMMETRY

1 Introduction

This chapter describes comparison of the Continuous Series II and mixed task, this time using the novel Mixed Category II task which is extended to include a four category switching condition. This allows for further investigation of the convergence between the two tasks at the 3-category switching level, as seen in Experiments 1 & 2. Three-category Mixed Category switching was more heavily biased towards semantic categories (semantic-overlearned-semantic). If errors in semantic categories were more quickly recovered from (by virtue of their lack of sequence positioning) then 3-category switching for the mixed task may not provide a true picture of mixed switching costs. Two further issues relating to the tasks are also considered. One is the phenomenon noticed (but not commented on) in the first two experiments of within-category errors mostly occurring within the category ‘days’, particularly as difficulty increases. Stimuli rather than switch related explanations are considered. The second issue considers possible explanations of switch cost in verbal task switching. Because the Mixed Category II task utilises tasks of differing difficulty it is possible to see whether there are differential times costs (asymmetric or otherwise) between semantic categories (harder task) and overlearned sequences (easier task). This might emphasise inertial effects already implicit to the task.

1.1 Contributory factors to 'days' producing the greatest number of errors

It has previously been noted with the Continuous Series II that within-category errors are far more likely to occur within the category 'days'. In Experiment 1 'days' produced significantly more errors than the other categories in 3- and 4-category switching. In Experiment 2 this occurs only for 4-category switching. There seem to be two obvious sources for this error weighting. Either something about the category itself attracts more errors, or the category's position within the task run may contribute to this. That this does not occur at every level of switching might suggest some combinatory effect – the level of difficulty may also be contributing. The position of the category is addressed in Experiment 4, Chapter 6 – a full answer to the question will not be possible until then. However, the issue of error distribution is formally addressed within this chapter – literature relating to the features of the category is addressed here.

Recently Kray, Karbach & Blaye (2012) utilised a small stimulus set size (*N* = 4), with the assumption that this would result in stronger task-stimulus priming, increasing the need for control. Rogers & Monsell (1995) previously stated that use of small sets of stimuli[66] actually resulted in stronger associations between cues, attributes of the stimuli and responses than would be found with larger sets. The assumption was that stronger associations would impair the ability to reconfigure task set, resulting in greater cost. Looking at error rates, Kray and colleagues found that the small set size did indeed require more control as it produced worse conflict adaptation[67] during repeat trials and larger interference costs for some

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[66] Common in developmental studies to make the task easier.

[67] Conflict adaptation was measured using the Gratton effect (Gratton, Coles & Donchin, 1992) whereby interference costs are smaller following incompatible than compatible trials. The effect is explained by the need to exert more control to ignore irrelevant information. More attention is therefore directed towards to subsequent trial, resulting in less interference (e.g. as described by Botvinick, Braver, Barch, Carter & Cohen, 2001

participants[68]. In the Continuous Series II the category ‘days’ contains only 7 stimuli, compared 12 for ‘months’, 26 for ‘letters’ and a far greater number for ‘numbers’. Given the assumption that greater control is needed for a smaller set size, it might follow that this would also result in more errors. Braver, Cohen & Barch (2002) concur that in situations requiring greater cognitive control more errors are committed. Reactive control, part of the DMC dual mechanism account (e.g. Braver, Reynolds & Donaldson, 2003; Braver & Hoyer, 2008) involves error monitoring after the fact (Alexander & Brown, 2010). Commission of an error is followed by longer RT (Laming, 1979) – error commission therefore involves greater subsequent control. Thus it could be that the greater number of errors in the category ‘days’ is caused by the small set size. This could occur at only the more difficult levels due to greater demands on cognitive control.

1.2 Asymmetry and the mixed category task

The Mixed Category II task allows for comparison of tasks of differing difficulty Semantic category production is more effortful and requires inhibition of past responses (Kellett et al., 2011), thus there is potential for transient inhibition to be a source of cost in the Mixed Category II task. This would be in the absence of bivalency (one stimulus affording two task responses) but would exclude the additional source of cost that bivalency brings, important in considering general switch cost. The current study calculates ‘local’ cost, not for individual responses but for individual categories within the task i.e. general cost for each category individually. Although inhibition would not be at the same level for univalent stimuli, there is still the potential that it would occur. Some descriptions of task switch cost cite relative differences in task activation as the source of asymmetry (e.g. Yeung & Monsell, 2003). Asymmetry is most readily associated with tasks that afford competing responses but

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[68] The sample was made up of children and young adults

some portion of the effect is related to the differing levels of difficulty and the differing involvement of control processes. More effortful (semantic) task production could well endure and affect overlearned sequence production by virtue of differing difficulty.

2 Hypotheses

1. Following previous results, performance for both tasks will deteriorate as the task becomes more difficult.
2. Similarly following Experiments 1 & 2, the Mixed Category II task will be more costly than the Continuous Series II – this will be particularly noticeable in 4-category switching.
3. In both tasks the greatest number of errors will occur in the category days, relating perhaps (but not exclusively) to the smaller category set size.
4. There will be a difference in local switch cost (cost per individual category) between semantic categories and overlearned sequences. It is not clear whether inertial effects will be present, so no directional prediction is made.

3 EXPERIMENT THREE

3.1 Method

3.1.1 Design

The study was a repeated measures 2 x 3 design for the assessment of Task Speech Rate (w/sec) and Switch Cost (% w/sec increase), with factors of Task Type (CS, MX) and Number of Categories (2, 3, 4). Local Switch Cost for individual categories was compared *within* each of the difficulty levels using a single factor of Category Type with 2, 3 and 4 levels as appropriate, to assess the relative contribution of categories at different levels of difficulty. Within and between category errors, localised error production (errors per Category Type) and self corrections were assessed variously as single factors of 2 or 3 levels within Task Types (CS, MX) appropriate to the distribution of the data.

3.1.2 Participants

The sample (n = 33, 27 females) was made up of undergraduate psychology students from the University of Hertfordshire, who received course credit for taking part, and individuals recruited from outside the University, who received no reward for their participation. All were right handed native English speakers, screened according to the criteria set out in Chapter 2. Demographic and background test results are given in Table 19. From the originally recruited sample of 39, four were excluded from the final analysis for failing to complete at least 70% of the task at all stages; two were excluded due to very low scores for NART (approx. 70 predicted IQ) suggesting undisclosed non-compliance with screening criteria. All participants were right handed native English speakers and had been screened according to the criteria set out in Chapter 2.

Table 19 Descriptive Statistics of Demographic and Background Measures for Cross Task (N = 33), and Mixed Category II Task (N = 20) Samples.

		Age	**NART**	**WAIS-R vocab.**	**Digit span forward**	**Digit span reverse**	**Conv. speech (w/sec)**
Cross task							
(N = 33)	*Mean*	22.61	102.00	10.94	6.94	5.39	2.64
	SD	6.13	7.28	2.32	1.32	1.06	0.59
Local cost							
MX (N = 20)	*Mean*	22.30	103.55	10.80	7.25	5.55	2.51
	SD	5.71	7.21	2.22	1.25	1.10	0.57

Twenty participants from Experiment 3 (see Table 19) were included in the analysis of local switch cost for the Mixed Category II task, with five excluded from the original sample due to between category error production and eight excluded due to corrupted or faulty audio files.

3.1.3 Stimuli

The Continuous Series II task was presented as detailed for Experiments 1 and 2. The Mixed Category task was extended to include a four-category switching level of difficulty (with number of iterations per level remaining the same as for the Continuous Series II), using categories from the discarded Verbal Fluency task, with category order and starting points as stated below:

2-cats = Vehicles + Months *(Free + July)*

3-cats = Clothing + Numbers + Fruit *(Free + 7 + Free)*

4-cats = Occupations + Days + Animals + Letters *(Free + Wednesday + Free + M)*

3.1.4 Calculation of local switch cost

Production time for each word in a category was calculated from the end of the previous word to the end of the target word. Words were timed manually using XNote digital stopwatch software version 1.6[69] and Audacity 1.2.6[70] to allow for more accurate determination of word form boundaries; time was measured three times for every word and the mean of these three measures was used. The production time for each word in a category[71] was added up to give the total category production time. Errors, self corrected responses (both justified and erroneous) and any responses accompanied by non-target utterances (e.g. “Have I already said that?”) were removed from the analysis as this additional word production clearly inflated the time taken to produce a response. Participants who made between-category errors were excluded from this analysis as switching could no longer be differentiated as occurring between pure ‘easier’ and ‘harder’ tasks. Switch cost was calculated using *single category* values of non-switching and switching w/sec rate:

$$\frac{\text{Category non-switching w/sec rate} - \text{category switching w/sec rate}}{\text{Category non-switching w/sec rate}} \times 100 = \%\ \text{switch cost}$$

3.2 Procedure

Background measures were administered to participants as for Experiment 1; the Continuous Series II and Mixed Category II tasks were administered as for previous experiments, with the exception that a 4-category switching condition was presented for the Mixed Category II task, in exactly the same way as for the Continuous Series II. Presentation of both tasks was counterbalanced.

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[69] Produced by dnSoft Research Group

[70] http://audacity.sourceforge.net

[71] $n - 1$ for the first category as the first word had no preceding word to start timing from.

3.3 Data Analysis

3.3.1 Data distribution

Age and both digit span measures (see Table 19 for means) were non-normally distributed in the whole sample ($N = 33$): Age $W(33) = 0.70$, $p = .0001$, with 55% of the sample aged 19 or 20 years, as expected from a student population. Forward digit span $W(33) = 0.89$, $p = .003$ presented over twice as many scores of 6 and 8 than the median score of 7; reverse digit span $W(33) = 0.88$, $p = .001$ showed 45% of the sample scoring at 5 digits. Although not normally distributed these scores were within clinically normal expectations (Lezak et al., 2004).

Task speech rate for the full sample was non-normally distributed for: $\mathrm{CS4}_{\mathbf{rate}}$ $W(33) = 0.87$, $p = .001$, positive skewness (attributable to a single participant scoring at 0.64 w/sec) $z = 3.52$, $p =$, evidence of leptokurtosis (peaking at 0.25-0.35) $z = 2.95$, $p =$ and $\mathrm{MX3}_{\mathbf{rate}}$: $W(33) = 0.88$, $p = .002$, positive skewness (single score of 0.54 w/sec at top end) significant $z = 3.19$, $p = .002$, with the rest of the distribution for both variables observed to follow normal expectations. Both measures were deemed acceptable for inclusion in parametric analyses and were not transformed.

All whole-sample switch cost measures were normally distributed, with the exception of $\mathrm{MX4}_{\mathbf{cost}}$ $W(33) = 0.88$, $p =.002$, negative skewed by two participants scoring at 84.82% and 84.90%, $z = 3.18$, $p = .002$ but otherwise observed to look normal and included in parametric analyses. All variables included in the *local* switch cost analyses for both tasks

(CS *N* = 18, MX *N* = 20) were normally distributed using a α level of .01 for the Shapiro-Wilk's test.

Within category errors (*n* = 33) were non-normal for: CS2 $_{\textbf{within}}$ *W*(33) = 0.58, *p* = .0001, positive skewness *z* = 6.00, *p* < .0001 , and with a leptokurtic distribution *z* = 7.97, *p* < .0001and for CS3 $_{\textbf{within}}$ *W*(33) = 0.82, *p* = .0001, skewness *z* = 4.32, *p* < .0001 , kurtosis *z* = 4.75, *p* < .0001. Such errors for CS were analysed non-parametrically. For the MX task MX2 $_{\textbf{within}}$: *W*(33) = 0.78, *p* = .0001, skewness was significant *z* = 4.03, *p* = .0001with two top-end scores of 5 and 6 but otherwise appearing normal and acceptable for parametric analysis. No between category errors were made for either task at the 2-category level and all other measures of this variable were non-normal using α = .01 and so analysed non-parametrically. Both right and wrong self-corrections (no wrong self-corrections were made for CS2) were non-normally distributed for all levels of both tasks using α = .01 and again were analysed non-parametrically. Variables relating to the total number of errors made in each category at each level of difficulty were non-normal (α = .01) for CS2 and CS3, and for all except the third category in CS4; all were analysed non-parametrically. All errors-per-category variables were non-normal (α = .01) for the MX task with the exception of MX2 and were analysed non-parametrically.

3.3.2 Statistical tests

Task speech rate and switch cost for both the full sample and local cost sub-sample were analysed over 2, 3 and 4 categories using GLM repeated measures ANOVA. Within category errors on the tasks were analysed using a Friedman's ANOVA and GLM repeated measures ANOVA, according to the distribution of the variables; between-category errors for both tasks used the Wilcoxon signed ranks test. The analysis of errors according to category position and self corrections both used Friedman's ANOVA.

All ANOVA/ ANCOVA results are reported using Wilk's lambda. Effect sizes are reported using partial η^2, interpreted as .01 = small, .06 = medium and .14 = large (Cohen, 1988). Error rates (within and between category errors) were analysed using the non-parametric Friedman's ANOVA and Wilcoxon signed-ranks test, with effect size reported as *r*, interpreted as .10 = small, .30 = medium and .50 = large (Cohen, 1988).

Significance levels for post-hoc contrasts made using t-tests or Wilcoxon signed ranks tests were appropriately adjust (see Experiment 1 Methods). All non-parametric significance levels are exact measures; for Wilcoxon signed ranks tests this is indicated in the text as one or two-tailed as appropriate. Effect size *r* was calculated as: t-tests, $\surd\ ((t^2 \div (t^2 + df))$; Wilcoxon signed ranks, test statistic $Z \div \surd$ number of observations.

3.3.3 Descriptive and preliminary statistics

All variables followed predictable patterns of decreased performance as the number of switching categories increased, with the MX task resulting in slower and more costly in-task speech (see Table 20).

NART IQ correlated significantly with forward digit span, $r = .35$, $p = .044$ and $r = .35$; both digit span measures correlated with each other, $r = .67$, $p = .0001$. For Task Speech Rate, age correlated with $\text{MX2}_{\textbf{rate}}$ $r = .39$, *p* (all correlational significance levels were two-tailed) = .027; NART IQ correlated with all but one measure, $\mathrm{CS2}_{\mathbf{rate}}$ *r* = .38, *p* = .028, $\mathrm{CS3}_{\mathbf{rate}}$ *r* = .54, *p* = .001, $\mathrm{CS4}_{\mathbf{rate}}$ *r* = .35, *p* = .046, $\mathrm{MX2}_{\mathbf{rate}}$ *r* = .49, *p* = .004, $\mathrm{MX4}_{\mathbf{rate}}$ *r* = .40, *p* = .023. $\mathrm{CS4}_{\mathbf{rate}}$ also correlated with forward and reverse digit spans, *r* = .45, *p* = .009 and *r* = .42, *p* = .015 respectively; NART IQ was entered as a potential covariate for both Task Speech rate measures.

For Switch Cost, NART IQ correlated with $\mathrm{CS3}_{\text{cost}}$ *r* = -.50, *p* = .003, $\mathrm{CS3}_{\text{cost}}$ *r* = -.35, *p* = .048 and $\mathrm{MX2}_{\text{cost}}$ *r* = -.55, *p* = .001. Forward digit span correlated with all but one cost measure, $\mathrm{CS2}_{\text{cost}}$ *r* = -.47, *p* = .005, $\mathrm{CS3}_{\text{cost}}$ *r* = -.42, *p* = .014, $\mathrm{CS4}_{\text{cost}}$ *r* = -.60, *p* = .0001, $\mathrm{MX2}_{\text{cost}}$ *r* = -.38, *p* = .029, $\mathrm{MX3}_{\text{cost}}$ *r* = -.38, *p* = .029; reverse digit span correlated with $\mathrm{CS2}_{\text{cost}}$ *r* = -.42, *p* = .005, $\mathrm{CS4}_{\text{cost}}$ *r* = -.44, *p* = .010, $\mathrm{MX2}_{\text{cost}}$ *r* = -.45, *p* = .009, with forward span indicated as a covariate for cost.

Within-category errors for the MX task only correlated with forward digit span at a single level, $\mathrm{MX4}_{\text{within}}$ *r* = -.41, *p* = .018 and so no covariates were entered. Forward digit span also only correlated with a single level of CS4 local errors, $\mathrm{CS4}_{\text{errors 1st}}$ *r* = -.42, *p* = .015, again not suggesting the need for a covariate analysis.

For the Continuous Series II local cost analysis (*N* = 20) forward and reverse digit span (see Table 19) again correlated, *r* = .62, *p* = .006. Forward digit span correlated with $\mathrm{CS2}_{\text{errors 1st}}$ *r* = -.50, *p* = .033, $\mathrm{CS4}_{\text{errors 3rd}}$ *r* = -.69, *p* = .002 and $\mathrm{CS4}_{\text{errors 4th}}$ *r* = -.61, *p* = .007 – this was no considered consistent enough for inclusion as a covariate.

For the Mixed Category II task local switch cost analysis ($N = 18$) the digit span measures correlated with each other, $r = .58$, $p = .007$. Normal speech rate was found to correlate with both MX2 local cost measures, $\text{MX2}_{\text{errors 1st}}$ $r = .49$, $p = .037$, $\text{MX2}_{\text{errors 2nd}}$ $r = -.53$, $p = .024$ and two of the MX3 measures, $\text{MX3}_{\text{errors 2nd}}$ $r = -.55$, $p = .017$, $\text{MX3}_{\text{errors 3rd}}$ $r = -.54$, $p = .022$ and was included as a covariate at both levels.

3.4 Results

3.4.1 Task speech rate

Task Speech Rate was significantly slower for task MX than for CS (see Table 20 for means), $\Lambda = .05$, $F(1, 32) = 547.87$, $p = .0001$, $\eta_p^2 = .95$; rate also decreased in line with the Number of Categories increasing (see Table 20 for means), $\Lambda = .04$, $F(2, 31) = 344.19$, $p = .0001$, $\eta_p^2 = .96$, with contrasts showing this to be significant both from 2-categories to 3-categories, $F(1, 32) = 323.232$, $p = .0001$, $\eta_p^2 = .91$ and from 3-categories to 4-categories, $F(1, 32) = 323.232$, $p = .0001$, $\eta_p^2 = .91$. There was a significant interaction between Task Type and Number of Categories, $\Lambda = .04$, $F(2, 31) = 333.86$, $p = .0001$, $\eta_p^2 = .96$. Contrasts revealed the difference in Task Speech Rate between Number of Categories to also be consistently significantly different when comparing the two tasks (CS & MX), 2-categories to 3-categories $F(2, 31) = 462.68$, $p = .0001$, $\eta_p^2 = .94$ and 3-categories to 4-categories $F(2, 31) = 79.18$, $p = .0001$, $\eta_p^2 = .71$.

Table 20 Descriptive Statistics for Task Speech Rate (w/sec) and Switch Cost (% w/sec increase) on Continuous Series II and Mixed Category II Tasks (N = 33).

	Continuous Series II			**Mixed Category task**		
	2-cats	**3-cats**	**4-cats**	**2-cats**	**3-cats**	**4-cats**
Task Speech rate (w/sec)						
Mean	1.27	0.58	0.33	0.32	0.28	0.21
SD	0.22	0.19	0.10	0.07	0.08	0.04
Switch cost (% increase)						
Mean	64.66	82.10	91.02	82.41	85.54	91.23
SD	7.12	6.67	3.30	3.90	4.22	2.40

CS rate: M = 0.73, SE = 0.03
MX rate: M = 0.27, SE = 0.10
2-cat rate: M = 0.79, SE = 0.02
3-cat rate: M = 0.43, SE = 0.02
4-cat rate: M = 0.27, SE = 0.01

CS cost: M = 79.26, SE = 0.90
MX cost: M = 86.39, SE = 0.52
2-cat cost: M = 73.54, SE = 0.88
3-cat cost: M = 83.82, SE = 0.87
4-cat cost: M = 91.13, SE = 0.45

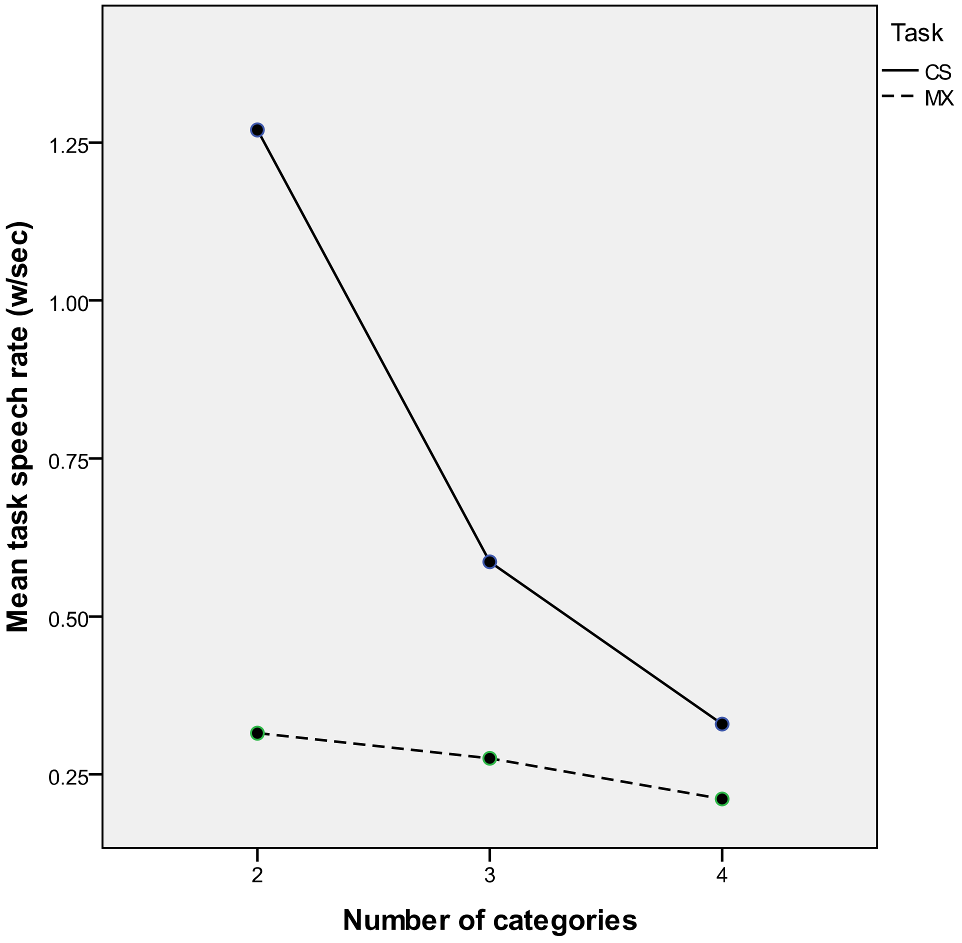

Figure 7 ***Task speech rate (w/sec) at increasing levels of task difficulty (2, 3 and 4 switching categories) for Continuous Series II and Mixed Category II tasks (N = 33)***

For the purposes of controlling for covariance, NART IQ was stratified into a categorical variable, Low (scores 86 – 98, *N* = 13, *M* = 95.08), Medium (scores 100 – 105, *N* = 10, *M* = 102.70), High (scores 106 – 118, *N* = 10, *M* = 110.30), allowing it to be entered as an independent measures variable as detailed in Chapter 2. There was an independent effect of the NART IQ covariate on Task Speech Rate, *F*(2, 30) = 5.38, *p* = .010, η_p^2 = .26. There was also some interaction with the factor of Task Type, Λ = .81, *F*(2, 30) = 3.46, *p* = .044, η_p^2 = .19, although none with Number of Categories, Λ = .77, *F*(4, 58) = 2.04, *p* = .101 ns, η_p^2 = .12. The previously identified interaction between Task type and Number for categories did not differ according to NART IQ, Λ = .78, *F*(4, 58) = 1.94, *p* = .115 ns, η_p^2 = .12. The overall pattern was interpreted as NART IQ level relating to semantic category production in the Mixed Category II task.

3.4.2 Switch cost

Once again there was a significant effect of both Task Type (see Table 20 for means), Λ = .18, *F*(1, 32) = 147.38, *p* = .0001, η_p^2 = .82 and Number of Categories (see Table 20), Λ = .04, *F*(2, 31) = 367.70, *p* = .0001, η_p^2 = .96 on Switch Cost, with further contrasts confirming that Number of Categories had a consistently significant effect on Switch Cost, 2-cats to 3-cats *F*(1, 32) = 243.83, *p* = .0001, η_p^2 = .88 and 3-cats to 4-cats *F*(1, 32) = 168.47, *p* = .0001, η_p^2 = .84. Both factors again produced a significant interaction, Λ = .08, *F*(2, 31) = 183.12, *p* = .0001, η_p^2 = .92; while this was again significant across both Difficulty Level transitions, 2-cats to 3-cats *F*(1, 32) = 227.83, *p* = .0001, η_p^2 = .88 and 3-cats to 4-cats *F*(1, 32) = 16.39, *p* = .0001, η_p^2 = .34 there was a much reduced effect size when switching from 3-cats to 4-cats. Figure 8 shows that, unlike the Task Speech Rate transition, cost for both tasks converges when switching over 4-cats.

Forward digit span was entered as a covariate for Switch Cost, with similar scores clustered together as Low (scores 5-6, N = 15, M = 5.67) and High (scores 7-9, N = 18, M = 8.00). The independent effect of forward digit span on Switch Cost was just within significance but with a low effect size, $F(1, 31) = 4.30$, $p = .047$, $\eta_p^2 = .12$. Again the covariate interacted with Task Type, $\Lambda = .87$, $F(1, 31) = 4.78$, $p = .037$, $\eta_p^2 = .13$, but not with Number of categories, $\Lambda = .93$, $F(2, 30) = 1.23$, $p = .308$ ns, $\eta_p^2 = .08$. The interaction between Task Type and Number of Categories did not differ according to forward digit span score, $\Lambda = .95$, $F(2, 30) = 0.87$, $p = .430$ ns, $\eta_p^2 = .06$. Again this appears indicative of a word production effect for the Mixed Category II task.

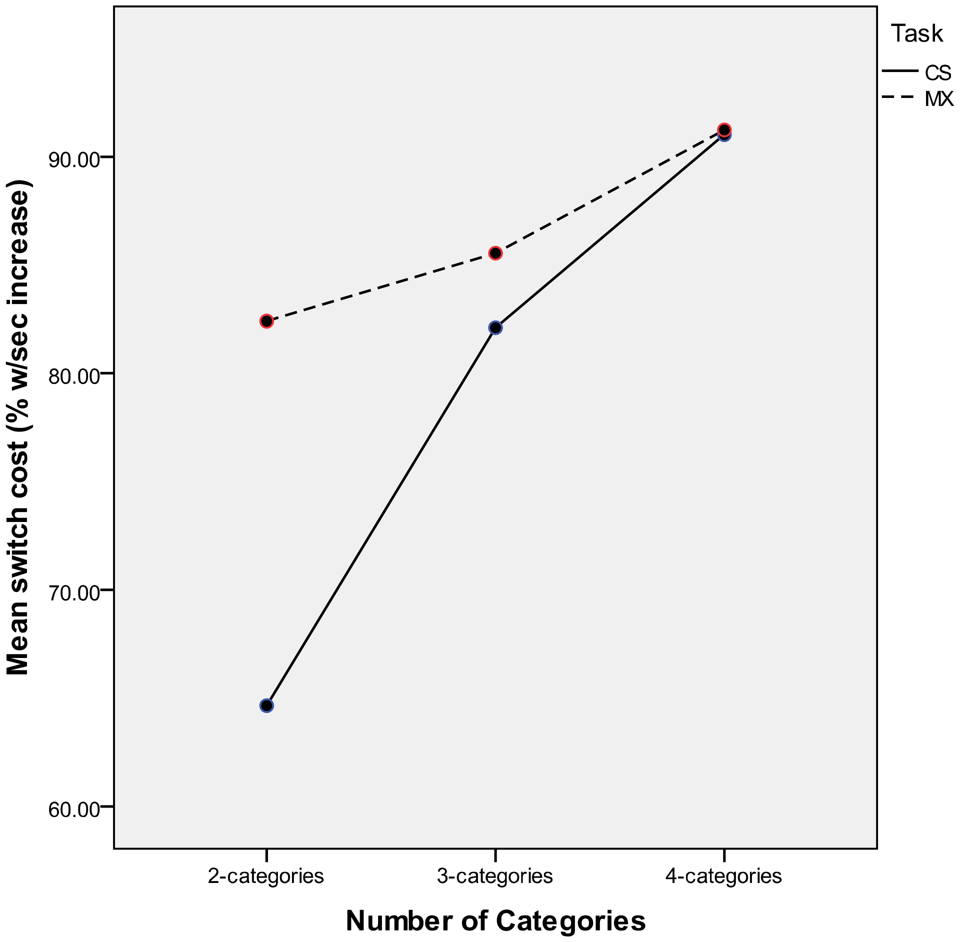

Figure 8 Switch cost (% w/sec increase) at increasing levels of task difficulty (2, 3 and 4 switching categories) for Continuous Series II and Mixed Category II tasks (N = 33)

3.4.3 Within category errors

A Friedman's ANOVA showed that for Continuous Series II there was a significant change in the number of within category errors (see Table 21) as the Number of Categories changed, χ^2 (2) = 59.86, *p* = .0001. Follow up Wilcoxon tests revealed this to be uniformly significant increase, CS2 to CS3, *T* = 16.50, *p* = .0001, *r* = -0.53, CS3 to CS4, *T* = 3, *p* = .0001, *r* = -0.61. For the Continuous Series II 68.56% of within-category errors were perseverative and 31.44% were sequencing.

Table 21 Within and Between Category Errors at each Level of Difficulty (2, 3 or 4 Categories) for Continuous Series II and Mixed Category II Tasks (N = 33).

		Continuous Series II			**Mixed Category task**		
		2	**3**	**4**	**2**	**3**	**4**
Within category errors							
	Sum	16	122	393	43	75	176
	N	10	28	33	22	28	31
	Mean	0.48	3.70	11.91	1.30	2.27	5.33
	SD	0.94	3.85	4.44	1.51	1.53	3.22
Between category errors							
	Sum	-	1	29	-	9	12
	N	-	1	5	-	4	4
	Mean	-	0.03	0.88	-	0.27	0.36
	SD	-	0.17	2.34	-	0.84	1.14

A GLM repeated-measures ANOVA indicated a significant effect of Number of Categories on within-category errors for the Mixed Category II task, Λ = .42, *F*(2, 31) = 21.88, *p* = .0001, η_p^2 = .59, increasing significantly at all levels, 2-cat to 3cat *F*(1, 32) = 8.79, *p* = .006, η_p^2 = .22 and 3-cat to 4-cat *F*(1, 32) = 36.38, *p* = .0001, η_p^2 = .53. Overall 75.78% of within-category errors were perseverative and 24.22% were sequencing.

3.4.4 Between category errors

Wilcoxon signed ranks tests showed that the number of errors produced during 3-cat and 4-cat switching increased significantly for Continuous Series II, CS3 to CS4 $T = 1.50$, $p = .023$, $r = -0.26$ but not for the Mixed Category II task, MX3 to MX4 $T = 12$, $p = .398$, $r = -0.04$. For the Continuous Series II over 4-categories 97.14% of errors were sequencing and 2.86% were omissions – for the Mixed Category II task 91.67% were sequencing and 8.33% omissions.

3.4.5 Analysis of errors according to category type

Total errors per Category type were not analysed for Continuous Series II 2-category switching as both categories returned a total of eight errors. Error distribution for 3-category switching (see Table 22) changed significantly between categories χ^2 (2) = 14.07, $p = .001$; this was confined to Days_{2nd} being significantly higher than Numbers_{1st} $T = 17.50$, $p = .001$, $r = -0.41$, with both Months_{3rd} and Numbers_{1st} $T = 75.50$, $p = .652$ ns, $r = -0.06$ and Months_{3rd} and Days_{2nd} $T = 82.50$, $p = .027$ ns, $r = -0.03$ being non-significant[72].

Four-category switching again showed a significant difference in errors per category χ^2 (3) = 12.96, $p = .004$, with Days_{2nd} producing significantly more errors than all other categories: Days_{2nd} and Numbers_{1st} $T = 53$, $p = .0001$, $r = -0.43$, Days_{2nd} and Months_{3rd} $T = 94.50$, $p = .011$, $r = -0.31$, Days_{2nd} and Letters_{4th} $T = 65$, $p = .001$, $r = -0.39$. All other contrasts were non-significant: Numbers_{1st} and Months_{3rd} $T = 204$, $p = .561$ ns, $r = -0.07$,

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[72] Holm's sequential Bonferroni adjustment

Numbers_{1st} and Letters_{4th} $T = 192$, $p = .804$ ns, $r = -0.03$, Months_{3rd} and Letters_{4th} $T = 182$, $p = .639$ ns, $r = -0.06$.

Table 22 Total Errors made (Within and Between Category) occurring in each Category at each Difficulty Level (2, 3 or 4 Categories) for Continuous Series II (N = 33).

	Continuous Series II								
	2-cats		**3-cats**			**4-cats**			
	Num.	**Day.**	**Num.**	**Day.**	**Mon.**	**Num.**	**Day.**	**Mon.**	**Let.**
Total errors									
Sum	8	8	27	59	37	93	140	100	91
Mean	0.24	0.24	0.82	1.79	1.12	2.82	4.24	3.03	2.76
SD	0.44	0.66	1.01	1.85	1.92	1.47	1.82	2.30	1.99

Num. = numbers; **Day.** = days; **Mon.** = months; **Let.** = letters

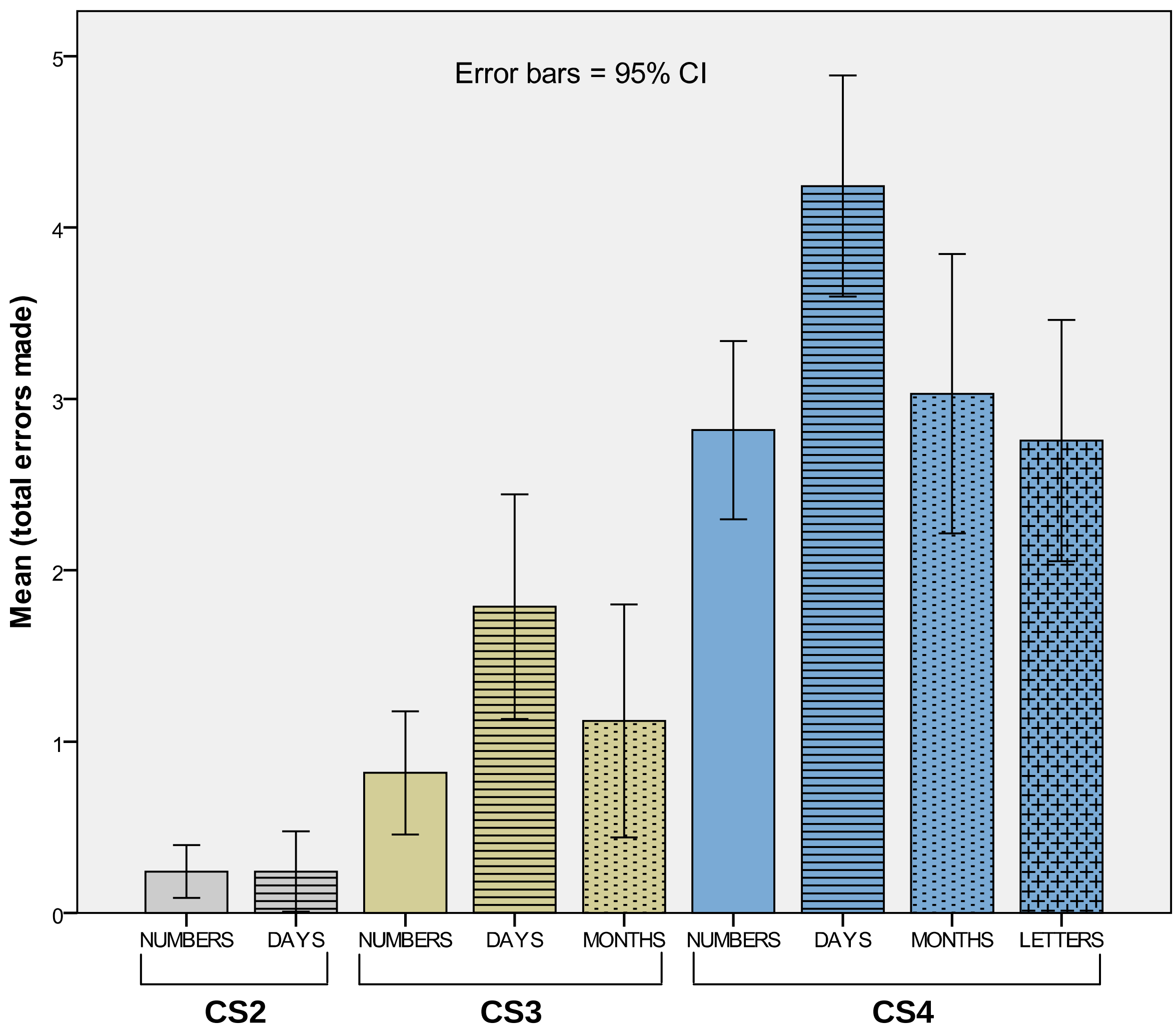

Figure 9 Mean total errors per category type for each difficulty level (2, 3 and 4 categories) for Continuous Series II (N = 33)

Table 23 Total Errors made (Within and Between Category) occurring in each Category at each Difficulty Level (2, 3 or 4 Categories) for Mixed Category II Task (N = 33).

	Mixed Category task								
	2-cats		**3-cats**			**4-cats**			
	Veh.	**Mon.**	**Clo.**	**Num.**	**Fru.**	**Occ.**	**Day.**	**Ani.**	**Let.**
Total errors									
Sum	15	28	16	46	21	9	100	18	64
Mean	0.45	0.85	0.48	1.39	0.64	0.27	3.03	0.55	1.94
SD	0.97	1.25	0.67	1.20	1.11	0.52	1.65	0.94	1.78

Veh. = vehicles; **Mon.** = months; **Clo.** = clothing; **Num.** = numbers; **Fru.** = fruit; **Occ.** = occupations; **Ani.** = animals; **Let.** = letters

For the Mixed Category II task there was no significant difference during 2-category switching, $T = 79$, $p = .208$ ns, $r = -0.16$. The difference in error distribution showed a significant change during 3-category switching, χ^2 (2) = 11.75, $p = .002$, with Numbers$_{2nd}$ producing a significantly higher number of errors than either Clothing$_{1st}$ $T = 32$, $p = .0001$, $r = -0.41$ or Fruit$_{3rd}$ $T = 60.50$, $p = .004$, $r = -0.28$; there was no significant difference between Clothing$_{1st}$ and Fruit$_{3rd}$ $T = 64$, $p = .570$, $r = -0.06$. There was a significant change in errors according to Category Type during 4-category switching, χ^2 (3) = 64.48, $p = .0001$, with only Occupations$_{1st}$ and Animals$_{3rd}$ showing a non-significant difference, $T = 25$, $p = .140$ ns, $r = -0.18$; Occupations$_{1st}$ and Days$_{2nd}$ $T = 0$, $p = .0001$, $r = -0.60$, Occupations$_{1st}$ and Letters$_{4th}$ $T = 0$, $p = .0001$, $r = -0.52$, Days$_{2nd}$ and Animals$_{3rd}$ $T = 3.50$, $p = .0001$, $r = -0.58$, Days$_{2nd}$ and Letters$_{4th}$ $T = 42$, $p = .001$, $r = -0.39$, Animals$_{3rd}$ and Letters$_{4th}$ $T = 29$, $p = .0001$, $r = -0.43$.

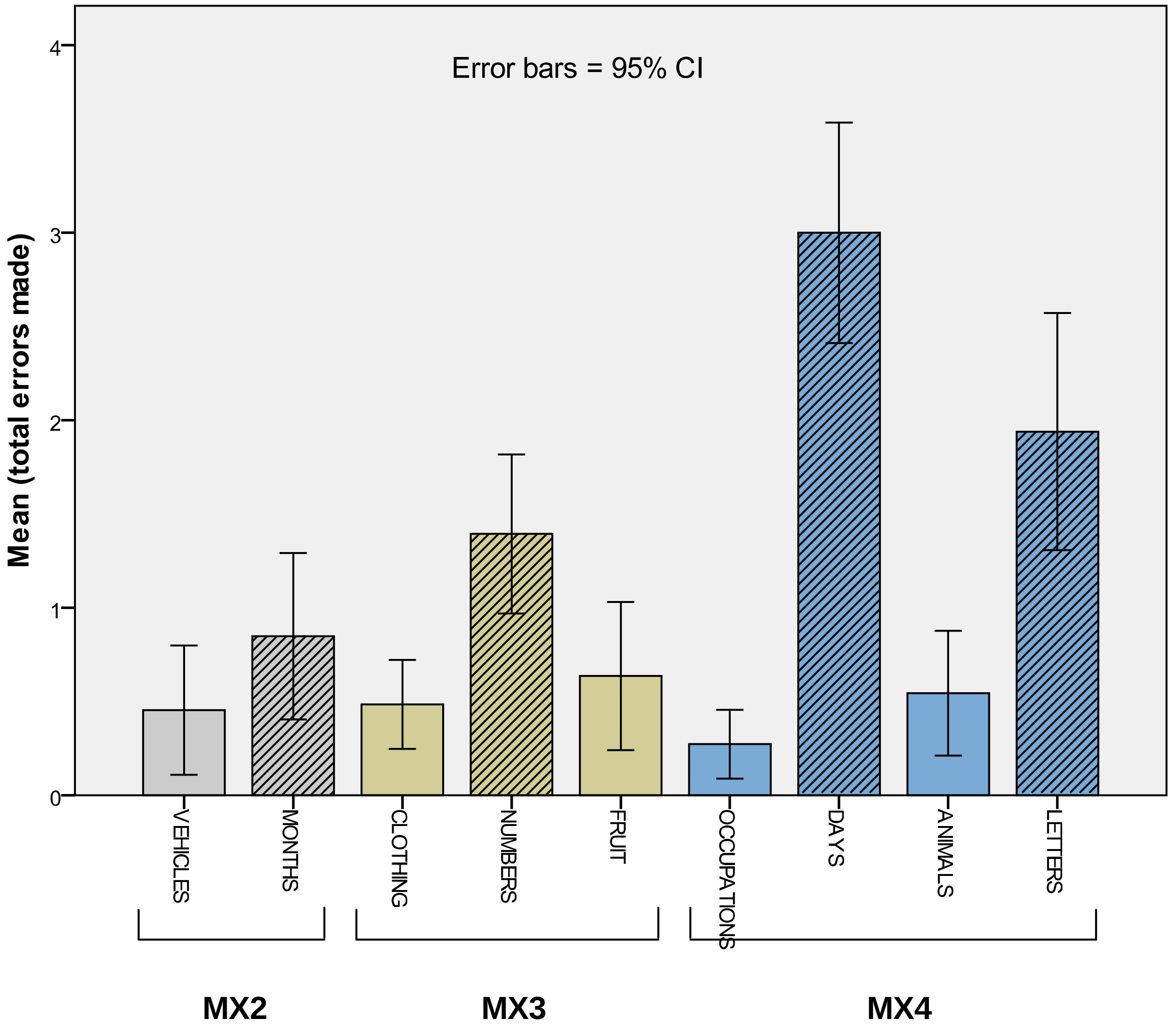

Figure 10 Mean total errors per category type for each difficulty level (2, 3 and 4 categories) for Mixed Category II task (N = 33)

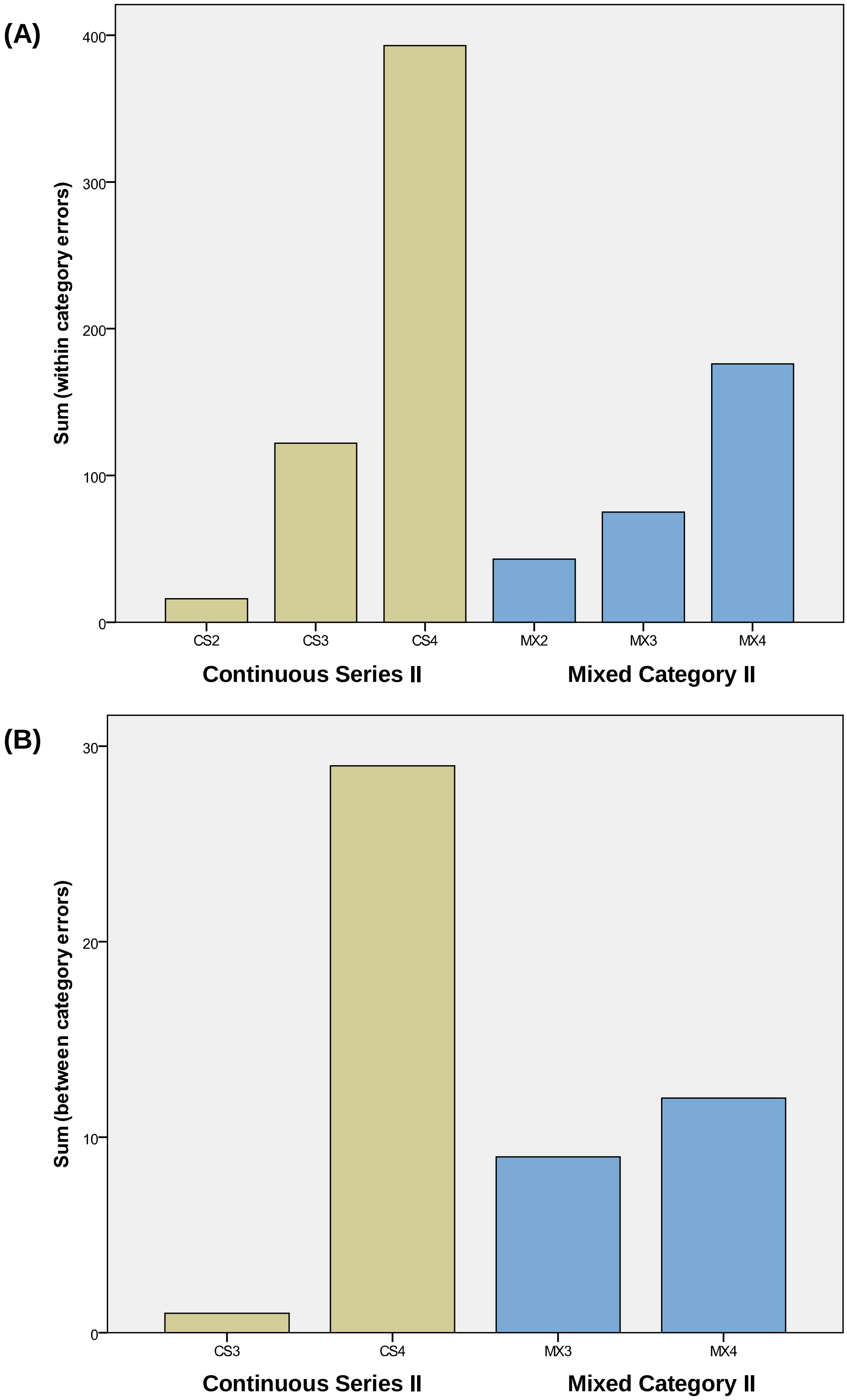

Figure 11 Sum within-category errors (A) and between-category errors (B) for the Continuous Series II and Mixed Category II tasks

3.4.6 Self-corrections

Self-corrections (SC) made by participants at each Difficulty Level of both tasks were observed to increase in line with the Number of Categories (as shown in Table 24) and be more prevalent for CS than MX; corrections were interpreted as justified (right) and erroneous (wrong) according to whether an error had actually been made. For the Continuous Series II a Friedman's ANOVA revealed this increase to be significant for SC_{right}, χ^2 (2) = 33.74, *p* = .0001 with all contrasts significant[73], CS2 to CS3 *T* = 0, *p* = .0001, *r* = -0.52, CS2 to CS4 *T* = 0, *p* = .0001, *r* = -0.52, CS3 to CS4 *T* = 46, *p* = .07, *r* = -0.30. No wrong corrections were made during CS2; a Wilcoxon signed ranks test showed the difference between CS3 and CS4 to be significant, *T* = 42, *p* = .027, *r* = -0.27.

A Friedman's ANOVA showed a significant change in SC_{right} according to Number of Categories for the Mixed Category II task, χ^2 (2) = 10.43, *p* = .005. These corrections were significantly greater during MX4 than either MX2 *T* = 45, *p* = .002, *r* = -0.35 or MX3 *T* = 18.50, *p* = .008, *r* = -0.30; there was no significant difference between MX2 and MX3 *T* = 68.50, *p* = .266 ns, *r* = -0.10. Wrong corrections exhibited a significant change as categories increased, χ^2 (2) = 8, *p* = .014, though only in the comparison of MX2 and MX4 *T* = 45, *p* = .008, *r* = -0.31, MX2 to MX3 *T* = 2, *p* = .500 ns, *r* = -0.07, MX3 to MX4 *T* = 8, *p* = .057, *r* = -0.22.

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[73] Wilcoxon signed ranks test significance reported as exact (1-tailed)

Table 24 Self-Corrections (Correct and Incorrect) made at each Difficulty Level (2, 3 and 4 Categories) during the Continuous Series II and Mixed Category II Tasks.

		Continuous Series II			**Mixed Category task**		
		2	**3**	**4**	**2**	**3**	**4**
Self-corrections							
Right	*Sum*	4	39	65	11	15	30
	Mean	0.12	1.18	1.97	0.33	0.45	0.91
	SD	0.42	1.38	1.86	0.54	0.67	1.04
Wrong	*Sum*	-	12	27	1	2	9
	Mean	-	0.36	0.82	0.03	0.06	0.27
	SD	-	0.70	1.21	0.17	0.24	0.57

3.4.7 Local cost comparison of overlearned sequences and semantic categories

For the Mixed Category II task a series of appropriately adjusted paired samples *t*-tests were initially carried out to compare single category speech rates (see Table 23) for each of the difficulty level baseline measures, in order to determine whether the semantic categories could be deemed more difficult than the overlearned sequence categories for the purposes of assessing asymmetry. With the exception of baseline category rates for Clothing and Fruit in 3-category switching, $t(32) = 0.84$, $p = .406$, all comparisons were found to be significantly different to an alpha value of .0001; semantic categories produced significantly fewer words than their corresponding overlearned sequence categories (see Table 23) and so were considered to be more difficult.

Table 25 Baseline Speech Production Rates (w/sec) for Constituent Categories of the Mixed Category II Task.

	Veh.	**Mon.**	**Clo.**	**Num.**	**Fru.**	**Occ.**	**Day.**	**Ani.**	**Let**
Baseline rate (w/sec)									
Mean	0.58	2.90	0.74	4.23	0.71	0.60	2.98	0.79	5.38
SD	0.11	0.39	0.14	0.15	0.17	0.13	0.45	0.13	1.25

Veh. = vehicles; **Mon.** = months; **Clo.** = clothing; **Num.** = numbers; **Fru.** = fruit; **Occ.** = occupations; **Ani.** = animals; **Let.** = letters

For the Mixed Category II task, during 2-category switching production of Vehicles$_{\mathbf{1st}}$ (switching to Months$_{\mathbf{2nd}}$) was significantly less costly than Months$_{\mathbf{2nd}}$ (switching to Vehicles$_{\mathbf{1st}}$) $t(17) = -6.00$, $p = .0001$, $r = 0.76$, 95% CI (2.05 – 5.17). During 3-category switching there was significant difference between the categories $\Lambda = .23$, $F(2, 16) = 27.49$, $p = .0001$, $\eta_p^2 = .78$, manifesting significantly[74] between Clothing$_{1st}$ (switching to Numbers$_{2nd}$) & Numbers$_{2nd}$ (switching to Fruit$_{3rd}$) $t(17) = -5.39$, $p = .0001$, $r = 0.79$, 95% CI (-20.12 – -8.80) and Numbers$_{2nd}$ (switching to Fruit$_{3rd}$) and Fruit$_{3rd}$ (switching to Clothing$_{1st}$) $t(17) = 6.87$, $p = .0001$, $r = 0.86$, 95% CI (15.09 – 28.47) but not between Clothing$_{1st}$ (switching to Numbers$_{2nd}$) & Fruit^{3rd} (switching to Clothing$_{1st}$) $t(17) = 2.14$, $p = .048$, $r = 0.46$, 95% CI (0.09 – 14.55).

Finally, 4-category switching again revealed a main effect of Category Type, $\Lambda = .04$, $F(3, 15) = 127.85$, $p = .0001$, $\eta_p^2 = .96$, with Letters$_{4th}$ (switching to Occupations$_{1st}$) being significantly more costly than all other categories, Letters$_{4th}$ (switching to Occupations$_{1st}$) & Occupations$_{1st}$ (switching to Days$_{2nd}$) $t(17) = -12.60$, $p = .0001$, $r = 0.95$, 95% CI (-23.67 – -

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[74] Using Holm's sequential Bonferroni adjustment the significance level of .048 for pair Clothing$_{2nd}$ and Fruit$_{3rd}$ was non-significant to the adjusted α level of .02

16.88), Letters_{4th} & Days_{2nd} *t*(17) = -5.14, *p* = .0001, *r* = 0.78, 95% CI (-4.87 – -2.04), Letters_{4th} (switching to Occupations_{1st}) & Animals_{3rd} (switching to Letters_{4th}) *t*(17) = -19.01, *p* = .0001, *r* = 0.98, 95% CI (-23.34 – -18.67). Days_{2nd} (switching to Animals_{3rd}) was similarly more costly than Occupations_{1st} (switching to Days_{2nd}) *t*(17) = -10.50, *p* = .0001, *r* = 0.93, 95% CI (-20.20 – -13.44) and Animals_{3rd} (switching to Letters_{4th}) *t*(17) = 14.82, *p* = .0001, *r* = 0.96, 95% CI (15.06 – 20.05). Cost for the Occupations_{1st} (switching to Days_{2nd}) and $\text{Animals}_{3rd\ was}$ (switching to Letters_{4th}) very similar *t*(17) = 0.42, *p* = .678 ns, *r* = 0.01, 95% CI (-2.93 – 4.40).

Normal speech rate was divided into clusters of similar scores, to facilitate use as an independent measures covariate: scores less than 2 w/sec (*N* = 4, *M* = 1.77), scores 2 to 2.50 w/sec (*N* = 5, *M* = 2.28), scores 2.51 to 3 w/sec (*N* = 5, *M* = 2.73), scores more than 3 w/sec (*N* = 4, *M* = 3.32). For 2-category switching normal speech rate accounted for none of the variance independently, *F*(3,14) = 1.66, *p* = .220 ns, η_p^2 = .26 but did interact with the repeated measures factor of Category Type, Λ = .41, *F*(3, 14) = 6.72, *p* = .005, η_p^2 = .59. Over 3-cateogry switching there was no evidence covariance independently from normal speech rate, *F*(3,14) = 1.18, *p* = .354 ns, η_p^2 = .20 and no interaction with Category Type, Λ = .51, *F*(6, 26) = 1.72, *p* = .157 ns, η_p^2 = .28.

Table 26 Local Switch Cost (% w/sec increase) per Category Type at each Difficulty Level (2, 3 or 4 categories) for Mixed Category II Task (N = 33).

	Mixed Category II task								
	2-cats		**3-cats**			**4-cats**			
	Veh. To Mon.	**Mon.** To Veh.	**Clo.** To Num.	**Num.** To Fru.	**Fru.** To Clo.	**Occ.** To Day.	**Day.** To Ani.	**Ani.** To Let.	**Let.** To Occ.
Local switch cost (% increase)									
Mean	51.38	75.23	68.98	83.44	61.66	72.41	89.23	71.68	92.68
SD	13.82	7.53	8.38	7.28	11.05	7.72	4.09	6.66	2.65
Min	24.53	56.22	45.00	62.27	37.74	55.32	78.28	56.71	86.25
Max	78.08	86.82	78.08	92.27	77.50	84.93	94.29	82.00	96.42

Veh. = vehicles; **Mon.** = months; **Clo.** = clothing; **Num.** = numbers; **Fru.** = fruit; **Occ.** = occupations; **Ani.** = animals; **Let.** = letters

Calculation of local cost for each category includes switching *to* the next category.

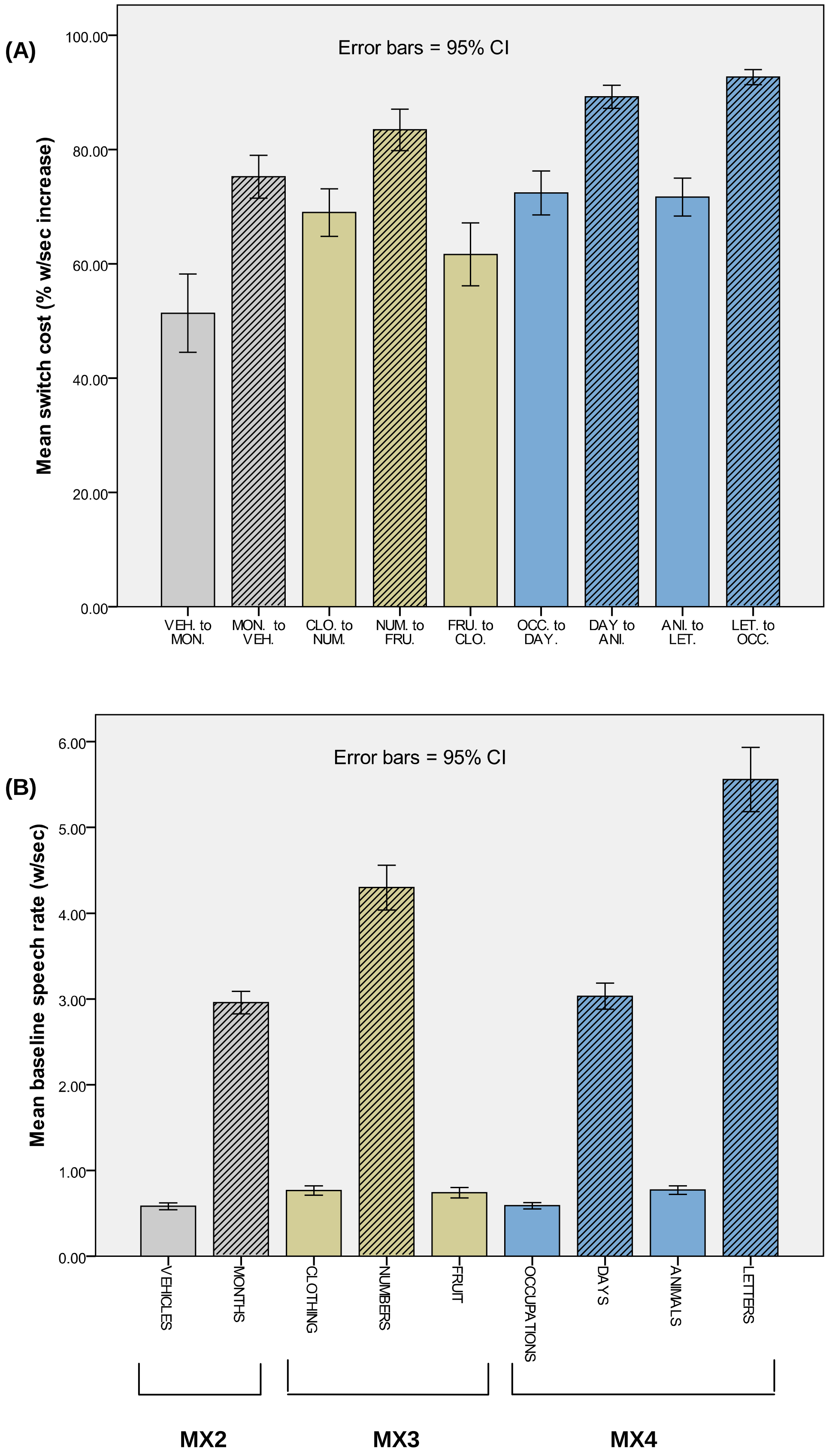

Figure 12 Mean local switch cost (A) per category type at all levels of task difficulty and baseline single category speech rate (B)

3.4.8 Comparison of constant categories over all difficulty levels

For the Continuous Series II the first two categories, Numbers and Days, were compared separately over all task difficulty levels to assess how their relative contribution changed in relation to difficulty. A GLM repeated measures ANOVA shows a significant difference between Numbers $_{\textbf{2-cats}}$ (*M* = 70.14, *SD* = 8.32), Numbers $_{\textbf{3-cats}}$ (*M* = 84.06, *SD* = 5.05) and Numbers $_{\textbf{4-cats}}$ (*M* = 89.62, *SD* = 4.19), Λ = .09, *F*(2, 16) = 85.49, *p* = .0001, η_p^2 = .91; paired-samples *t*-tests showed this to increase significantly with difficulty at all levels.

A second GLM repeated measures ANOVA showed the difference to also be significant between Days $_{\textbf{2-cats}}$ (*M* = 47.42, *SD* = 9.51), Days $_{\textbf{3-cats}}$ (*M* = 71.51, *SD* = 10.41) and Days $_{\textbf{4-cats}}$ (*M* = 83.77, *SD* = 7.80), Λ = .06, *F*(2, 16) = 123.63, *p* = .0001, η_p^2 = .94; paired-samples *t*-tests again showed this to increase significantly with difficulty at all levels.

4 Discussion

Task speech rate and switch cost for both tasks continued the pattern seen in the previous two experiments for 2 and 3-category switching. Rate reduced gradually over all levels of difficulty for the Mixed Category task; there was again evidence of a 2-category advantage for the Continuous Series II. Changes in cost appeared more dramatic than for rate in the Mixed Category II task when looking at the change from 3 to 4-category switching – both tasks converged to almost identical scores at 4-category switching. The lack of within-category errors over 2-category switching would again seem to offer only a partial explanation for the Continuous Series II 2-switch advantage. Two-category switching is once again far more efficient for Continuous Series II than Mixed Category II task, as assessed by RT related measures of rate and cost (see Figures 7 & 8). It is possible that there is a ceiling effect for the Mixed Category II task as degradation in speech rate is much more gradual than for the Continuous Series II – this would intuitively seem at least in part to be attributable to the contribution of the slower production rate (see Table 20) for semantic items. Rate itself does not to change very much across the varying difficulty levels in comparison to switch cost which accounts for the greater similarity (and reduced variance when compared to the Continuous Series II) in baseline non-switching rates per category.

Within-category errors for both tasks increased significantly as the tasks became more difficult, following the general pattern displayed in Experiments 1 and 2. The increase from 2 to 3-categories was much more pronounced for the Continuous Series II which increased seven-fold as oppose to doubling for the Mixed Category II task. The Mixed Category II task produced around half as many within-category errors as the Continuous Series II for 4-category switching. This reversal of previous results may mean that the difference is anomalous and perhaps related to the vocabulary of the sample in relation to semantic category errors. Only Experiment 2, which had an older sample, showed greater errors for the Mixed Category task – it is possible that greater executive impairment is causing more errors. Between-category errors for both tasks were absent over 2-categories; the Mixed Category II task produced more over 3-categories whereas the Continuous Series II produced more over 4-categories. The increased number of between-category errors at 3-categories for the Mixed Category II task could be due to the reconfiguration of semantic categories between this and the original version of the task. In the original task the category 'sports' led to a greater number of early cessations for the task at this level (though still within the 70% completion criterion) which gave less opportunity for errors to be made. Just over two-thirds of Continuous Series II within-category errors were perseverative, increasing to three-quarters for the Mixed Category II task. Again no between-category errors were perseverative – for the Continuous Series II nearly 100% were sequencing, dropping a little to around 90% for the Mixed Category II task. On the Mixed Category II task one participant made a sequencing error involving a category not present in the task at that difficulty level (4-categories) but which had been present at the last difficulty level; this would suggest for that individual at least there was evidence of enduring long term interference of the type posited by Wylie and Allport (2000) in their associative interference account.

For 3 and 4-category Continuous Series II switching the category 'days' produced far more errors than all other categories. It is not possible at this stage to determine whether this was a task related or switch related phenomenon. 'Days' was the shortest sequence – as well as the effect of reduced set size, increased repetition of items as they cycled round may have been compounded by the repeated suffix '-day'. Alternatively the position of the category in the task sequence may have had some affect on the production of errors (as addressed in

Experiment 4, Chapter 6). Increased errors could be due to the category ‘days’ in a difficult switching scenario or the position of the category in the sequence given that it was placed after the first switch. In more typical per-switch calculation of switch cost made for the alternating runs paradigm switch cost only increases in the first trial of a run (Rogers & Monsell, 1995). If the sequence of 3 or 4-categories can be considered equivalent to this task run then the category ‘days’ immediately follows the first switch of the sequence, although the beginning of the sequence is embedded in the continuous nature of the task. Switch cost for the individual categories (as discussed below) indicated that ‘days’ contributed the least cost at all difficulty levels, although this would not appear to be at a degree sufficient to indicate a speed-accuracy trade off (there was no significant difference from ‘months’). It is feasible that the reduced set size contributed to error production but this would surely have resulted in a concomitant increase in cost due to increased control, which was not seen. Therefore the increased number of errors would seem to be either due to an artefact of the stimuli (the repeated suffix) or the category’s position in the run after the first switch. Experiment 4 will shed more light on this issue.

The Mixed Category II task has only one occurrence of ‘days’ – all overlearned sequence categories produce more errors than semantic categories but ‘days’ produced most of all, although again it is placed second out of four categories so some combinatory effect could still be in evidence. At this stage it is unclear which explanation is more likely – further work on the Continuous Series II changing the placement of the category would need to be carried out to address this. Self-corrections were observed to increase as the task became more difficult. More self corrections were made during the Continuous Series II, presumably in line with the fact that more errors were made – this would also tie in with the fact that corrections of both types increased with difficulty. Most corrections made for both tasks were justified suggesting that conflict monitoring and resolution were for the most part successful.

As predicted, local cost (per category) for overlearned sequences and semantic categories differed in the Mixed Category II task. If local cost attributed to each category is taken as indicative of the switch *to* the next category (which is incorporated in the local cost score) then scores at all levels of difficulty for the Mixed Category II task show a pattern of reverse asymmetry whereby it is *less* costly to switch to the easier task. For example, for 2-category switching the lower cost associated with ‘vehicles’ indicates the faster time taken to switch *to* the category ‘months’ (see first bar on chart A, Figure 12). The overall pattern is one of taking less time to switch *to* the easier task which suggests that carryover of the last task set is not occurring to a degree that would present a problem for switching. As noted earlier the nature of the component tasks in the Mixed Category II task are not as likely to prompt continued activation of a now erroneous task set in the same way as Stoop-style stimuli as responses to semantic and overlearned sequence categories do not have the same degree of overlap as Stroop word/ colour naming. However, the lack of asymmetry using stimuli outside of that requirement is further evidence that a carryover account of switch cost may necessarily be limited to amenable stimuli. In keeping with Yeung and Monsell (2003, see page 29 of this document) it is possible that the ability for the harder task to carryover and interfere with the easier is just not present using the current stimuli.

As a caveat it should be noted that in calculation of local cost the production rate and consequently switch cost for each category includes both the inter-task gap (from end of category A to beginning of category B) during which time the switch is made to category B and production of the category B task itself– there is no distinction between the relative contributions of the two. Although for the purposes of assessing asymmetry the cost for the *previous* category is taken as indicative of the time taken to switch *to* the next one, the merging of both sources of cost should be noted when interpreting those switching-to results. Future analysis of any such results should seek to extract the inter-task gap in isolation from production cost of the previous category. The cost for category 'fruit' switching to 'clothing'[75] in 3-category switching (see Figure 12) would appear to buck the trend of reverse asymmetry as it is not significantly different from category 'clothing' switching to 'numbers' and may be indicative of a greater contribution made by the cost of the previous category, although it is possible that some task-specific feature of either of these two categories may have contributed to this anomalous result.

5 Conclusion

- In line with hypothesis 1, that difficulty would increase with the number of categories, rate, switch cost and general error production continued the pattern seen in the previous experiments, with the Mixed Category II task behaving in the same way as the Continuous Series II for 4-category switching.
- The Mixed Category II task was more costly than the Continuous Series II, in agreement with hypothesis 2.
- Errors again showed no perseveration between categories although repeating of items *within* categories was more widespread.
- In agreement with hypothesis 3, 'Days' produced more errors in the Continuous Series II, suggesting either a task-related artefact or some relation to first trial

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[75] From the end to the beginning of the 3-category iteration

confinement of switch cost, although the current structure of the task does not allow this to be probed further.

- In agreement with hypothesis 4, that there would be a difference between local cost for overlearned sequences and semantic categories, the Mixed Category II task displayed a reverse asymmetry for switch cost between the two types of verbal category. This suggested that TSI-type interference based explanations of switch cost do not lend themselves to continuous verbal switching of this type.

CHAPTER SIX: INVESTIGATION OF CATEGORY ORDER EFFECTS

1 Introduction

Chapter four investigates whether patterns of switch cost and error distribution seen in earlier experiments can be attributed as an artefact of task design. During Experiment 2 (and in previous presentations of the task (Essig, 2004)) participants were noted to append a date suffix to the category ‘numbers’ during switching[76] (this did not occur during baseline non-switching word production). It is possible that this may have facilitated switching by giving the sequence a more meaningful structure – meaningful material is easier to recall than arbitrary items or sequences (Craik & Lockhart, 1972) and as such both the sequence of categories and the position of individual items within those categories may have been easier to keep in memory. This could have expedited switch cost directly as well as reducing time taken recovering from errors, although Experiment 3 suggests that the contribution this makes to cost might be less than would be supposed. Certainly it could be one explanation of the apparent ‘2-switch advantage’ seen in the early stages of the task. Conversely, holding a representation of the task as a date sequence might also serve as a more explicit cue for the sequence with potentially negative effects. Koch (2008) has noted that sequence-related implicit cues remain relatively unattended, not requiring the additional processing associated with explicit cues (Logan & Bundesen, 2003). By reformulating the implicit sequence with additional date information it may be acting as a more explicit cueing device resulting in reprocessing of the ‘date cue’ at every iteration (acknowledging the date formulation and then

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[76] Some participants have been noted to do this, seemingly unknown to themselves, all the way through the task.

the specific ‘date’ that fits). This could result in losing the advantage of a single processing of the sequential task instruction at the beginning of the task (Logan & Schneider, 2006a).

Another feature seen in the earlier experiments was the phenomenon of errors being mostly committed in the second category of the task ‘days’. These would seem to be production errors rather than speech errors although it was unclear whether this pattern of errors was associated with the task (the category ‘days’) or the act of switching itself. Due to the shorter length of the sequence, ‘days’ are the most frequently occurring items within the task but (with the exception of ‘letters’ for which there is no data) the least frequently occurring of the categories in everyday language (Leech, Rayson & Wilson, 2001). However, the automatic rather than semantic nature of such speech categories should negate any frequency effects.

Also the potential ‘anchoring’ effect of the category ‘numbers’ discussed in Experiment 2 may have an additional function. Participants have commented that the non-cyclical (non-ending) nature of the category makes it easier to remember. This would also tie in with the supposition that the short sequence length of days may contribute to increased errors in that category. Coupled with the application by some participants of a date suffix it would seem prudent to assess the effect of moving ‘numbers’ to other positions in the category sequence.

Given that there is evidence for spatial representation of overlearned sequences (Gevers, Reynvoet & Fias, 2003, 2004; Previtali, de Hevia & Girelli, 2010), it is possible that the comparative length of the surface form of the various categories, single or double tokens for ‘letters’ and ‘numbers’ and longer for ‘days’ and ‘months’, may have had some effect on internal representation and subsequent production of the task. It is noted by Kleinsorge & Gajewski (2008) that theories relating to heavily stimulus driven switching do not account sufficiently for the role of internal representation of stimuli. The original Continuous Series II has single token categories occurring as the first and last in four-category switching, in effect placing them next to each other in the continuous loop of category production. If, as stated earlier (pages 56-57), there is some quasi-visuo-spatial element to the Continuous Series II then placement of categories according to surface length could have some bearing. The categories may be subject to some variation of the word length effect, given that both numbers and letters are visually, syllabically and phonemically shorter than the other two categories. The word length effect has been found to relate to syllables as well as visual length (Bireta, Neath & Suprenant, 2006). The word length effect (whereby short words are recalled better than longer words) traditionally relates to list recall (Cowan, Baddeley, Elliot & Norris, 2003; Hulme, Suprenant, Bireta, Stuart & Neath, 2004). However, in questioning after the Continuous Series II many participants state that they hold the categories in their mind’s eye in a visual list-like form. If task versions that separate visually short and long categories by interspersing them result in differences in switch cost or error production compared to the original task version then an argument can be made for a visual element to the verbal switching process. However, it is not predicted that the overall effect of decreasing performance in line with task difficulty will be negated, rather that some portion of costs might be attributable to task design.

2 Aims and Hypotheses

As the task order in the original version of the Continuous Series II was arbitrary, the possibility that task structure is in some way detrimental to its validity needs to be ruled out. The aim of the current experiment was to investigate any possible contribution to task costs from the structure of the task, specifically the order of categories within the overall sequence.

1. Rate, switch cost and error will follow the same pattern of performance deteriorating as the task becomes more difficult regardless of the task version.
2. Versions of the task with a ‘spatially separated’ task sequence (versions B, C & D) will provide a statistically significant difference in switch cost for 4-category switching from the original version due to their previous placement next to each other.
3. Versions of the task beginning with ‘numbers’ (versions A and B) will result in lower switch cost than other task versions.
4. There will be a difference in the number of within-category errors produced between the different categories regardless of task version. It is unclear whether the bias towards ‘days’ will remain as it cannot yet be determined whether this relates to a feature of the category itself or its position within the task. If the latter i.e. increased error load only occurs when ‘days’ is the second category, then potentially this relates to the first trial confinement of cost (Rogers & Monsell, 1995). In this instance the second category, regardless of contents, would always return the greatest number of errors.

3 EXPERIMENT FOUR

3.1 Method

3.1.1 Design

Speech rate (w/sec) and switch cost (% w/sec increase) were each analysed as a mixed 5 x 3 design, with a between-participants factor of Category Order (A, B, C, D or E – see Table 28 for a description of order variation) and a within-participants factor of Difficulty Level (2, 3 or 4 switching categories). Error distribution presented as a mixed 5 x 3 x 2 design, with the addition of Error Type (Within or Between categories). Additionally, all five variations of the task order were compared over 4-category switching only (as a 5 x 4 mixed design) to determine whether error production was related to either the position (factor Category Position (1, 2, 3 or 4)) or type of category (factor Category Type (Numbers, Days, Months or Letters)) within the task, as indicated by results from Experiment 3.

3.1.2 Participants

The sample (*N* = 115, females = 97) was recruited from the University of Hertfordshire; all participants were undergraduate or taught postgraduate students and received course credit for participation; all were right handed native English speakers, screened according to the criteria set out in Chapter 2. Of the original 133 tested, 6 were excluded from the final analysis due to production of an excessive number of between category errors, 2 due to very early discontinuation of the task, 5 due to subsequent disclosure of non-adherence to screening criteria and 5 due to low scores on background measures below the normal range. Demographic and baseline measures for the sample are given in

Table 27; a series of one-way ANOVAs showed no significant difference between groups on demographic measures.

Table 27 Descriptive statistics of Background Battery (NART predicted Full Scale IQ, WAIS-R Vocabulary sub-test, Forward and Backward Digit Span and Conversational Speech Eate) N = 115.

Group	Age	NART IQ	WAIS-R vocab.	Digit span forw.	Digit span backw.	Conv. speech rate
Group A (n = 21)						
Mean	24.38	102.52	10.95	6.52	4.95	2.55
SD	7.02	7.26	2.58	1.17	0.67	0.52
Group B (n = 24)						
Mean	23.63	100.29	10.21	6.42	4.83	2.49
SD	7.73	8.24	2.89	1.14	0.96	0.43
Group C (n = 24)						
Mean	24.13	101.50	10.79	7.13	4.96	2.49
SD	8.09	7.65	2.04	0.85	0.91	0.36
Group D (n = 24)						
Mean	21.67	99.96	10.25	6.63	4.88	2.51
SD	5.01	7.96	2.13	1.01	0.85	0.48
Group E (n = 22)						
Mean	23.18	100.91	10.77	6.77	4.95	2.66
SD	8.34	8.00	2.29	1.23	1.00	0.47
Whole group (N = 115)						
Mean	23.37	101.00	10.58	6.70	4.91	2.54
SD	7.26	7.76	2.38	1.09	0.87	0.45

3.1.3 Stimuli

The Continuous Series II task was used, with four additional variations of category order within the task (see Table 28). The format of the original version was followed, in that categories remained static with another added for each level of difficulty. Starting categories were varied so that each appeared in position one (twice for ‘Numbers’ as it appeared at the beginning of the original version) and subsequent categories were ordered so as to alternate between single symbol (numbers, letters) and whole word (days, months) item representations. Identical category starting points were used for 4-category switching.

Table 28 Category Order and Start Points for all Verbal Switching Task Versions in Experiment Four.

Task & Number of Categories		Categories	Start points
Version A (original)	*2*	Numbers – Days	6 – Tuesday
	3	Numbers – Days – Months	4 – Friday – October
	4	Numbers – Days – Months – Letters	9 – Wednesday – February – H
Version B	*2*	Numbers – Days	6 – Tuesday
	3	Numbers – Days – Letters	4 – Friday – P
	4	Numbers – Days – Letters – Months	9 – Wednesday – H – February
Version C	*2*	Days – Letters	Tuesday – P
	3	Days – Letters – Months	Friday – C – October
	4	Days – Letters – Months – Numbers	Wednesday – H – February – 9
Version D	*2*	Letters – Months	P – October
	3	Letters – Months – Numbers	C – April – 6
	4	Letters – Months – Numbers – Days	H – February – 9 – Wednesday
Version E	*2*	Months – Numbers	October – 6
	3	Months – Numbers – Days	April – 4 – Tuesday
	4	Months – Numbers – Days – Letters	February – 9 – Wednesday – H

3.2 Data Analysis

3.2.1 Data distribution

Normality of all variables was assessed using the Shapiro-Wilk's tests with significance set at .01 and a z limit of + 2.71 (equivalent to an α level of .01(Field, 2009)) for assessment of skewness and kurtosis, where separate examination was carried out. Age was found to be non-normally distributed across all groups with an α level of .0001. All other background measures were normal with the exception of Digit Span measures (again with an α level of .0001) specifically presenting as: Digit Span Forward for Group C, $W(24) = 0.87$, $p = .01$ and Group D, $W(24) = 0.87$, $p = .01$; Digit Span Backward for Group A, $W(21) = 0.80$, $p = .001$; Group B, $W(24) = 0.77$, $p = .0001$; Group C, $W(24) = 0.84$, $p = .002$; Group D, $W(24) = 0.87$, $p = .006$.

Continuous Series II rate was non-normal for 3 and 4-categories, $CS3_{\mathbf{rate}}$ $W(115) = 0.95$, $p = .0001$, $CS4_{\mathbf{rate}}$ $W(115) = 0.94$, $p = .0001$; this was specifically linked to Group D for 3-categories and Group A for 4-categories. As the deviation of distribution was not widespread through the sample transformations were not considered.

Continuous Series II switch cost was again non-normal for 3 and 4-categories, $CS3_{\mathbf{cost}}$ $W(115) = 0.94$, $p = .0001$, $CS4_{\mathbf{cost}}$ $W(115) = 0.95$, $p = .0001$; closer inspection showed this to be related to Group D for 3-categories and Group A for 4-categories. Once again the variation was considered to be sufficiently localised to allow parametric analyses to be carried out on non-transformed data.

All measures of within category errors at the 2-category switching level were non-normally distributed to $p = .0001$; $CS3_{\mathbf{within}}$ Group C, $W(24) = 0.85$, $p = .002$, $CS3_{\mathbf{within}}$ Group E, $W(22) = 0.75$, $p = .0001$, $CS4_{\mathbf{within}}$ Group C, $W(24) = 0.88$, $p = .007$. No between category errors were made when switching between 2-categories and only by Group B during 3-category switching; all between category errors made during 4-category switching were non-normally distributed at $p = .0001$. Self-corrections $_{\mathbf{right}}$ and self-corrections $_{\mathbf{wrong}}$ were all non-normally distributed at $p = .0001$; self-corrections $_{\mathbf{wrong}}$ were only made by Groups D & E when switching between 2-categories. Error and self-correction variables were not able to be corrected by transformation of the data and so were subject to non-parametric evaluation.

During 4-category switching the number of errors per category *type* (numbers, days, months or letters = e.g. $CS4_{\mathbf{error\ numbers}}$) were also analysed. All measures were found to be non-normally distributed $p = .0001$ – this distribution was not normalised by any type of transformation and so non-parametric measures were applied.

3.2.2 Statistical tests

Significance levels for post-hoc contrasts made using t-tests or Wilcoxon signed ranks tests were determined using Holm's sequential Bonferroni adjustment throughout (Holm, 1979). All non-parametric significance levels are exact measures; for Wilcoxon signed ranks tests this is indicated in the text as one or two-tailed as appropriate. Effect size *r* was calculated in the following ways (Field, 2009): t-tests, $\surd\ ((t^2 \div (t^2 + df))$; Wilcoxon signed ranks, test statistic $Z \div \surd$ number of observations.

3.3 Results

3.3.1 Descriptive and preliminary statistics

All versions of the Continuous Series II showed the same increase in switch cost and errors and decrease in speech rate seen in the previous three experiments to occur in line with increasing task difficulty. Task versions showed greater disparity in rate and cost over 2-category switching with convergence of scores over 4-categories. Two-category rate was slowest for version D ($M = 0.65$) and fastest for version A (the original version) ($M = 1.24$); rate measures at 4-categories were all within 0.06 w/sec of each other. Task version D displayed far less of the previously seen 2-switch advantage for either rate or switch cost. Again matching to rate the lowest switch cost over 2-categories was version A ($M = 64.63$) and the highest was version D ($M = 78.63$), with convergence of scores again at 4-categories.

Age correlated with predicted NART IQ, $r = .56$, $p = .0001$. Additionally predicted NART IQ was found to correlate with forward digit span $r = .30$, $p = .001$, reverse digit span $r = .23$, $p = .014$ and CS4$_{rate}$ $r = .27$, $p = .003$. Forward digit span was found to correlate with reverse digit span $r = .64$, $p = .0001$, CS3$_{rate}$ $r = .36$, $p = .0001$, CS4$_{rate}$ $r = .43$, $p = .0001$, CS3$_{cost}$ $r = -.29$, p - .001 and CS4$_{cost}$ $r = -.33$, $p = .0001$. Reverse digit span correlated with all rate measures CS2$_{rate}$ $r = .22$, $p = .019$, CS3$_{rate}$ $r = .48$, $p = .0001$, CS4$_{rate}$ $r = .44$, $p = .0001$ and two cost measures CS3$_{cost}$ $r = -.37$, p - .0001 and CS4$_{cost}$ $r = -.30$, $p = .001$. Normal speech rate correlated only with CS2rate $r = .20$, $p = .036$. Reverse digit span was considered a potential covariate for both rate and cost measures.

3.3.2 Task speech rate

There was a significant effect of number of categories (for means see Table 30), $\Lambda = .09$, F (2, 109) = 528.93, $p = .0001$, $\eta_p^2 = .91$ with rate reducing significantly across the task as difficulty increased (alpha = .017) CS2$_{rate}$ to CS3$_{rate}$ $t(114) = 20.19$, $p = .0001$, $r = 1.78$, CI (0.42 – 0.52); CS2$_{rate}$ to CS4$_{rate}$ $t(114) = 23.91$, $p = .0001$, $r = 0.83$, CI (0.64 – 0.75); CS3$_{rate}$ to CS4$_{rate}$ $t(114) = 19.18$, $p = .0001$, $r = 0.76$, CI (0.20 – 0.25). There was a significant effect of task version $F(4, 110) = 11.34$, $p = .0001$, $\eta_p^2 = .29$ and a significant interaction $\Lambda = .47$, F (8, 218) = 12.68, $p = .0001$, $\eta_p^2 = .32$. Task speech rate differed between groups at 2-category switching $F(4, 114) = 21.91$, $p = .0001$ and at 3-categories $F(4,114) = 3.04$, $p = .020$ but not over 4-categories (see Figure 13) $F(4, 114) = 1.38$, $p = .247$. Follow up independent t-tests (alpha = .005) showed 2-category significance to widespread and to be sourced to a comparison between version A and version C $t(43) = 4.29$, $p = .0001$, $r = 0.55$, CI (0.15 – 0.42), version A and version D $t(43) = 8.29$, $p = .0001$, $r = 0.79$, CI (0.45 – 0.74), version A and version E $t(41) = 3.16$, $p = .003$, $r = 0.44$, CI (0.07 – 0.34), version B and version C $t(46)$

= 3.39, p = .001, r = 0.46, CI (0.10 – 0.40), version B and version D $t(46) = 7.13$, p = .0001, r = 0.73, CI (0.40 – 0.72), version C and version D $t(46) = 4.18$, p = .0001, r = 0.54, CI (0.16 – 0.46) and between version D and version E $t(44) = -5.19$, p = .0001, r = 0.62, CI (-0.54 – -0.24). Three-category significance was associated with a single comparison between version A and version D $t(43) = 3.86$, p = .0001, r = 0.51, CI (0.07 – 0.22).

The analysis was repeated using reverse digit span stratified as an independent variable to determine covariance. Scores were grouped as follows: Low (scores of 3 or 4, N = 39, M = 3.95), Medium (scores of 5, N = 50, M = 5.02) and High (score of 6, 7 or 8, N = 26, M = 6.20). In this format reverse digit span was found to have some independent effect $F(2, 100) = 17.89$, p = .0001, $\eta_p^2 = .26$ but did not interact with number of categories $\Lambda = .88$, F (4, 198) = 3.25, p = .053, $\eta_p^2 = .06$, task version F (8, 100) = 0.70, p = .690, $\eta_p^2 = .05$ or a combination of the two $\Lambda = .89$, F (16, 198) = 0.70, p = .788, $\eta_p^2 = .05$.

3.3.3 Switch cost

Predictably there was a significant effect of number of categories (for means see Table 30) $\Lambda = .12$, F (2, 109) = 391.04, p = .001, $\eta_p^2 = .88$ with cost increasing significantly across the task as difficulty increased (alpha = .017) $CS2_{cost}$ to $CS3_{cost}$ $t(114) = -17.80$, p = .0001, r = 0.74, CI (-15.39 – -12.47); $CS2_{cost}$ to $CS4_{cost}$ $t(114) = -22.52$, p = .0001, r = 0.82, CI (-22.87 – -19.17); $CS3_{cost}$ to $CS4_{cost}$ $t(114) = -16.92$, p = .0001, r = 0.72, CI (-7.81 – -6.17). Task version also had a significant effect, F (4, 110) = 5.35, p = .001, $\eta_p^2 = .16$ and there was a significant interaction between the two $\Lambda = .51$, F (8, 218) = 10.99, p = .0001, $\eta_p^2 = .29$. Groups differed significantly over 2-categories $F(4, 114) = 9.49$, p = .0001 and over 3-categories $F(4, 114) = 4.83$, p = .001 but gain not over 4-categories $F(4, 114) = 2.32$, p =

.062. Follow up independent *t*-tests (alpha = .005) showed 2-category significance to be linked to a comparison between version, version A (*M* = 64.63) and version D (*M* = 78.63) *t*(43) = -4.71, *p* = .0001, *r* = 0.582, CI (-19.98 – -8.00), version B (*M* = 65.11) and version D (*M* = 78.63) *t*(46) = -4.89, *p* = .0001, *r* = 0.58, CI (-19.09 – -7.95) and version D (*M* = 78.63) and version E (*M* = 67.43) *t*(44) = 3.62, *p* = .001, *r* = 0.48, CI (4.97 – 17.44). Difference over 3-categories was linked to a single comparison of version B (*M* = 85.59) and version E (*M* = 81.08) *t*(44) = 2.95, *p* = .005, *r* = 0.41, CI (1.43 – 7.59).

The analysis was again rerun with the stratified reverse digit span measure entered as a potential covariate. There was some independent effect of reverse digit span, *F* (2, 100) = 7.81, *p* = .001, η_p^2 = .14 but no interaction with either number of categories Λ = .88, *F* (8, 198) = 3.29, *p* = .012, η_p^2 = .06, task version *F* (8, 100) = 0.68, *p* = .710, η_p^2 = .05 or a combination of the two Λ = .88, *F* (16, 198) = 0.80, *p* = .688, η_p^2 = .06.

In order to determine whether differences between groups at the 2-category level for both rate and switch cost were related to individual differences in non-switching production rate for the individual categories ‘numbers’ and ‘days’, one-way ANOVAs were run on baseline rates for those two categories. No significant difference between groups was found for either ‘numbers’ *F*(4, 57) = 2.25, *p* = .076 or for ‘days’ *F*(4, 57) = 1.13, *p* = .351. Full data for non-switching rates are given in Table 23.

Table 29 Non-Switching Baseline Production Rates (w/sec) for all Groups.

	Non-switching rate (w/sec)			
	Numbers	**Days**	**Months**	**Letters**
Group A *(n = 21)*				
Mean	1.83	3.39	3.61	1.11
SD	0.38	0.50	0.50	0.32
Group B *(n = 24)*				
Mean	1.78	3.39	3.44	1.39
SD	0.43	0.61	0.78	0.70
Group C *(n = 24)*				
Mean	1.89	3.44	3.56	1.22
SD	0.33	0.53	0.73	0.67
Group D *(n = 24)*				
Mean	1.86	3.00	3.86	1.14
SD	0.38	0.00	0.38	0.38
Group E *(n = 22)*				
Mean	2.50	3.17	3.50	1.33
SD	1.23	0.41	0.84	0.52

Table 30 Task Speech Rate (w/sec) and Switch Cost (% w/sec increase) (N = 115).

	Task speech rate (w/sec)			**Switch cost (% increase)**		
	2-cats	**3-cats**	**4-cats**	**2-cats**	**3-cats**	**4-cats**
***Group A** (n = 21)*						
Mean	1.24	0.61	0.33	64.63	81.16	90.91
SD	0.20	0.13	0.09	7.47	5.12	3.18
***Group B** (n = 24)*						
Mean	1.21	0.56	0.32	65.11	85.59	91.29
SD	0.28	0.19	0.10	6.89	4.18	2.26
***Group C** (n = 24)*						
Mean	0.96	0.51	0.35	71.69	84.29	89.18
SD	0.24	0.15	0.08	9.63	4.51	3.26
***Group D** (n = 24)*						
Mean	0.65	0.47	0.31	78.63	85.81	90.65
SD	0.27	0.13	0.10	11.67	5.14	2.97
***Group E** (n = 22)*						
Mean	1.03	0.57	0.29	67.43	81.08	91.46
SD	0.23	0.16	0.08	9.00	6.08	2.66
***Whole group** (N = 115)*						
Mean	1.01	0.54	0.32	69.66	83.69	90.68
SD	0.32	0.16	0.09	10.40	5.35	2.95

CS rate: *M* = 0.63, *SE* = 0.01
2-cat rate: *M* = 1.02, *SE* =0.02
3-cat rate: *M* = 0.54, *SE* = 0.01
4-cat rate: *M* = 0.32, *SE* = 0.01
Group A rate: *M* = 0.73, *SE* = 0.03
Group B rate: *M* = 0.70, *SE* = 0.03
Group C rate: *M* = 0.61, *SE* = 0.03
Group D rate: *M* = 0.47, *SE* = 0.03
Group E rate: *M* = 0.63, *SE* = 0.03

CS cost: *M* = 81.26, *SE* = 0.45
2-cat cost: *M* = 69.50, *SE* = 0.85
3-cat cost: *M* = 83.59, *SE* = 0.47
4-cat cost: *M* = 90.70, *SE* = 0.27
Group A cost: *M* = 78.90, *SE* = 1.06
Group B cost: *M* = 80.66, *SE* = 0.99
Group C cost: *M* = 81.72, *SE* = 0.99
Group D cost: *M* = 85.03, *SE* = 0.99
Group E cost: *M* = 79.99, *SE* = 1.04

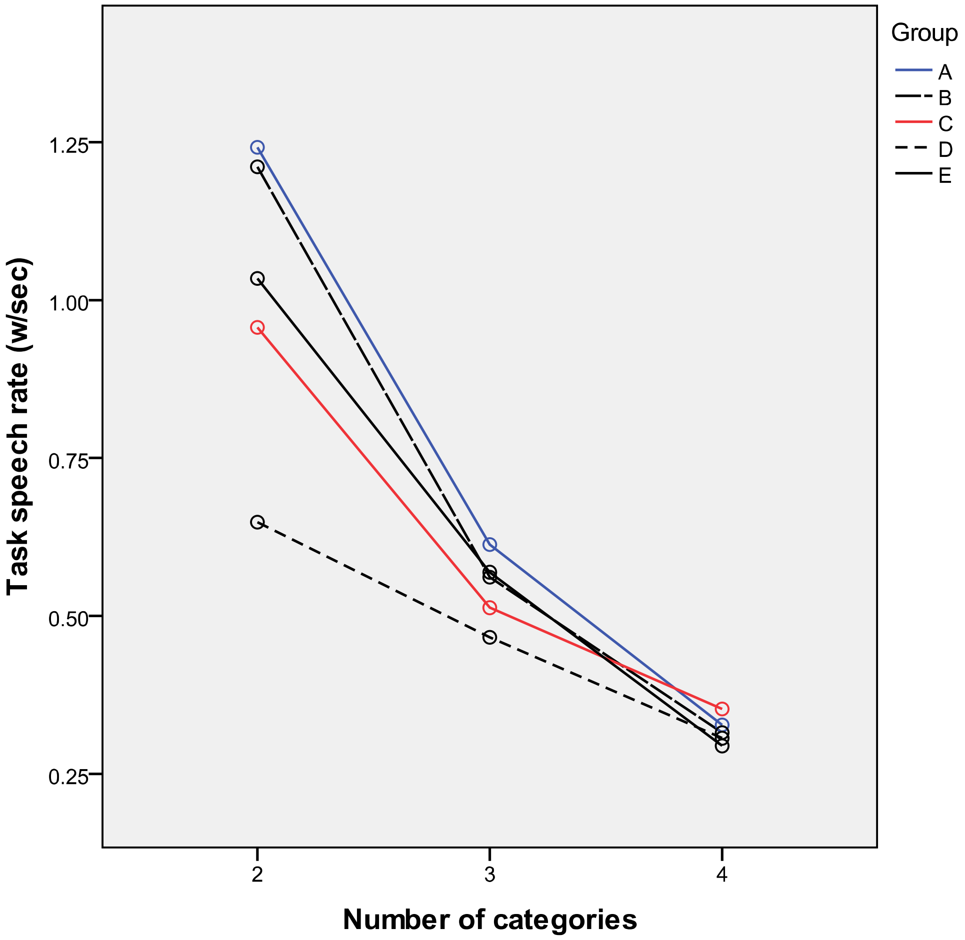

Figure 13 Task production rate (w/sec) for all task variation groups over 2, 3 and for category switching for the Continuous Series II

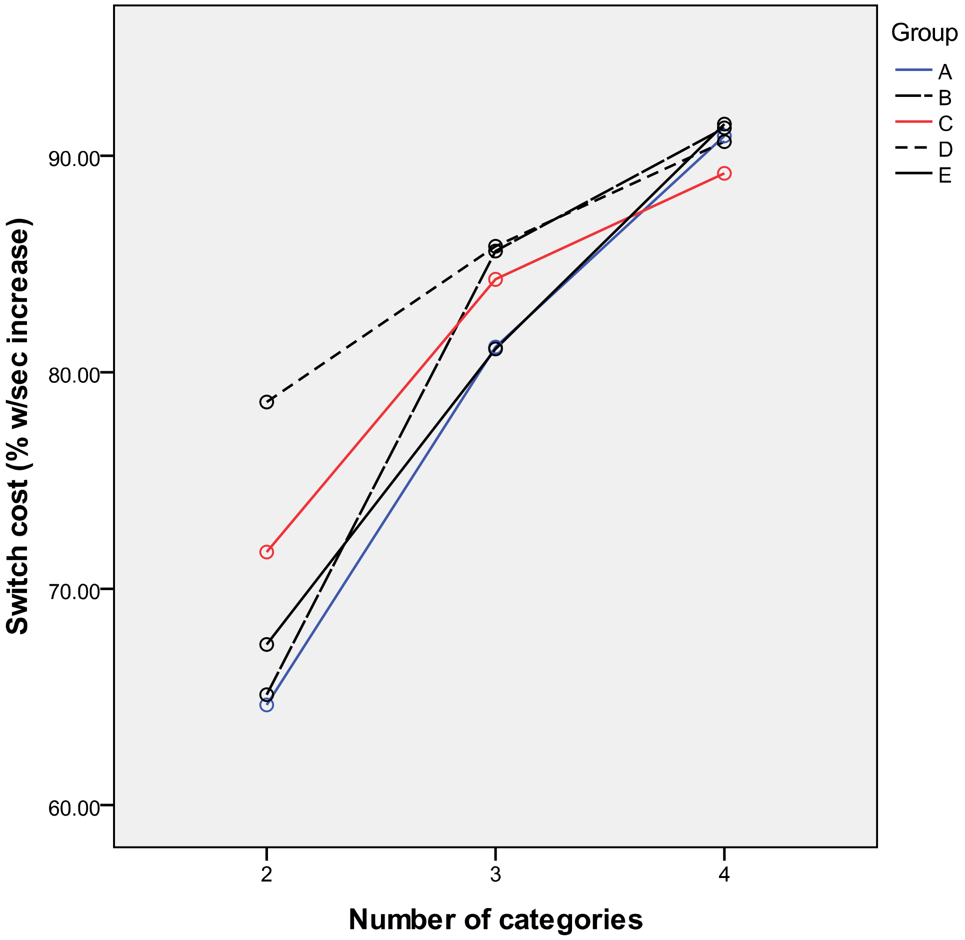

Figure 14 Switch cost (% w/sec increase+) for all task variation groups over 2, 3 and for category switching for the Continuous Series II

3.3.4 Within-category errors

A Friedman's ANOVA showed that within category errors increased significantly as the task became more difficult (see Table 31) $\chi^2(2) = 207.95$, $p = .0001$. Follow up Wilcoxon signed ranks tests showed this significance to present at every level of difficulty CS2 to CS3

T = 23.30, *p* = .0001, *r* = -0.55, CS3 to CS4 *T* = 10.75, *p* = .0001, *r* = -0.60. Kruskal-Wallis tests revealed there to be no significant difference between task versions over 2-category switching *H*(4) = 4.37, *p* = .358 or over 3-category switching *H*(4) = 5.05, *p* = .282; however, there was a significant difference over 4-category switching *H*(4) = 10.88, *p* = .028. Appropriately adjusted Mann-Whitney follow up tests (alpha = .005) showed this difference to be linked to the comparison between task versions A (*Mdn* = 11.00) and C (*Mdn* = 8.00), *U* = 132.50, *z* = -2.73, *p* = .005, *r* = -0.18. Analysis of the type of errors showed 61.40% to be perseverative and 38.60% to be sequencing.

3.3.5 Between category errors

A Friedman's ANOVA showed that between-category errors increased significantly as the task became more difficult (see Table 31), $\chi^2(2) = 60.67$, *p* = .0001. Follow up Wilcoxon signed ranks tests showed this not to be significant between the first two difficulty levels CS2 to CS3 *T* = 0, *p* = .180, *r* = -.09 but was significant as the task became harder CS3 to CS4 *T* = 2, *p* = .0001, *r* = -.32. Kruskal-Wallis tests showed there to be to be no significant difference between task versions over 3-category switching (2-category switching was not analysed as no between-category errors were made at that difficulty level), *H*(4) = 7.65, *p* = .105 and also no significant difference over 4-categories, *H*(4) = 4.80, *p* = .308. There was one perseverative error, accounting for 0.90% of the total; 95.54% were sequencing errors and 3.56% were errors of omission.

Table 31 Within and Between Category Errors at each Level of Difficulty (2, 3 or 4 Categories) for all Task Versions (A-E) on the Continuous Series II Task (N = 115).

	Within-category errors			**Between-category errors**		
	2	**3**	**4**	**2**	**3**	**4**
Group A						
Sum	9	59	251	0	0	22
N	5	18	21	-	-	5
Mean	0.43	2.81	11.95	-	-	1.05
SD	0.98	2.27	4.15	-	-	2.31
Group B						
Sum	11	115	240	0	5	15
N	7	23	24	-	2	7
Mean	0.46	4.79	10.00	-	0.21	0.63
SD	0.93	3.89	4.43	-	0.83	1.10
Group C						
Sum	13	70	207	0	0	12
N	10	16	24	-	-	5
Mean	0.54	2.92	8.63	-	-	0.50
SD	0.72	3.23	3.87	-	-	1.18
Group D						
Sum	16	78	231	0	0	39
N	13	22	24	-	-	11
Mean	0.67	3.25	9.63	-	-	1.63
SD	0.70	2.31	3.47	-	-	2.26
Group E						
Sum	15	83	254	0	0	23
N	9	20	22	-	-	6
Mean	0.68	3.77	11.55	-	-	1.05
SD	1.09	3.55	4.21	-	-	2.10
Whole group						
Sum	64	405	1183	0	5	111
N	44	99	115	-	2	34
Mean	0.56	3.52	10.29	-	0.21	0.97
SD	0.88	3.16	4.15	-	0.83	1.86

3.3.6 Analysis of errors according to category type

The total number of errors per category type for each task version was analysed (see Table 32). A Friedman's ANOVA showed that there was a significant difference between the number of errors committed overall in each category according to type, $\chi^2(3) = 32.81$, $p = .0001$. Appropriately adjusted follow up Wilcoxon signed ranks tests (alpha = .008) showed that Days$_{\mathbf{2nd}}$ produced significantly more errors than all other categories, more than Numbers$_{\mathbf{1st}}$ $T = 1518$, $p = .003$, $r = .14$, more than Months$_{\mathbf{3rd}}$ $T= 1052$, $p = .0001$, $r = .22$ and more than Letters$_{\mathbf{4th}}$ $T = 793$, $p = .0001$, $r = .23$ – see Figure 15 for a comparison between task versions. There were also significantly more errors in Numbers$_{\mathbf{1st}}$ than in Letters$_{\mathbf{4th}}$ $T = 1409$, $p = .006$, $r = .13$. Kruskal-Wallis tests showed that the different task versions differed significantly on Numbers$_{\mathbf{1st}}$ $H = 16.79$, $p = .002$ and on Days$_{\mathbf{2nd}}$ $H = 10.17$, $p = .038$ but not on Months$_{\mathbf{3rd}}$ $H = 3.66$, $p = .453$ or on Letters$_{\mathbf{4th}}$ $H = 3.29$, $p = .51$. Follow up Mann-Whitney tests (adjusted alpha = .008) showed that differences between tasks versions were almost exclusively confine to the category Numbers$_{\mathbf{1st}}$ and were evident between version A (*Mdn* = 3.00) and version C (*Mdn* = 1.50), $U = 126$, $z = -2.92$, $p = .003$, $r = -.03$, between version C (*Mdn* = 1.50) and version D (*Mdn* = 4.00), $U = 130$, $z = -3.301$, $p = .001$, $r = -.03$ and between version C (*Mdn* = 1.50) and version E (*Mdn* = 4.00), $U = 116$, $z = -3.301$, $p = .001$, $r = -.03$. There was also a significant difference in the category Days$_{\mathbf{2nd}}$ between version A (*Mdn* = 3.00) and version C (*Mdn* = 1.50), $U = 130$, $z = -2.81$, $p = .0005$, $r = -.02$.

Table 32 Mean Total Errors (Within and Between-Category) per Category Type for all Task Versions.

	Mean errors per category			
	Numbers	**Days**	**Months**	**Letters**
Group A *(n = 21)*				
Mean	3.05	4.52	2.76	2.67
SD	1.16	1.97	2.57	1.77
Group B *(n = 24)*				
Mean	2.83	3.13	2.00	2.67
SD	1.95	1.94	1.91	1.58
Group C *(n = 24)*				
Mean	1.71	2.88	2.42	2.13
SD	1.40	1.48	1.59	1.60
Group D *(n = 24)*				
Mean	3.46	3.29	2.42	2.00
SD	1.82	1.46	1.59	1.38
Group E *(n = 22)*				
Mean	3.64	3.86	2.73	2.36
SD	2.11	1.94	1.42	2.04
Total *(N= 115)*				
Mean	2.92	3.50	2.45	2.36
SD	1.89	1.83	1.83	1.67

Group A: *M* = 3.25, *SE* = 0.25
Group B: *M* = 2.66, *SE* = 0.24
Group C: *M* = 2.28, *SE* = 0.24
Group D: *M* = 2.79, *SE* = 0.24
Group E: *M* = 3.15, *SE* = 0.25

Numbers: *M* = 2.94, *SE* = 0.17
Days: *M* = 3.54, *SE* = 0.17
Months: *M* = 2.47, *SE* = 0.17
Letters: *M* = 2.36, *SE* = 0.16

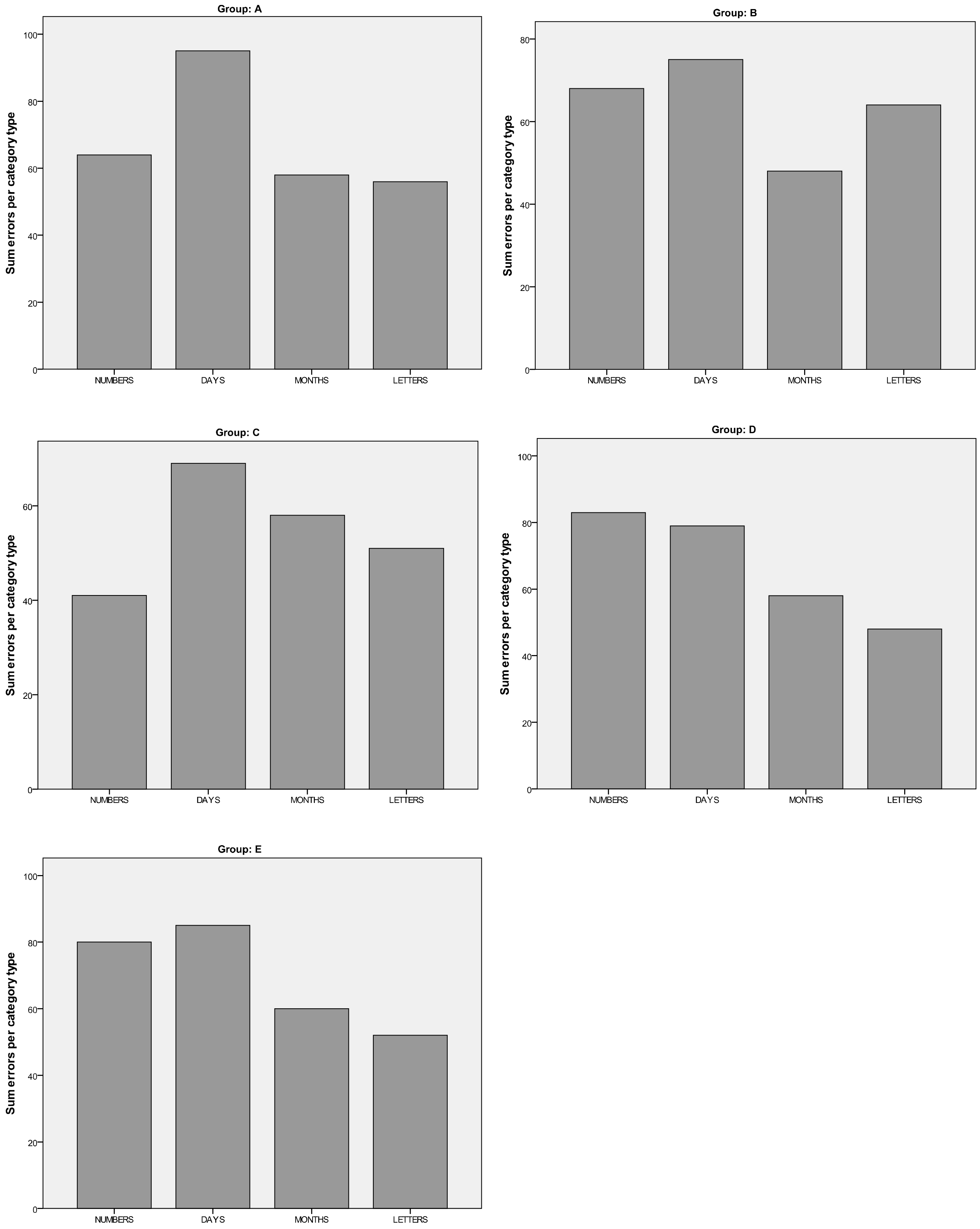

Figure 15 Sum errors per category type for task versions A-E over 4-category switching on the Continuous Series II (refer to Table 28 for differing task order)

4 Discussion

Task speech rate decreased for all task versions as the task became more difficult. The original version of the task resulted in the fastest speech rate, although this was overtaken at 4-category switching by version C. Over 2-category switching version D was the slowest at over half the rate of version A; version A and B were similar, with versions C and E lying close to each other in between the two extremes. Versions A and D remained fastest and slowest respectively at 3-category switching, being the only significantly different comparison. Task speech rate converged at 4-category switching with all versions scoring within 0.06 w/sec of each other. Task versions followed the same pattern for switch cost running from least cost for version A to most for version D; convergence of scores again increased as the task became more difficult with scores ranging within 2.5% of each other over 4-categories.

It is possible that individual differences could account for the differences in rate and switch cost seen over 2-category switching; individual differences in control have been related to activation and maintenance of task set (Adrover-Roig & Barceló, 2010). Convergence between task versions of the Continuous Series II at 4-category switching and also between different versions of the verbal task in Experiment 3 would suggest that increasing difficulty is a limiting factor for such differences in the task. It would seem intuitive that individual differences in strategy would more likely be seen when the task became more difficult – variability in strategic processes would seem less likely when the task involves only alternation between two categories. However, individual differences as well as inter-trial differences are a common feature of task switching studies (Karayanidis et al., 2010). Given the relatively short duration of the Continuous Series II it is possible that normal order differences from both these sources are more obvious at the 2-category level, with slowing from increasing task difficulty masking the effect as the number of categories increase. Higher switch costs in the face of increased task difficulty have been noted as a factor to be controlled when probing individual differences in switching (Wager, Jonides & Smith, 2006) so it would follow that difficulty would exert this masking effect.

Within and between-category errors also followed the established pattern of increasing as the task became more difficult. For within-category errors the most variation between the versions occurred during 3-category switching, with version B scoring at least 30% more errors (and as much as almost 50%) than any other version. This variation reduced to around 17% at 4-category switching, although with the exception of version C all were within 9% of each other. Between-category errors occurred only at the 4-category level (with the exception of 2 individuals from version B scoring at 3-categories), with version D notable for a relatively high score.

Difference between version A and all other versions of the task was not uniform as predicted. Version B, also beginning with ‘numbers’, scored very closely to version A for rate and switch cost. As predicted by the third hypothesis these two versions resulted in faster rate and lower cost than the other versions. All other versions of the task were significantly different from version A during 2-category switching but the convergence caused by increasing task difficulty overtook this difference. Beginning the sequence with the category ‘numbers’ clearly facilitated some kind of anchoring or other beneficial effect during the task (anecdotally reported as due to the continuous nature of the category), in excess of any difference caused by separating out short and long categories. ‘Numbers’ also stands out from the other categories in that it is much more strongly associated with spatial representation (Dehaene, Bossini & Giraux, 1993; Dehaene, Piazza, Pinel & Cohen, 2003) which could also have contributed to this ‘anchoring’ effect.

Overall ‘days’ produced the most errors – the only other significant difference was between ‘numbers’ and ‘letters’ with ‘numbers’ scoring higher. The category ‘days’ produced the highest number of errors in all task versions except for version D (see Figure 15) where ‘numbers’ was highest. There was no consensus regarding placement of the other categories between task versions. The concentration of errors in ‘days’ at the highest difficulty level is therefore a feature of the category itself and not related to confinement after the first switch of the trial as would relate to cost distribution noted by Rogers and Monsell (1995). The concentration of errors moved with the category rather than remaining static at the second category of four. It should be noted that two of the task versions, A and B, included ‘days’ during 2-category switching and, in line with the usual patterns of costs at this level, hardly any errors were reported. The task related aspect of ‘days’ which causes increased error production only comes into play when the task overall becomes more difficult, possibly tying in with the as yet unspecified factor of 4-category switching that causes convergence of rate and switch cost at this level (and similarly with the two verbal tasks in Experiment 3).

In this experiment the task preceding ‘days’ is different every time (although the same for versions A and B) so it cannot be said that there is a *specific* effect of a recently performed task (Mayr & Keele, 2000). Task difficulty (4-categories) enhances the propensity of ‘days’ for errors regardless of what the switch is *from* (with the exception of version D where ‘numbers’ (the third category) produces most errors with ‘days’ (the fourth category) a close second). Yeung & Monsell (2003) state that the ability of one task to interfere with another (as in the case of asymmetric costs, Allport, Styles & Hsieh, 1994) is dependent on the relative initial strength of those tasks (in their case the relationship between the task and the stimuli). If the repeated ‘day’ suffix causes confusion as to which item was last produced and therefore which should be produced on the current iteration then ‘days’ could be considered to be a weaker task and more prone to interference by the proximity of multiple adjacent tasks. In this instance it would appear that three adjacent tasks is the rate limiting step for this category. As there is no exogenous component to the task (stimuli or cues) then reconfiguration to ‘days’, with the ambiguity of a repeated suffix, is done in an environment where the ‘path’ to the task is not entirely clear (Monsell’s mental gear shift idea (Monsell, 2003)). Perhaps facilitation of the switch with the use of an external cue would negate the combination of complexity and task ambiguity and 4-category switching – this is addressed in Experiment 6, Chapter 8.

5 Conclusion

- In accordance with hypothesis 1, predicting greater difficulty with increasing categories, general patterns of rate, switch cost and error increasing in line with task difficulty are common to all versions of the task. These appear to not be artefacts of task design, although there appears to be evidence of inter-individual variation at the lower level of difficulty.
- There is negation for hypothesis 2 (spatially separated versions of the task would relate in different cost to the original version) and support for hypothesis 3 (versions starting with ‘Numbers’ would result in lower cost). The order categories are placed within the task does not make a lot of difference to this overall pattern other than to

identify a beneficial effect of starting the sequence with ‘numbers’. This reflects a task specific feature but not one that seems to have a detrimental effect on switching measures.

- In support of hypothesis 4 (differential within-category errors between categories), a similarly task specific artefact is that of the bulk of errors follow the category ‘days’, seemingly in accordance with the weakening (in terms of task and item maintenance) effect of suffix repetition in the category. This would suggest a degree of caution to be exerted when interpreting error data at the most difficult task level.
- Overall the measure of switch cost and error in the Continuous Series II is a stable phenomenon, although a degree of each (certainly not the majority) is attributable to task related effects.

CHAPTER SEVEN: EXAMINING THE LOAD OF SWITCHING BETWEEN FOUR CATEGORIES

1 Introduction

This chapter addresses the issue of whether switching between 4-categories *per se* is the difficult aspect of the task or whether the nature of the categories (sequences which need updating on every iteration) is the main contributor to difficulty. This is of particular relevance to the convergence of both different types (Experiment 3) and different versions (Experiment 4) of the task seen at the most difficult level of switching. Switching in the alternating runs paradigm incorporates mixing costs (Fagot, 1994), the time costs of performing tasks in close proximity to each other additionally to the cost of switching between them, seen in repeats in the mixed (A-A-B-B…) block. Such costs are known to inflate measures of general switch cost and so the cost of performing four tasks next to each other may be additional to that of switching between them. Although mixing costs (as determined for the alternating runs paradigm) are caused by response competition for bivalent stimuli (Rubin & Meiran, 2005) still occurring on the repeat as opposed to switch trials, they could be seen to apply in a different form to the 'quasi-multivalent' stimuli of the Continuous Series II. Switching to the category 'days' for example would provide the 'stimulus', for which there are seven possible responses to compete. Mixing costs have also been said to reflect sequential elimination in search of the correct response (Steinhauser & Hübner, 2005) which would fit particularly well with the nature of response selection for overlearned sequences. Braver et al. (2003) concur that (from a neurological point of view) a significant degree of switch cost comes from the load of performing several tasks in close proximity to each other rather than just the act of switching from one task to another i.e. most costs are global (that is including things other than the element related to switching).

Switching between four tasks is not usual in the literature (an exception being Buchler, Hoyer and Cerella, 2008) unless, as previously noted, it is arrived at through a factorial combination of two response choices and S-R mappings (e.g. Allport, Styles & Hsieh, 1994, Experiment 1). The effect of these quasi-mixing costs (as they might apply for ‘stimuli’ in the verbal paradigm) for four separate tasks with four separate multiple response sets is therefore unknown. By manipulating the *content* of categories and removing response competition it will be possible to assess switching in the absence of any mixing-style costs, As stated, they are thought the reflect response competition rather than working memory load related to the number of tasks (Rubin & Meiran, 2005). The current experiment comprises of four difficulty levels but keeps the number of switching categories constant at four throughout by utilising arbitrary non-updating categories of repeated colour names. As such the degree of competition for task responses will increase as the number of overlearned sequences increase. Therefore it will be possible to determine how much of the general cost relates to switching between four tasks and how much relates to the *content* of those tasks.

One obvious question relating to the construction of the Continuous Series II is whether switch cost in the verbal task (particularly at the highest difficulty level) is due to high cognitive load from the content of the individual categories? While this undoubtedly has a degree of relevance to all types of task switching, it might be particularly so for sequential verbal tasks, which are more complex and ‘load worthy’ in the first place. Although the Continuous Series II has not been associated with *additional* memory load (Gurd et al., 2002) this assertion has not been specifically tested. Memory load is thought to be dissociable from switching processes (e.g. Logan, 2004; Wager, Jonides & Smith, 2007) and as such would be a co-contributor to overall general cost as measured in the verbal task. While the use of overlearned sequences is not thought to be particularly taxing on working memory in itself (certainly not as much as semantic categories) the use of four switching categories may, by itself or in combination with such sequences, be the limiting factor for verbal task switching. It has been noted (Liefooghe, Barrouillet, Vandierendonck & Camos, 2008) that the act of switching increases load on working memory (rather than working memory contributing to switch cost). Recall was shown to decrease as a function of the number of task switches - the simultaneous load on item maintenance did not affect switch costs. Task switching itself incurs a cost on WM. So by this means the increased number of switches at the highest level of difficulty in the Continuous Series II might be contributing to working memory load and, by that circular mechanism, general cost accrued in the task. Conversely Ward, Roberts & Phillips (2001) posited that extensive time for preparation and reliable predictability of the switching task should extinguish the effects of cognitive load. It could therefore be argued that cognitive load should not overtly contribute to the convergence effect seen in the Continuous Series II.

Reconfiguration accounts such as that of Rogers and Monsell (1995) consider reconfiguration processes to be separate from any task properties. Such separation is demonstrated by the attribution of task related decision errors and switch related wrong-task errors (Arbuthnott & Frank, 2000). In the current study such errors are attributed to Kahneman’s (2011) automatic System 1 (for task errors) and the more effortful executive System 2 (for switching errors), still differentiating between task contents and switching. The type of difficulty experienced *within*-task in the Continuous Series II and switching itself contribute to switch cost in an additive manner (Rubinstein et al., 2001). However, the isolation of switch cost from task effects, as presented by reconfiguration accounts, is questioned by results which show an effect of the *type* of task on switch cost (Chamberland & Tremblay, 2011). This is despite previous studies showing switch cost to be separable from aspects relating to the speed at which a task can be carried out (e.g. Rubinstein et al., 2001 and Meiran, 2005). If the *type* of task/ category in the Continuous Series III (the colour version used in the current experiment) has a demonstrable effect on switch cost then reconfiguration might not be the sole cause of that cost. Although the calculation of general cost in the verbal task does not allow separation of task and switch related costs this does not preclude the notion that switch related cost itself might be vulnerable to the effects of task features. The effect of the faster production time for the single-syllable colour names is negated by calculation of non-switching rate from speeded production of those names in the baseline condition.

In addition to the effects on switch cost, category content might also have an effect on the type of errors made during the task. It would follow that within-category task related errors cannot occur when the response is always the same, as in the arbitrary colour categories. There is however still the scope for errors to occur between categories which have thus far been associated with overall task difficulty and have occurred most readily during 4-category switching. It is not clear whether such errors are a feature of switching between four categories or switching between four ‘complex’ categories. If they are caused by the *number* of switching categories then they should occur at all difficulty levels of the colour-based Continuous Series III as each level has the same number of categories. If individual task complexity is a contributor to between-category errors then their occurrence should change as the number of overlearned sequences categories increases. Any significant difference in the number of between-category errors would suggest that ‘task identification’ errors do not entirely represent failure of executive processes as suggested by Arbuthnott and Frank (2000) or the current reference to System 2. They would in fact represent at least *some* element of task related factors. As such this would again call into question the suitability of a reconfiguration-only account of costs and the definition of error types.

2 Aims and Hypotheses

The aim of this experiment is to determine whether cost at the most difficult level of the Continuous Series II is due to maintaining four separate tasks in memory or whether the content of those categories is a main contributor to cost.

1. All measures will increase significantly as the number of overlearned sequences contained within the task increases.
2. Within-category errors will only be committed in overlearned sequence categories – the distribution of errors according to category type will favour overlearned sequences over arbitrary categories, due to the repetitive nature of the colour categories. Errors will significantly increase as the number of overlearned sequences categories increases.
3. Between-category errors will occur in both category types (overlearned sequences and colour categories) as they will reflect switching rather than task content.

3 EXPERIMENT FIVE

3.1 Method

3.1.1 Design

Task speech rate (w/sec), switch cost (% w/sec increase) and total number of errors made were assessed using a single 4-level factor, Difficulty Level (1, 2, 3 or 4 overlearned sequence (OS) categories).

3.1.2 Participants

The sample (*n* = 28, females = 21) were recruited from the University of Hertfordshire (undergraduate and taught postgraduate psychology students) and from the wider community by word of mouth. Students received course credit for participation; non-students received no reward for taking part. Of the original 32 recruited and tested, one participant was withdrawn from the analysis due to a backward digit span score of 2 and a large number of errors over 3 and 4 category switching, suggesting undisclosed non-compliance with exclusion criteria. A second participant was withdrawn due to an inability to complete the 4-category switching level and two more were withdrawn due to continual and disruptive non-target utterances throughout the task. All participants were right handed native English speakers, screened according to the criteria set out in Chapter 2. Mean demographic and baseline measures were as follows: Age *M* 22.22 (*SD* 6.96); NART IQ *M* 100.41 (*SD* 8.21); WAIS-R vocabulary *M* 10.22 (*SD* 1.34); digit span forward *M* 6.85 (*SD* 1.10); digit span backward *M* 5.11 (*SD* 0.93); normal speech rate *M* 2.55 (*SD* 0.38).

3.1.3 Stimuli

Unlike the original Continuous Series II, the Continuous Series III ‘dummy category’ task had four levels of difficulty instead of three. Each level continued for 23 iterations and included four categories, using a mix of overlearned sequences and arbitrary ‘low load’ categories which required the same word (colour names) to be repeated every time they occurred, unlike overlearned sequences where the item changed every time (e.g. “1-red-green-blue-2-red-green-blue...”). Difficulty level was determined by changing the ratio of overlearned sequence: arbitrary categories rather than the absolute number of categories; at the lowest level the ratio was 1: 4, with overlearned sequence categories increasing incrementally at each level, as shown in Table 33. Non-switching speech rate was calculated thus: $Cat^A + Cat^B + Cat^C + Cat^D / 4$.

Table 33 Category Order and Start Points for Dummy Category Verbal Switching Task.

Difficulty level		Categories & overlearned sequence (OS) start points
Number of OS	*1*	Numbers (‘3’) – Red – Green – Blue
categories	*2*	Numbers (‘6’) – Days (‘Tuesday’) – Blue – Red
	3	Numbers (‘4’) – Days (‘Friday’) – Months (‘October’) – Green
	4	Number (‘9’) – Days (‘Wednesday’) – Months (‘February’) – Letters (‘H’)

3.2 Procedure

The background measures and task were administered as indicated in Chapter 2 and as for previous experiments. For the verbal switching task participants were instructed recite four categories, progressing incrementally through items in sequence for the overlearned sequence categories and repeating the same word at each iteration for the colour categories.

3.3 Data analysis

3.3.1 Data distribution

Age and both digit span measures were found to be non-normally distributed: Age $W(28) = 0.59$, $p = .0001$, with 64% of the sample aged 18-20 years presenting a marked leptokurtic distribution; forward digit span $W(28) = 0.91$, $p = .015$, presenting as mildly platykurtic from scores 6-8; reverse digit span $W(28) = 0.86$, $p = .001$ had a slight positive skew with two high scores at 7. As previously noted the digit span measures were within a clinically normal range (Lezak et al., 2004).

Task speech rate and switch cost were both non-normally distributed at the 4OS difficulty level, though this was not unexpected in comparison to previous results: $4OS_{\mathbf{rate}}$ $W(28) = 0.89$, $p = .005$, with a positive skew due to a high score of 0.66; $4OS_{\mathbf{cost}}$ $W(28) = 0.85$, $p = .001$, negatively skewed due to two lower scores (representing faster performance) at around 80%. The violations were within normal expectations for the task and so both task speech rate and switch cost were analysed parametrically.

Colour categories produced no errors and so were disregarded for error distribution analysis according to category type; the overlearned sequence category from the 1OS Difficulty Level was excluded due to a lack of comparative categories. Both overlearned sequence categories in the 2OS Difficulty Level were non-normally distributed: $2OS_{\mathbf{errors\ 1st}}$ $W(28) = 0.72$, $p = .0001$, with a positive skew caused by single scores at 3 and 4; $2OS_{\mathbf{errors\ 2nd}}$ $W(28) = 0.68$, $p = .0001$, positively skewed due to a single score at 3. The 3OS level was also non-normal throughout: $3OS_{\mathbf{errors\ 1st}}$ $W(28) = 0.88$, $p = .004$, presenting as platykurtic due to a dip at score 2; 3OS $_{\textbf{errors 2nd}}$ $W(28) = 0.91$, $p = .019$, positively skewed by scores at 8 and 10; 3OS $_{\textbf{errors 3rd}}$ $W(28) = 0.89$, $p = .006$, again showing a positive skew due to a score at 5. The 4OS Difficulty Level presented non-normally for errors in the second and fourth categories: 4OS $_{\textbf{errors 2nd}}$ $W(28) = 0.85$, $p = .001$, showing a leptokurtic distribution due to almost half the participants scoring at 3; 4OS $_{\textbf{errors 4th}}$ $W(28) = 0.86$, $p = .001$, positively skewed due to an isolated score at 9. All measures of error per category position and the comparison of total errors were analysed using non-parametric methods.

Between-category errors did not occur during 1OS or 2OS switching. Errors of this nature during the remaining difficulty levels showed non-normal distributions for 3OS $W(28) = 0.34$, $p = .0001$ and for 4OS $W(28) = 0.48$, $p = .0001$. Comparison of errors for these two difficulty levels was made using non-parametric measures.

3.3.2 Statistical tests

Task speech rate and switch cost were analysed using a single factor GLM repeated measures ANOVA; where indicated, potential covariates were additionally entered into the analysis as between-subjects factors, as indicated in Chapter 2. Errors per category type were analysed using a Wilcoxon signed ranks test for 2OS; 3OS and 4OS were assessed using a Friedman’s ANOVA, as were total errors per difficulty level.

Significance levels for post-hoc contrasts made using t-tests or Wilcoxon signed ranks tests were determined using Holm’s sequential Bonferroni adjustment throughout (Holm, 1979). All non-parametric significance levels are exact measures; for Wilcoxon signed ranks tests this is indicated in the text as one or two-tailed as appropriate. Effect size *r* was calculated in the following ways (Field, 2009): t-tests, $\sqrt{((t^2 \div (t^2 + df))}$; Wilcoxon signed ranks, test statistic $Z \div \sqrt{}$ number of observations.

3.4 Results

3.4.1 Descriptive and preliminary statistics

As predicted, speech during the task became slower and more costly as the number of overlearned sequence categories increased; the total number of errors also increased in line with this. ‘Days’ was only the most error-laden category during the 3OS difficulty level; at 2 OS it was beaten by the first category, numbers, and at 4OS days only exceeded numbers by 1 error.

Age correlated significantly with NART IQ, $r = .67$, $p = .0001$, WAIS-R vocabulary, $r = .50$, $p = .007$ and $2OS_{\textbf{rate}}$, $r = .41$, $p = .032$. As expected NART IQ correlated significantly with WAIS-R vocabulary, $r = .70$, $p = .0001$ and also $2OS_{\textbf{rate}}$, $r = .45$, $p = .016$ and $3OS_{\textbf{rate}}$, $r = .40$, $p = .036$. WAIS-R vocabulary was also found to correlate with $2OS_{\textbf{rate}}$, $r = .42$, $p = .026$. Forward digit span predictably correlated with reverse span, $r = .61$, $p = .001$, with the three most difficult task speech rate measures and the middle two switch cost, $2OS_{\textbf{rate}}$, $r = .50$, $p = .007$, $3OS_{\textbf{rate}}$, $r = .61$, $p = .001$, $4OS_{\textbf{rate}}$, $r = .50$, $p = .007$, $2OS_{\textbf{cost}}$, $r = -.47$, $p = .011$, $3OS_{\textbf{cost}}$, $r = -.52$, $p = .005$. Reverse digit span correlated with the same measures, $2OS_{\textbf{rate}}$, $r = .55$, $p = .003$, $3OS_{\textbf{rate}}$, $r = .48$, $p = .010$, $4OS_{\textbf{rate}}$, $r = .44$, $p = .019$, $2OS_{\textbf{cost}}$, $r = -.48$, $p = .010$, $3OS_{\textbf{cost}}$, $r = -.40$, $p = .037$. Normal speech rate did not correlate with task speech rate or switch cost at any level of task difficulty.

3.4.2 Task speech rate

A one-way GLM ANOVA showed that difficulty level content had a highly significant effect on task speech (see Table 34) rate with rate reducing as the task became more difficult (see Figure 16), $\Lambda = 0.02$, $F(3, 25) = 333.78$, $p = .0001$, $\eta^2 = 0.98$. Appropriately adjusted follow up paired samples *t*-tests showed this reduction to be uniformly significant, 1OS-2OS $t(27) = 16.55$, $p = .0001$, 1OS-3OS $t(27) = 28.27$, $p = .0001$, 1OS-4OS $t(27) = 31.11$, $p = .0001$, 2OS-3OS $t(27) = 18.76$, $p = .0001$, 2OS-4OS $t(27) = 20.59$, $p = .0001$, 3OS-4OS $t(27) = 13.09$, $p = .0001$.

For the purposes of covariance, reverse digit span was stratified into a categorical variable, Low (score of 4, $n = 9$, $M = 4$), Medium (score of 5, $n = 10$, $M = 5$), High (score of 6-7, $n = 9$, $M = 6.22$) and entered as an independent measures variable (see Chapter 2). There was no independent effect of reverse digit span, $\Lambda = 0.76$, $F(6, 46) = 1.13$, $p = .358$, $\eta^2 = 0.13$ and so no covariance attributed to this variable.

Table 34 Descriptive Statistics for Sample (N = 28) on Task Speech Rate (w/sec) and Switch Cost (% increase) for the Continuous Series III.

	Continuous Series III			
	1 OS cat	**2 OS cat**	**3 OS cat**	**4 OS cat**
Task speech rate (w/sec)				
Mean	2.67	1.52	0.54	0.33
SD	0.42	0.37	0.15	0.11
Switch cost (% increase)				
Mean	23.21	55.00	81.95	89.99
SD	11.52	10.63	5.75	3.50

3.4.3 Switch cost

A one-way GLM ANOVA showed that content of difficulty level content had a highly significant effect on switch cost (see Table 34) which increased in line with difficulty level (see Figure 17), $\Lambda = 0.02$, $F(3, 25) = 368.39$, $p = .0001$, $\eta^2 = 0.98$. Follow up pairwise comparisons indicated this to be uniformly significant , 1OS-2OS $t(27) = -15.48$, $p = .0001$, 1OS-3OS $t(27) = -29.42$, $p = .0001$, 1OS-4OS $t(27) = -32.94$, $p = .0001$, 2OS-3OS $t(27) = -18.58$, $p = .0001$, 2OS-4OS $t(27) = 22.02$, $p = .0001$, 3OS-4OS $t(27) = -11.01$, $p = .0001$.

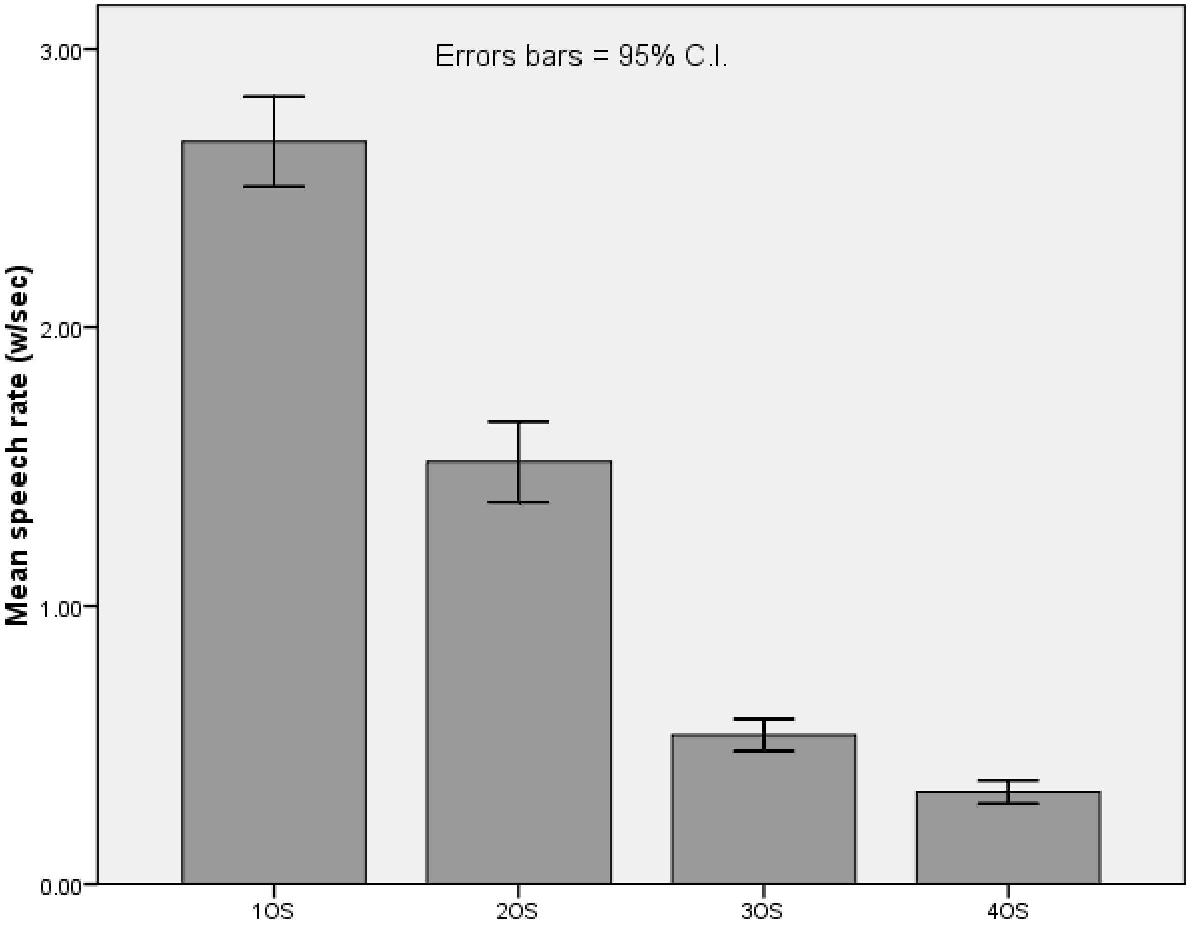

Figure 16 Mean task speech rate (w/sec) for all difficulty levels of the Continuous Series III verbal switching task

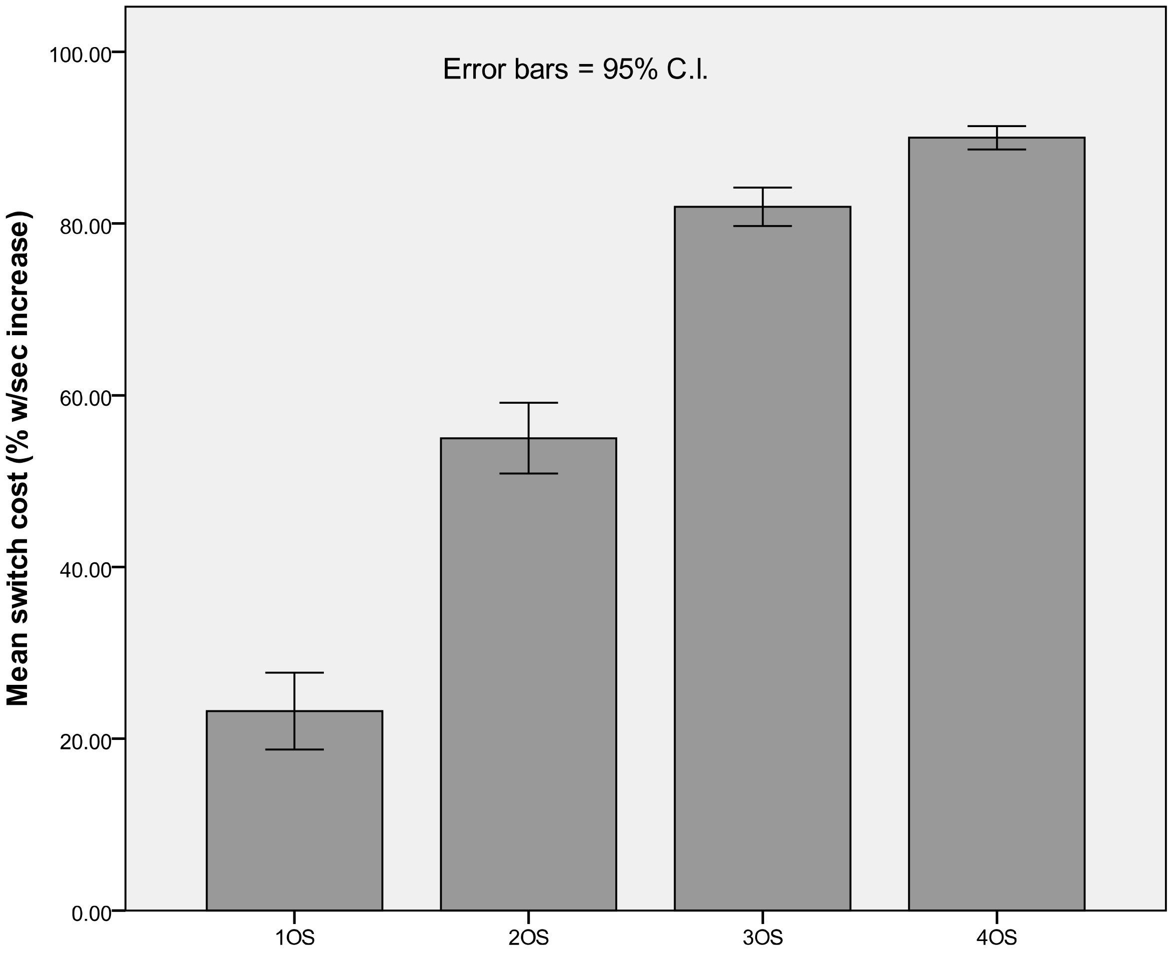

Figure 17 Mean switch cost (% w/sec increase) for all for difficulty levels of the Continuous Series III verbal switching task

3.4.4 Errors per category type

For difficulty level 2OS, although errors decreased from Numbers$_{\mathbf{1st}}$ to Days$_{\mathbf{2nd}}$ (see Table 35), a Wilcoxon signed ranks test showed that this decrease was not significant $T = 6$, $p = .506$, $r = -0.13$. For difficulty level 3OS a Friedman's ANOVA showed that the number of errors changed significantly according to category type, $\chi^2(2) = 13.28$, $p = .001$; Table 35 shows Numbers$_{\mathbf{1st}}$ and Months$_{\mathbf{3rd}}$ to have similar scores, with Days$_{\mathbf{2nd}}$ scoring almost twice as highly. Follow up Wilcoxon signed ranks tests showed Numbers$_{\mathbf{1st}}$ scored significantly lower than Days$_{\mathbf{2nd}}$ $T = 4$, $p = .005$, $r = -.53$, that there was no significant difference between Numbers$_{\mathbf{1st}}$ and Months$_{\mathbf{3rd}}$ $T = 12$, $p = .804$, $r = -.05$ and that Months$_{\mathbf{3rd}}$ also scored significantly lower than Days$_{\mathbf{2nd}}$ $T = 4$, $p = .001$, $r = -.60$. Finally, for 4OS the Freidman's ANOVA showed a significant difference in errors according to category type $\chi^2(3) = 16.54$, $p = .001$; Table 35 shows this as very similar high scores for Numbers$_{\mathbf{1st}}$ and Days$_{\mathbf{2nd}}$ and lower scores for the last two categories. Follow up Wilcoxon signed ranks test showed no significant difference between Numbers$_{\mathbf{1st}}$ and Days$_{\mathbf{2nd}}$ $T = 10$, $p = .714$, $r = -.07$ or between Months$_{\mathbf{3rd}}$ and Letters$_{\mathbf{4th}}$ $T = 8$, $p = .135$, $r = -.28$; errors in Numbers$_{\mathbf{1st}}$ were significantly higher than in Months$_{\mathbf{3rd}}$ $T = 7$, $p = .026$, $r = -.42$ or than in Letters$_{\mathbf{4th}}$ $T = 4$, $p = .001$, $r = -.60$; errors in Days$_{\mathbf{2nd}}$ were significantly higher than in Months$_{\mathbf{3rd}}$ $T = 8$, $p = .024$, $r = -.43$ or than in Letters$_{\mathbf{4th}}$ $T = 4$, $p = .003$, $r = -.56$.

Table 35 Descriptive Statistics for Errors per Difficulty Level and Category Type (N = 28).

	Continuous Series III															
	1 OS cat				**2 OS cat**				**3 OS cat**				**4 OS cat**			
	1*	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Sum	4	0	0	0	20	15	0	0	47	93	45	0	105	106	77	61
n	3	-	-	-	12	10	-	-	21	26	21	-	27	26	26	21
Mean	0.14	-	-	-	0.71	0.54	-	-	1.68	3.32	1.61	-	3.75	3.79	2.75	2.18
SD	0.45	-	-	-	1.05	0.84	-	-	1.33	2.61	1.42	-	1.94	1.81	1.62	2.20

1 OS cat 1: Numbers	2 OS cat 1: Numbers	3 OS cat 1: Numbers	4OS cat 1: Numbers
1 OS cat 2: Red	2 OS cat 2: Days	3 OS cat 2: Days	4 OS cat 2: Days
1 OS cat 3: Green	2 OS cat 3: Blue	3 OS cat 3: Months	4 OS cat 3: Months
1 OS cat 4: Blue	2 OS cat 4: Red	3 OS cat 4: Green	4 OS cat 4: Letters

3.4.5 Between-category errors per difficulty level

No between-category errors were made during 1OS or 2OS switching – descriptive data for the two difficulty levels was as follows: 3OS (sum = 7, $N = 3$, $M = 0.25$, $SD = 0.84$)

and 4OS (sum = 20, *N* = 6, *M* = 0.71, *SD* = 1.72). Using a Wilcoxon signed ranks test between-category errors for the two difficulty levels were found not to be significantly different, *T* = 8, *p* = .158, *r* = -0.27. None of the errors were perseverative – 90% wee sequencing errors and 10% were errors of omission.

4 Discussion

Both task speech rate and switch cost changed significantly at every level of difficulty, indicating that difficulty was related to some degree to the content of the categories and not just to the number of categories being switched between. It would seem that proximity costs relating to performing four tasks together, in a similar vein to mixing costs in the alternating runs paradigm, account for a lesser portion of the overall general cost. It had been suggested by Braver et al. (2003) and others (e.g. Los, 1996) that the majority of costs were related to this proximity effect but, for the Continuous Series III task at least, it would seem that task *content*-related costs account for more than proximity. General switch cost for the Continuous Series tasks incorporates both the cost of switching between tasks and the cost of switching within tasks. Although a substantial amount of cost is attributable to the content of the categories being switched between (an increase of almost 67% switch cost from 1 overlearned sequence to 4 overlearned sequences), this is not to say that Continuous Series switching is any less valid than switching paradigms using less complex dual decision (e.g. number parity) tasks. It also has to be acknowledged that complex task switching such as is carried out in everyday life involves manipulation of the tasks as well as switching between them. They are not empty place holders as is seen in real world studies of multi-tasking. For example, managing multiple office activities (González & Mark, 2004), combining factual recall and game-play (Ratan, Santa-Cruz & Vorderer, 2007) or considering factors such as task urgency and duration in real life scenarios (Wickens & McCarley, 2007).

Switching *within* a task and the ensuing addition to cost of task complexity must be a feature of any realistic measure of task switching.

Updating an item in an overlearned sequence should not be any more complex than configuring the correct S-R mapping *and* then choosing the correct response when both have a dual nature, for example Allport, Styles &Hsieh (1994). A highly overlearned sequence item will surely be more readily available than a recently learned and sometimes arbitrary combination of relationships which contradict themselves when mappings change. The 1 overlearned sequence (easiest) condition also shows that there is still a notable cost of switching (almost 25%) between four categories when the need to switch within is removed. It must therefore be assumed that an undisclosed portion of the task related costs seen in relation to the increasing overlearned sequence content of the task must be accounted for by direct switch related costs. The limitation of the calculation of general cost is that task, proximity and switch costs are inevitably merged. If memory load is indeed dissociable from switching processes (Logan, 2004; Wager, Jonides & Smith, 2007) then both must be represented in what is taken to be non-proximity task-related costs, as demonstrated by the 1 overlearned sequence condition . Separation of proximity costs at least (in comparison of 1 overlearned sequence and 4 overlearned sequence conditions) is possible to a degree and so the contribution of these mixing-style costs can be acknowledged.

It was posited that a demonstrable effect of category content on switch cost might indicate that reconfiguration is not the sole cause of cost, in line with recent work showing a direct effect of task type on cost (Chamberland & Temblay, 2011) and a consequent lack of separability between the two. There is a clear effect of task content on switch cost in this instance, although it is acknowledged that the nature of cost calculation in the verbal task masks direct switch costs within these task related costs. It must therefore be considered that other causes of cost such as carryover of activation from the last task might be at play. There is no overt indication of carryover in particular, as might be suggested by perseverative between-category errors. However, again the calculation of general cost places a limit on the degree to which finite sources of cost can be identified. A non-exclusively reconfiguration source for cost must at least be considered on that basis. However, Baddeley, Chincotta and Adlam (2001) suggest that recitation of overlearned sequences block the phonological loop, used presumably for recitation of task order sequence via the mechanism of inner speech (Bryck & Mayr, 2005), with little attentional demand. This would suggest that task related load and attentional switching processes could lend themselves to being separated out (as suggested by Rubinstein et al., 2001 and Meiran, 2005). The blocking of the phonological loop would tie in with the profusion of between-category errors of the sequencing type (categories in wrong order rather than perseveration of the last category. The lack of perseverative errors is already noted) and would seem, as evidenced by the low rate of between-category errors, to be a partial and surmountable effect. The suitable error pattern would seem to make Baddeley and colleagues' explanation of overlearned sequence action more plausible. Thus the content related load of categories in the Continuous Series tasks would appear to give further evidence to an additive contribution to general cost and, if separable from attentional switching processes, would not preclude a reconfiguration-only source for those switching processes.

Analysis of errors per category type at every difficulty level confirmed that, as predicted, there were no errors of either type in any of the colour categories. Removal of the need to update items in these categories confirmed that errors of the within-category type are entirely task related as indicated by Arbuthnott and Frank's (2000) interpretation and the suggestion that they are under the control of the automatic System 1 (Kahneman (2011). Both relate to task-related issues, albeit in different ways (Arbuthnott via WM and Kahneman via the type of control). Unusually the category 'days' did not produce significantly more errors at the highest difficulty level of 4 overlearned sequences – the category did produce significantly more errors during the 3 overlearned sequence trial. No clear reason for the lack of prominence for 'days' presented itself and so the finding could be anomalous. Any difference between Continuous Series III and previous presentations of the verbal task would have to be related to the preceding trial (3 overlearned sequences with four categories including one colour). There is no obvious reason why increased task difficulty in terms of number of categories on the preceding 3 overlearned sequence trial would increase errors for the category 'numbers' (this scored one error less than 'days').

As well as being absent from colour categories, between-category errors were seen to increase with the number of overlearned sequence categories present in the task. That no such errors were committed in relation to colour categories would suggest that the content of the categories contributes to occurrence of the errors and so they may not be entirely executive related as suggested by Arbuthnott and Frank (2000) and the current work. However, this is not to say that such errors are necessarily entirely memory based . Gurd et al. (2003) have suggested that task switching errors are not inevitably memory related, although offer no further discussion as to their source. The lack of differentiation between error types in the literature and indeed the lack of consideration of error rates at all[77]give limited background against which to interpret the presentation of error rates in the current work. Interpretation of

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[77] For example, Gilbert & Shallice (2002) disregard discussion of error rates in their work "…since reaction times have received greater attention than errors in studies of task switching…" (Gilbert & Shallice (2002), p.314)

between-category errors as relating to Kahneman's (2011) System 2 would dictate that such errors are following interpretation of rules and are analytic and sequential (Tsujii & Watanabe, 2009), in effect executive errors. However, WM supports System 2 thinking, offering a workspace within which to reason. Between-category errors may therefore reflect some element of WM as well as (and inevitably concomitant to) executive function. However, accounting for memory in this error type goes no further in explaining why it does not occur of colours. Is it instead entirely task related?

Equally it could be that repeating the same response over and over, as for the colour categories, does not constitute a task switch in the same way as a two choice decision (as in the Arbuthnott and Frank and many other studies). There could be a threshold for activation of executive errors which requires some executive content to the task. This might act in a similar way to the suppression threshold suggested by Yeung and Monsell (2003) for asymmetry related interference. In the same way that the ability of tasks to interfere with each other temporally was relative to their comparative content, the ability of tasks of categories to interfere with each other at an executive sequencing level may be relative to there being an executive choice-based element to that category. Under such conditions the assumption that between-category errors would occur in colour categories would be erroneous. Unlike the Arbuthnott and Frank study the majority of between-category errors were again sequencing rather than perseverative. This suggests that activation for the previous task is not 'lingering' as in a TSI-based account of switch cost (Allport, Styles & Hsieh, 1994), although again the limitation of not being able to differentiate between alternating and non-alternating per-switch cost restricts the certainty of this supposition. However, the nature of between-category errors may cautiously be taken as support for a reconfiguration basis for switch cost. This is in conjunction with the proposed threshold requirement for category content which would support separation of task and switching processes (lack of errors in colour categories would otherwise suggest incomplete separation).

As a caveat it should be noted that, as well as differentiating between decision (task related System 1) and switch (executive System 2) errors using surface features relating to the content of the errors (right task/ wrong item and wrong task respectively), Arbuthnott and Frank (2000) typified task related (within-category) errors as occurring uniformly across all switching conditions. Executive errors occurred more frequently in the alternating switch condition (A-B-A) than the non-alternating (A-B-C) and no-switch conditions. The no-switch equivalent in the Continuous Series tasks is the non-switching baseline, which is of limited duration (15 seconds per category) in comparison to the full task. Within-category errors (task-related decision error equivalents) at this baseline stage are rare, due to the overlearned nature of sequences and truncated length of the task. Due to the continuous nature of the task and the calculation of general switch cost it is not possible to make any comparison to the alternating and non-alternating switching conditions in the Arbuthnott and Frank study. The possible limitation of comparison of within/ between and decision/ wrong-task errors using only the surface features of error content should be acknowledged, although no other description of errors in the literature is as amenable to error production in the Continuous Series tasks.

5 Conclusion

- In line with both hypothesis 1 (difficulty would increase with number of categories) and all other versions of the task, rate, switch cost and number of errors increase as the task becomes more difficult in terms of increasing the number of overlearned sequences.

- More cost seems attributable to the content than the number of categories being switched between, although whether single response choice colour categories fully constitute a task in the more usual sense is questionable.
- While calculation of general switch cost does not allow direct switch costs to be explicitly separated from task and task proximity costs, it is clear that some portion of overall costs are attributable to direct switch costs.
- The effect of category content on switch cost is not taken to exclude reconfiguration as a source for switch cost – the task related cost of producing overlearned sequences is seen as separable from attentional switching costs, a requirement for reconfiguration accounts.
- Hypothesis 2, that within category errors would occur only in overlearned sequence categories, is supported.
- Hypothesis 3, that between-category errors would occur in both category types. is not supported. The lack of between-category errors in colour categories is interpreted in terms of a threshold relating to task content – rather than being tied to the content of overlearned sequence categories, which would suggest a non-reconfiguration basis for switch cost, the error production is suppressed (or not initiated) by the *lack* of content in the colour categories.

CHAPTER EIGHT: INVESTIGATING THE USE OF CONTINUOUSLY AVAILABLE EXPLICIT CUES DURING VERBAL TASK SWITCHING

1 Introduction

Chapter six discusses the use of cues with the Continuous Series II task. The verbal switching task typically makes no use of externally presented cues or stimuli. This arguably increases memory load during the task by reliance on foreknowledge, although the overlearned nature of the categories is asserted to minimise any such effects (Gurd et al., 2002). Additionally this does away with the need to process any additional cue information (Logan & Bundesen, 2003, 2004). It has been asserted that uncued switching sequences are too burdensome to working memory (Rogers & Monsell, 1995) but this has been countered by the claim that highly familiar and explicit cues externalise too much of the decision process in switching (Rubinstein, Meyer & Evans, 2001). Reliance on foreknowledge places greater demands on self initiated preparation for switching than reliance on cues, which has the support of an external trigger for switching. It has been found that PD patients cannot make use of foreknowledge in the absence of cues (Werheid, Koch, Reichert & Brass, 2007), providing evidence for separation of these preparation processes. Logan and Bundesen (2003) go further by stating that the use of cues during switching entirely negates the need for self initiated control. However, Monsell and Mizon (2006) refute this with the claim that task predictability was not controlled for in the Logan and Bundesen study, removing the requirement for active use of cues to indicate the upcoming task. Clearly the comparison between foreknowledge and cued task identity is not clear cut, with processing advantages and disadvantages associated with both.

The use of cues more generally allows for manipulation of the cue-stimulus interval (CSI) and the utilisation of an unpredictable task order (e.g. Monsell, Sumner & Waters, 2003). In such circumstances the longer the CSI the greater the reduction in switch cost due to maximal preparation time for the upcoming task. The incremental updating of items within categories in the Continuous Series II and the fixed order of the task sequence does not allow for random task order. Manipulation of CSI is therefore not practical (see Figure 18) and so cues used during the current task are continuously available. This has the advantage of only requiring cues to be processed once at the beginning of the task, much as the instructional cue paradigm employed by Logan & Schneider (2006a).

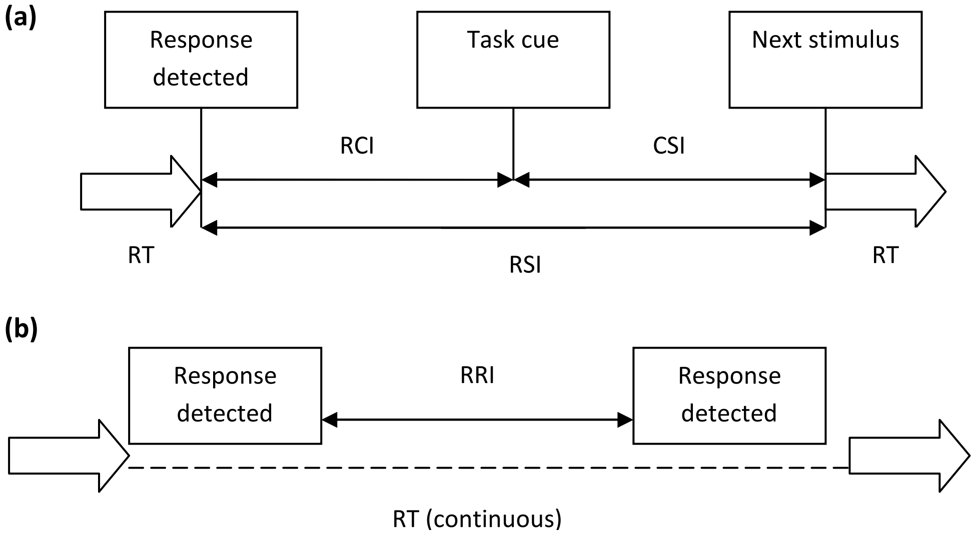

Figure 18 Typical cued switching task (a) and verbal switching task (b). RCI = response-cue interval; CSI = cue-stimulus interval; RSI = response-stimulus interval; RRI = response-response interval; RT = reaction time

The type of cues used in the current study are whole word (‘Days’) and initial letter (‘D’ = Days) cues. Both are linguistic and related to the upcoming task but vary only in their physical length and explicitness. A similar format (using arbitrary rather than initial letters) has been used by Logan and Bundesen (2004) to investigate coincidence and divergence of cue and task repeats; differences in data were related to differential processing of the type of cue. In accordance with this, Lavric, Mizon & Monsell (2008) found additional left hemisphere processing in response to a picture as oppose to a verbal cue, suggesting additional translational processing was required for the picture cue. Elchlepp et al. (2012) used ERP data to show that use of an explicit verbal cue has a ‘special efficacy’ in triggering advance TSR and refocuses attention automatically.

It is expected that whole-word cues will have a beneficial effect on switch cost. Monsell (2005) states that explicit external word cues are supportive of verbal self-instruction. Goshcke (2000) goes further in stating that linguistic self-instruction is critical for task-set reconfiguration. Monsell notes that it is difficult to directly compare verbal and non-verbal (pictorial, symbolic) cues as it is hard to match all properties other than their linguistic content. It is likely that translation will be required for initial letter cues so these will be less successful than whole words – cue translation has been cited as a contributor to the inhibitory costs of backward inhibition (e.g. Grange & Houghton, 2010). It is unclear whether the cost of translation will supersede the assumed benefit of using a cue. Appropriate verbal cues such as full names should alleviate the need to make one’s own as in the use of inner speech as a self-cueing device (Emerson & Miyake, 2003; Kray, Eber & Lindenberger, 2004). It has been found that use of a verbal cue (e.g. ‘colour’) partially overcomes the suppressive effect of irrelevant speech during switching (Miyake et al., 2004). Therefore full name cues should overcome any suppressive effect that rehearsing category order using inner speech has on updating of items within categories. As a result use of full name cues (and to a lesser extent initial letter cues) should result in a reduction in the number of within-category errors as well as reducing switch cost.

Although the Continuous Series II is not felt to overly load working memory during switching (Gurd et al. 2002), the ‘double switch’ nature of the task (switching between categories and updating items within categories) could be construed as more complex than tasks generally seen in the literature, particularly at the most difficult 4-category level. Increasing the number of switches has been found to increase interference with working memory (Liefooghe et al., 2008). The use of continuously available cues will remove the need to remember task order (removing the need to rely on foreknowledge of the task) as well as item order. Due to the more complex nature of the constituent tasks there will still be an executive element within the tasks, thus addressing Rubinstein, Meyer & Evans’s (2001) criticism that explicit cues remove too much of the decision making process from switching while still addressing the question of working memory load (Rogers & Monsell, 1995). The need to rely on foreknowledge will be removed in a way that places less processing load on the use of cues. As such it is predicted that both types of cue will reduce the degree of switch cost produced at each level of difficulty. Whole word cues will be expected to be more successful in this due to the reduced processing requirement compared to initial letter. The benefit of whole word cues is expected to be most obvious at the 4-category switching level, due to the greater interference in working memory caused by the greater number of switches (as per Liefooghe et al., 2008).

As well as reducing switch cost, the alleviation of memory load for category order is expected to extinguish between-category errors. Although such errors are posited as being under the control of System 2 (Kahneman (2011) in that they represent executive control of switching, it should be remembered that System 2 is underpinned by WM. Between-category errors occur as the task becomes more difficult and the need to rely on foreknowledge of task order increases – errors of this nature do not occur when switching between only 2-categories. Reliance on foreknowledge in this way would explain why between-category errors in the Continuous Series II would appear to be at least partially memory reliant. It has been previously stated (Experiment 5, Chapter 7) that between category errors might not be fully representative of executive control over switching[78]. If between-category errors are just a case of forgetting then use of cues (particularly whole word cues) will eradicate them. If between category errors are not eradicated then it can safely be concluded that they are not wholly memory related and do largely draw on executive failure (which would also explain their rarity in healthy participants).

2 Aims and Hypotheses

The introduction of full name and initial letter constantly available cues to the Continuous Series II is predicted to reduce reliance on foreknowledge for task order, resulting in a reduction in switch cost, a reduction in within-category errors and elimination of between-category errors. Full name cues are predicted to be more successful than initial letter cues.

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[78] Although it was noted that the lack of between-category errors in colour categories could have been due to the lack of executive content in the task.

1. Cues of both types will reduce switch cost, initial letter cues to a lesser degree than whole word cues.
2. Cues of both types will reduce within-category errors, due to their ability to overcome the suppressive effect that rehearsing category order might have on producing category items.
3. Cues of both types will eliminate between-category errors as they will be supportive of verbal self-instruction/ inner speech. This will indicate a memory element for such errors as suggested in Experiment 5, Chapter 7.

3 EXPERIMENT SIX

3.1 Method

3.1.1 Design

Task speech rate (w/sec) and switch cost (% w/sec increase were assessed using a 3 x 3 mixed design, with a between-participants factor of Cue type (None, Low and High[79]) and a within-participants factor of Task Difficulty (2, 3 or 4 categories). Within and Between category errors were assed non-parametrically

3.1.2 Participants

The sample (*N* = 124, females = 93) were undergraduate and taught postgraduate students from the University of Hertfordshire who received course credit for taking part and individuals from the wider community recruited by word of mouth who received no payment.

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[79] ‘Low’ and ‘High’ refers to the level of semantic content.

All participants were right handed native English speakers and were screened according to the criteria set out in Chapter 2. Of the original 136 participants recruited and tested one was excluded due to an extreme number of errors (only 40% accuracy) during 4-category switching, one was excluded due to a total inability to keep category order over 3 and 4-category switching, six were excluded due to early discontinuation (completing 25-40%) of 4-category switching, three due to very low NART IQ scores and one due to late disclosure of screening ineligibility. The cue groups did not differ significantly on demographic or baseline measures (see Table 36).

Table 36 Demographic and Baseline Measures for Cue Sample.

Group	Age	NART IQ	WAIS-R vocab.	Digit span forw.	Digit span backw.	Conv. speech rate
Whole sample (N = 124)*						
Mean	25.71	102.13	10.67	6.79	4.77	2.58
SD	*(10.09)*	*(8.04)*	*(2.07)*	*(1.22)*	*(1.08)*	*(0.55)*
Cues = None (n = 41)						
Mean	26.28	101.87	10.49	6.97	4.82	2.58
SD	*(10.55)*	*(8.30)*	*(2.00)*	*(1.27)*	*(1.14)*	*(0.60)*
Cues = Low (n = 41)						
Mean	25.40	101.48	10.78	6.83	4.80	2.55
SD	*(9.68)*	*(7.58)*	*(2.21)*	*(1.01)*	*(0.99)*	*(0.61)*
Cues = High (n = 42)						
Mean	24.90	102.88	10.61	6.63	4.80	2.63
SD	*(9.79)*	*(7.94)*	*(2.02)*	*(1.34)*	*(1.10)*	*(0.45)*

* Whole sample *N* = 123 for WAIS-R, *N* = 121 for normal speech rate

3.1.3 Stimuli

For all cue conditions the Continuous Series II task was used, the only difference being the type of cues presented – no cues (‘None’), low semantic content cues (‘Low’) and high semantic content cues (‘High’). Low and high semantic content referred to the relationship between the cue and the target category, with the cue presenting either the initial letter or whole name of the category e.g. ‘N’ or ‘Number’. Cues were presented centrally placed in black Arial font (bold, size 36) on a laptop PC, using MS PowerPoint 2007.

3.2 Procedure: Deviation from general method

The procedure followed that described in Chapter 2 up until commencement of the switching task. Participants in the ‘no cue’ condition proceeded as per the general method description; those in the two cued groups were told that a visual aid would be placed in front of them (see Appendix D for full instructions). As the order of categories for each level of the task was explained, the experimenter pointed to the relevant cues, which remained in place for the duration of that level of the task. The procedure was repeated for each difficulty level. The position of the cues was adjusted to the eye level of each participant and presented approximately 60 cm in front of them on a laptop computer, as previously described. The keyboard of the computer was covered with a sheet of white card so as to prevent any additional or conflicting letter or number cues.

3.3 Data Analysis

3.3.1 Data distribution

Normality of all variables was assessed using the Shapiro-Wilk’s test with significance set at .01 and a z limit of + 2.71 (equivalent to an α level of .01 (Field, 2009)) for assessment of skewness and kurtosis where applicable. Age was non-normally distributed $W(120) = 0.73$, $p < .0001$, as was WAIS-R vocabulary $W(124) = 0.96$, $p = .001$. Both digit span measures were non-normally distributed– forward $W(120) = 0.93$, $p < .0001$ and reverse $W(120) = 0.89$, $p < .0001$.

Task speech rate for the whole sample over 4-categories was found to be non-normally distributed, $W(120) = 0.93$, $p < .0001$; this presented as a leptokurtic distribution peaking at around 0.25-0.35 w/sec with a significant z-score of 1.58 for kurtosis. However, non-normal distribution over 4-categories was expected, in line with previous experiments, and so parametric measures were used. Switch cost for the whole sample was non-normally distributed over 2-categories, $W(120) = 0.96$, $p = .001$, 3-categories, $W(120) = 0.96$, $p = .003$ and 4-categories, $W(120) = 0.95$, $p < .0001$. However, as data was largely symmetrical and had no outliers, a transformation was not applied and data was analysed as is (Howell, 2002).

Within-category errors were found to be non-normally distributed over 2-categories $W(120) = 0.56$, $p < .0001$ and over 3-categories $W(120) = 0.90$, $p < .0001$; due to the validity of a zero score for these variables, transformation was not considered and they were assessed non-parametrically due to the severe non-symmetrical distribution. All levels of the task showed a non-normal distribution for between-category errors (no errors were scored over 2-categories), 3-categories $W(120) = 0.26$, $p < .0001$, 4-categories $W(120) = 0.41$, $p < .0001$; these were again analysed using non-parametric tests. All measures of self-corrections from between-category errors presented non-normally $p < .0001$.

3.3.2 Statistical tests

Significance levels for post-hoc contrasts made using t-tests or Wilcoxon signed ranks tests were determined using Holm’s sequential Bonferroni adjustment throughout (Holm, 1979). All non-parametric significance levels are exact measures; for Wilcoxon signed ranks tests this is indicated in the text as one or two-tailed as appropriate. Effect size r was calculated in the following ways (Field, 2009): t-tests, $\sqrt{((t^2 \div (t^2 + df))}$; Wilcoxon signed ranks, test statistic $Z \div \sqrt{}$ number of observations.

Task speech rate, switch cost and local switch cost were all analysed using GLM mixed ANOVAs and ANCOVAs, where potential covariates were indicated by bivariate correlational analysis. Within category errors were assessed using a Friedman's ANOVA and between category errors using the Wilcoxon signed ranks test.

3.4 Results

3.4.1 Descriptive and preliminary statistics

As with all previous presentations of the Continuous Series II, task speech rate decreased and switch cost increased as the task became more difficult (see Table 37) – cue groups did not appear to differ from each other noticeably in this regard. Within-category error distribution (see Table 38) did change between groups – 'None' and 'Low' groups returned around twice as many errors as 'High' over 2-categories. 'Low' and 'High' scored similarly over 3-categories, with 'None' scoring marginally less. There was more of a stepped distribution over 4-categories, with errors increasing as the cue became more explicit. No between-category errors were made over 2-categories. All cue types scored similarly over 3-categories. However, there was a marked difference over 4-categories with 'None' scoring around 87% more errors than the two cue conditions.

Age was found to correlate with NART IQ, $r = .54$, $p < .0001$ and with WAIS-R vocabulary, $r = .30$, $p = .001$ (all significance values two-tailed). NART IQ also correlated with WAIS-R vocabulary r = .67, p < .0001, forward digit span r = .30, p = .001, reverse digit span r = .31, p < .0001, CS3$_{\textbf{rate}}$ r = .24, p = .006 and CS4$_{\textbf{rate}}$ r = .26, p = .004. WAIS-R vocabulary correlated with CS2$_{\textbf{cost}}$ r = .19, p = .036. Forward digit span correlated with WAIS-R vocabulary r = .35, p , .0001, reverse digit span r = .55, p < .0001, CS2$_{\textbf{rate}}$ r = .20, p =.025, CS3$_{\textbf{rate}}$ r = .39, p < .0001 and CS4$_{\textbf{rate}}$ r = .44, p < .0001, CS3$_{\textbf{cost}}$ r = -.27, p = .002 and CS4$_{\textbf{cost}}$ r = -.21, p = .018. Reverse digit span showed correlations with WAIS-R vocabulary r = .31, p < .0001, speech rate r = .20, p = .029 and all three rate measures CS2$_{\textbf{rate}}$ r = .34, p < .0001, CS3$_{\textbf{rate}}$ r = .36, p < .0001 and CS4$_{\textbf{rate}}$ r = .41, p < .0001. Consequently both forward and reverse digit span were highlighted as a possible covariates for task speech rate and forward digit span as one for switch cost.

3.4.2 Task speech rate

Task speech rate (see Table 37 and Figure 19) slowed significantly as the task became more difficult, Λ = .06, F(2, 120) = 990.29, p < .0001, η^2 = .94. Post-hoc pairwise comparisons showed this difference to be significant at all levels, p < .0001. There was no significant effect of cue type F(2, 121) = 1.31, p = .273, η^2 = .02 and no significant interaction, Λ = .93, F(2, 240) = 2.25, p = .064, η^2 = .04. Both forward and reverse digit span were stratified – forward digit span (Low M = 5.58, High M = 8.26[80]), reverse digit span (Low M = 3.79, High M = 5.51). These were entered into the analysis to determine any covariate effect. These were found to be independently non-significant: digit span forward (stratified) F(2, 107) = 1.68, p = .192, η^2 = .03; digit span reverse (stratified) F(1, 107) = 0.82, p = .368, η^2 = .01.

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[80] Medium level for forward digit span was a constant of 7

3.4.3 Switch cost

As predicted, switch cost (see Table 37 and Figure 20) increased as the task became more difficult, $\Lambda = .07$, $F(2, 120) = 775.88$, $p < .0001$, $\eta^2 = .93$. Post hoc comparisons revealed this to be significant at all levels, $p < .0001$. For switch cost there was no significant effect of cue type, $F(2, 121) = 2.71$, $p = .071$, $\eta^2 = .04$. There was however a significant interaction between the number of categories and the type of cue, $\Lambda = .92$, $F(4, 240) = 2.62$, $p = .036$, $\eta^2 = .04$. Digit span forward was found to have no independent effect as a covariate on switch cost, $F(2, 115) = 2.09$, $p = .128$, $\eta^2 = .04$.

Table 37 Descriptive Statistics for Whole Sample including Cue Groups (N = 124) for Task Speech Rate and Switch Cost.

	Continuous Series II					
	Speech rate (w/sec)			Switch cost (% w/sec increase)		
Group	2-cats	3-cats	4-cats	2-cats	3-cats	4-cats
Whole sample (N = 124)						
Mean	1.19	0.57	0.32	63.46	81.05	90.31
SD	0.24	0.20	0.10	9.23	6.71	3.41
Cues = None (n = 41)						
Mean	1.23	0.62	0.32	61.57	79.32	90.17
SD	0.23	0.21	0.09	9.89	7.36	3.49
Cues = Low (n = 41)						
Mean	1.16	0.52	0.32	65.87	82.87	90.79
SD	0.25	0.20	0.10	7.51	5.81	3.22
Cues = High (n = 42)						
Mean	1.18	0.56	0.33	62.96	80.96	89.99
SD	0.25	0.19	0.11	9.76	6.54	3.56

‘None’ rate: $M = 0.72$, $SE = 0.02$
‘Low’ rate: $M = 0.67$, $SE = 0.02$
‘High’ rate: $M = 0.69$, $SE = 0.02$
2-cat rate: $M = 1.19$, $SE = 0.02$
3-cat rate: $M = 0.57$, $SE = 0.02$
4-cat rate: $M = 0.32$, $SE = 0.01$

‘None’ cost: $M = 77.02$, $SE = 0.87$
‘Low’ cost: $M = 79.84$, $SE = 0.87$
‘High’ cost: $M = 77.97$, $SE = 0.86$
2-cat cost: $M = 63.47$, $SE = 0.82$
3-cat cost: $M = 80.67$, $SE = 0.79$
4-cat cost: $M = 90.29$, $SE = 0.40$

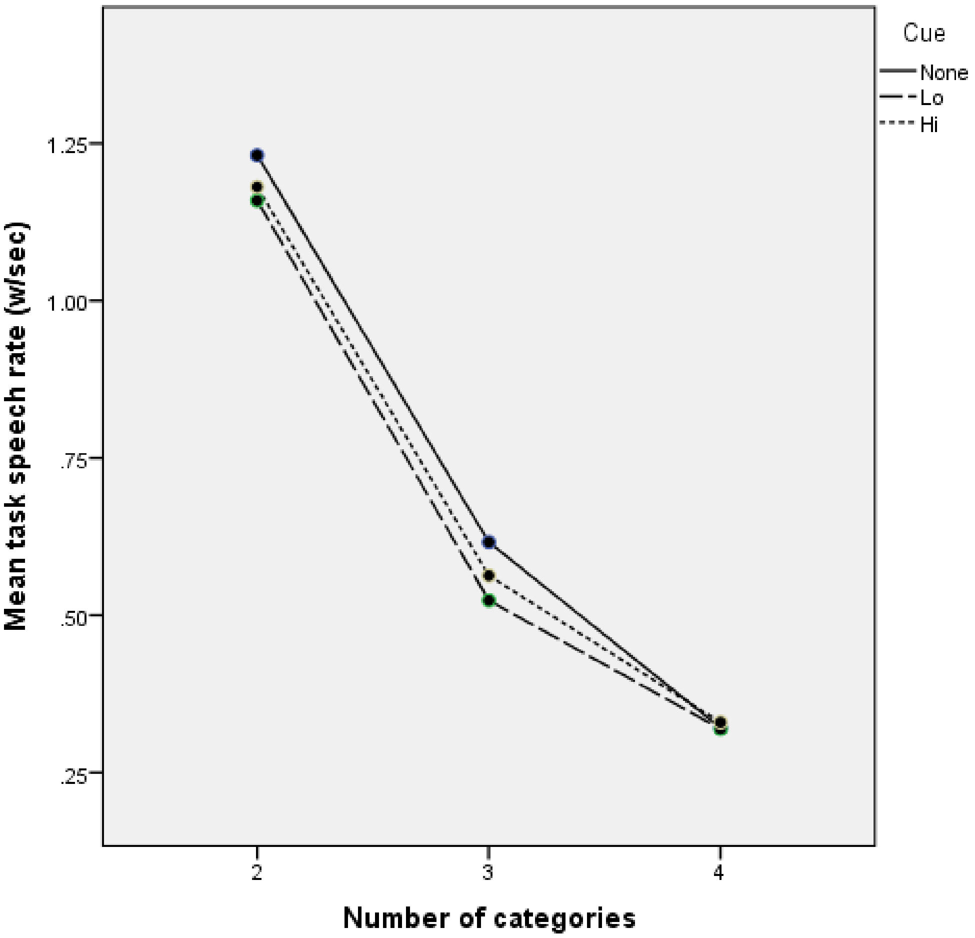

Figure 19 Task speech rate (w/sec) for Continuous Series II in conditions cue = None, cue = Low and cue = High

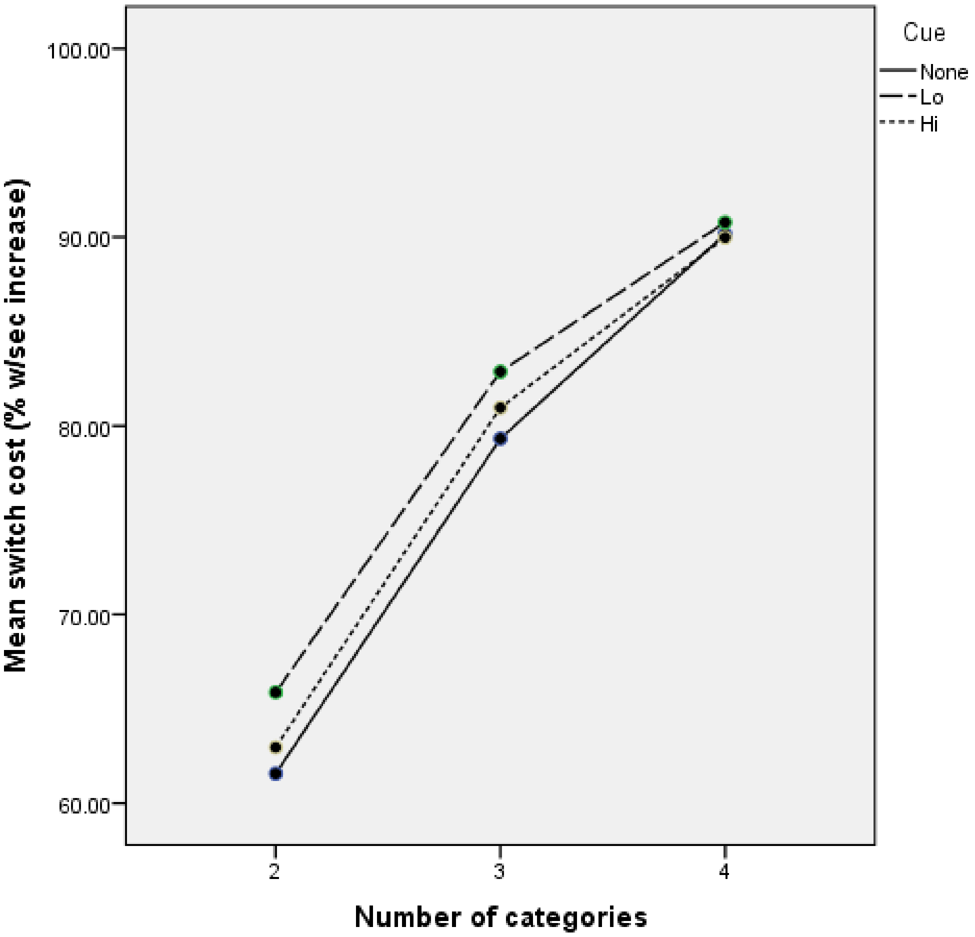

Figure 20 Switch cost (% w/sec increase) for Continuous Series II in conditions cue = None, cue = Low and cue = High

3.4.4 Within category errors

The number of within category errors (see Table 38) was not significantly different between cue groups at any difficulty level: 2-categories, $H(2) = 3.76$, $p = .153$, 3-categories $H(2) = 0.95$, $p = .623$ and 4-categories, $H(2) = 4.92$, $p = .085$.

3.4.5 Between category errors

No between-category errors were made over 2-categories. There was no significant difference between cue groups over 3-categories $H(2) = 0.28$, $p = .870$ but there was over 4-categories $H(2) = 15.54$, $p < .0001$. Post-hoc comparisons using Mann-Whitney tests (at an alpha level of .017) showed this significance to occur between cue groups ‘None’ and ‘Low’ $U = 608.00$, $z = -3.05$, $p = .002$, $r = -0.34$ and cue groups ‘None’ and ‘High’ $U = 618.50$, $z = -3.13$, $p = .002$, $r = -0.34$ but not between groups ‘Low’ and ‘High’ $U = 858.50$, $z = -0.05$, $p = .960$, $r = -0.06$. In both significant conditions the no-cue group scored many more errors than the two cue groups.

Table 38 Descriptive Statistics for Whole Sample including Cue Groups (N = 79) for Within and Between Category Errors.

	Continuous Series II Within-category errors			Between-category errors		
Group	2-cats	3-cats	4-cats	2-cats	3-cats	4-cats
Sample (N = 124)						
Sum	36	506	1382	0	31	66
n	31	102	122	-	8	20
Mean	0.29	4.08	11.15	-	0.25	0.53
SD	0.54	3.76	5.34	-	1.03	1.54
Cues = None (n = 26)						
Sum	17	164	419	0	12	53
n	14	33	40	-	3	14
Mean	0.41	4.00	10.22	-	0.29	1.29
SD	0.63	3.96	5.31	-	1.15	2.34
Cues = Low (n = 27)						
Sum	12	171	505	0	10	7
n	10	33	40	-	3	3
Mean	0.29	4.17	12.32	-	0.24	0.17
SD	0.56	3.09	5.48	-	0.99	0.70
Cues = High (n = 26)						
Sum	7	176	576	0	9	6
n	7	34	42	-	2	3
Mean	0.17	4.07	10.90	-	0.21	0.14
SD	0.38	4.22	5.16	-	0.98	0.65

3.4.6 Self-corrections

Self corrections were analysed to see how many occurred that were corrections *away* from a between-category error (e.g. in category days "March – no, Wednesday"). For this analysis both correct and incorrect self-corrections were considered together – it did not matter whether the correction was to a correct response, only that it was *from* a between-category error. Comparisons were made for each level of difficulty using the Kruskal-Wallis test for several independent samples. For 2-category switching such corrections were only made by the whole word cue group (see Table 39); for 3 and 4 category switching they were made by all three cue groups. Initial letters were highest followed by whole words and no cues. However, results were non-significant: 2-categories $H(2) = 1.95$, $p = .377$, 3-categories $H(2) = 4.58$, $p = .101$, 4-categories $H(2) = 2.72$, $p = .257$. Further to this, for 2-category switching 100% of corrections were made in the absence of between category errors; for 3-category switching 96% of corrections were in the absence of between category errors; for 4-category switching it was 85%.

Table 39 Descriptive Statistics for Self-Corrections from Between-Category Errors..

		2-cats	**3-cats**	**4-cats**
Whole group (n = 124)				
	Sum	1	40	47
	N	1	31	35
	Mean	0.01	0.32	0.40
	SD	0.09	0.63	0.75
None (n = 41)				
	Sum	0	7	10
	N	-	7	8
	Mean	-	0.17	0.24
	SD	-	0.38	0.54
Low (n = 41)				
	Sum	0	19	22
	N	-	15	14
	Mean	-	0.46	0.59
	SD	-	0.71	1.02
High (n = 42)				
	Sum	1	14	15
	N	1	9	13
	Mean	0.02	0.33	0.36
	SD	0.15	0.72	0.58

4 Discussion

Neither task speech rate nor switch cost exhibited a significant effect of cue; in both instances the original task with no cues was the fastest/ least costly and initial letter cues were the slowest/ most costly. Crucially the presumably non-translational full name cue did not have a beneficial effect. Despite the single continuous presentation of cues (assumed to result in reduced cue processing) and use of directly related cues there failed to be a beneficial effect. Foreknowledge in the absence of cued task identity (as in the no-cue condition) is the most effective approach to completing the task. Both measures displayed convergence of cue types at 4-category switching of the type seen previously with different task versions (Experiment 3) and with categories in different orders (Experiment 4). Convergence was previously partially attributed to the beneficial effect of largely error free switching at 2-categories and partially to the slowing effect of switching between 4-categories; in the current study convergence could certainly be due to difficulty related slowing.

As in the Logan and Bundesen (2004) study, full name cues resulted in faster results than initial letter cues (in that study arbitrary), reflecting as they stated the ‘transparent’ nature of the more meaningful cue. In that study the letter is assumed to be translated to the whole word and then used jointly with the target to retrieve the response from memory. In the current study this compound effect is not taking place in the same way, mediated by the fact that the Continuous Series II does not use externally presented stimuli. Internal representation of the category stimuli does not seem to have the same effect as overt presentation. Even though the cue is removing the load from working memory it is not being compounded by the presentation of a visible stimulus as is occurring in the Logan and Bundesen study. The strength of this compound effect is apparently such that, on its own, the processing of the cue exerts a negative effect in that it contributes an extra step to be completed before the response is delivered. The compound cue effect itself is said to be sufficient to facilitate switching in the absence of reconfiguration (Logan & Schneider, 2010). The current study therefore supports those studies which highlight cue processing as an additional contributor to cost (e.g. Logan & Bundesen 2003, 2004), something which is emphasised in the absence of externally presented stimuli. The additional activity required to process the cue carried more weight in the overall cost equation than any beneficial effects to memory.

Switching in the verbal task is predictable; preparation for the upcoming *response* can occur immediately after the last one is delivered. This has been noted by Monsell & Mizon (2006) to elicit the same type of reduction in switch cost as the cueing paradigm. So the no cue condition is perhaps the best level of cost to be achieved in the task – cues introduce an additional level of processing cost not able to be mediated by a compound stimulus presentation. Additionally the fact that full name cues do not have a beneficial effect does not fully equate with the conclusions of Logan & Schneider (2006) who suggest that cues trigger goals, and that goal awareness is adequate for a successful task response. The findings of the current study suggest that the opposing view of cues triggering rules, which in turn facilitate a successful response, may be more appropriate (see Mayr & Kliegl, 2000). Despite Monsell's (2005) assertion that whole word cues entirely mimic and support self-verbalisation, it would seem that processing of even such transparent cues represent and additional costly step. Cues are beneficial (and of course necessary) in random order presentation but are not the most efficient approach for fixed order foreknowledge-based tasks.

Results for within-category errors did not support the hypothesis that errors would be reduced for the two cue conditions. There was no significant difference in the number of within-category errors between cue conditions at any difficulty level. The additional processing of the cue seems to be equally as catastrophic for error production as for speech rate and switch cost. It may have been reasonable to suppose that use of cues would support representation of the task order (mediated by phonological representation of the task as posited by Emerson & Miyake, 2003), freeing up inner speech to rehearse item order and so reduce within-category errors. However, the cost of processing the cues appears to overcome any supposed benefit of this nature. Anecdotally many participants reported that they found processing of the cues to be confusing – they found the extra level of phonological processing to interfere with production of category items. Thus rather than freeing up inner speech it would appear that representation of the externally presented cue is *occupying* this self-cuing device. Foreknowledge of the task, as in the non-cue condition, has the benefit of being a singly 'presented' cue that can be referred to without further effortful processing. Although one of the aims of having a constantly available cue was to prevent constant cue reprocessing this was not the case. The row of cues was read linearly at each iteration of the category order (e.g. numbers, days, months, numbers...). During silent reading the acoustic representations of inner speech are automatically activated (Abramson & Goldinger, 1997), thus there is no capacity for inner speech to be freed up for item rehearsal. Processing of the cue forces the use of inner speech. Again in terms of item accuracy it would seem that even transparent cues are not beneficial for fixed order foreknowledge-based language switching.

Use of a cue was beneficial in greatly reducing but not extinguishing between-category errors when the task was at its most difficult level only. The type of cue used made no difference to the reduction; use of no cue resulted in over seven times as many errors as using either a full name or initial letter cue. Use of a cue therefore did not appear to entirely take over the role of foreknowledge in the task. Alleviation of cues was not triggered until the 4-category switching level – when switching over 3-categories the number of errors was comparable for all three conditions. Task difficulty would seem to be a factor in the usefulness of cues to reduce between-category errors. However, this is not equivalent to the predicted extinguishment of errors. And why was the reduction only seen at the most difficult level? The phenomenon of participants not having to use cues unless stimulus information is ambiguous (in this case unless it is difficult) has been noted as a problem in application of cue use (Mayr & Keele, 2000 – page 55 of this document). When informally questioned after the task a notable number of participants stated that they only actively used the cues when the task reached the most difficult level. This incomplete application of cue use could also explain the continuing low level of between-category error production over 4-categories rather than complete elimination. Additionally the issue of between-category errors is compounded by the commission of such errors which are then corrected. If cues are acting as predicted no such corrections should occur. Corrected between category errors were committed by all three groups (more so by cue groups, but not significantly). The vast majority of such corrected errors were committed in the absence of any *un*-corrected between-category errors, meaning that commission of between-category errors was actually far more widespread than analysis of errors alone shows. The continued commission of between-category errors, both corrected uncorrected (albeit at a reduced rate), would give evidence that costs within the Continuous Series II are not overtly memory related. As such it is possible, along with results from previous experiments, to preclude memory-based explanations of switch cost such as the TSI and associative interference hypotheses that rely on carryover of task set within memory.

5 Conclusions

- Hypothesis 1, that both types of cues would reduce cost, is not supported. Cue processing in the absence of externally presented stimuli to provide a compound effect offers an additional level of processing which adds to overall costs.
- Similarly, hypothesis 2, that both types of cues would reduce within-category errors, is also not supported. Within-category errors are not reduced by the use of cues. Constant unforeseen reprocessing of the cue on every iteration takes precedent in inner speech and very likely interferes with self-verbalisation.
- Finally hypothesis 3, that between-category errors would be eliminated, has also not been supported. Between-category errors are greatly reduced but not eliminated at the most difficult level of the task. Such failure of cues would suggest that memory-based explanations of switch cost do not apply for the Continuous Series II.

CHAPTER NINE: GENERAL DISCUSSION

1 Introduction

The current thesis has examined the Continuous Series II (a task which requires individuals to switch between increasing numbers of overlearned sequences), examining the effects of introducing semantic categories to the task, of changing the order of the overlearned sequences within the task, of manipulating the complexity of items within the sequences (by using single word repetitions instead of overlearned sequences) and of introducing explicit cues to prompt the sequences. It has been shown that the Continuous Series II offers a reliable measure of continuous task general switch cost – cost and errors consistently increase in line with the number of categories being switched between. A degree of this real time whole-task cost is attributable to the updateable 'complex' content of the category tasks. As indicated by the results of Experiment 5, the content of the task (overlearned sequences as oppose to repeated colour words) significantly contributes towards both switch cost and error rate. However, as seen from the results of Experiment 4, the *order* the categories are presented in does not contribute to the overall cost. A proportion of the switch cost in the verbal task is therefore task-related. Nevertheless, the complex nature of these real time tasks has intrinsic value that compensates for this merging of different sources of cost. As noted by Altmann (Altmann, 2004; Altmann & Trafton, 2004), discrete measures of per-switch cost occupy a fraction of the time period taken to complete whole tasks. 'Higher level' tasks such as those used by Altmann & Trafton (2004) (a simulated war strategy task) and the Continuous Series II require a broader measure of whole-time costs to capture the continuous strategy employed to complete the tasks in an environment that includes recovery from, and avoidance of, errors. As such the calculation of a multicomponent whole-task cost is valuable as it reflects the entire process of completing multiple tasks. Faster completion of the task was not facilitated by the inclusion of explicit external cues – reliance on foreknowledge rather than cues resulted in faster responses, although cues were successful in reducing errors. The implications of these findings apply themselves in three main areas as identified in the Thesis Aims – general costs of continuous switching over time, switching in working memory as a separable process to perceptual switching and interpretation of errors during switching. Additionally results are considered in terms of reconfiguration and carryover accounts of switch cost.

1.1 Real time tasks and the use of general switch cost

Switching between continuous tasks over time is not well represented in the literature; Altmann & Trafton (2004) question the usefulness in assessing true *task* switching of the more typical experimental tasks which in effect span one or two switches for the purposes of measuring switch cost. The Continuous Series II measures the cumulative effects of switching over time, as one might do in a real-life instance of multi-tasking (e.g. González & Mark, 2004). Although the constituent tasks themselves (repeating overlearned sequences) are not entirely ‘everyday’, their changing and interactive nature is more in line with the ecologically valid criterion set by Altmann. In all the experiments contained within the current work the Continuous Series II delivered a whole-task measure of switch cost that consistently rose as the number of tasks being switched between increased. As such the task offers a reliable measure of whole-task costs over time in the face of increasing same-task difficulty i.e. difficulty is not increased by introducing tasks of different types. The task reflects the “…global representational structures…” (Kleinsorge et al., 2004, p.31) within which switching behaviour takes place. These account not only for the responses that have been made (current and preceding trial) but also for the potential responses that could have been made for the preceding, current and subsequent trials. It has been demonstrated by Kleinsorge et al. (2004) that certain aspects of switch cost are only apparent when four possible tasks are required to complete a whole block, rather than considering a switch between two tasks in isolation. Costs observed between Task A and Task B in a block where four tasks could potentially be employed were greater than for just an isolated switch between Task A and Task B. They proposed that such costs were separate from mixing costs (which are the extra time it takes to repeat a task in a switch block as opposed to a single task block) representing the cost of maintaining two tasks sets extra to switching. How difficult a task switch is deemed to be (and so how effectively it is achieved) depends on what other potential switches may have occurred in its place, which involves more than just the *maintenance* of tasks sets as is the case for mixing costs. Of course, Kleinsorge and colleagues' interpretation only applies to situations where switching potentially occurs between more than two tasks, but as such is ideally employed in thinking about the calculation of cost for the Continuous Series II. Indeed, it is doubly applicable to the verbal switching paradigm as switching occurs *within* each task (choosing the correct item rather than always making the same response to particular task) as well as between tasks. The global "…task space…" (Kleinsorge et al., 2004, p.39) embeds representations of all potential behaviours. Task switches do not occur in isolation but in the context of a broader range of representations and behaviours, including the need to recover from interruptions (Altmann & Trafton, 2004) which in this context would be posed by errors.

Although trials in the alternating runs paradigm (and others) are *measured* on an individual basis their presentation is within the structure of a lengthy block of trials. Work which has looked specifically at global effects (e.g. Gopher et al., 2000, Kleinsorge et al.,

2004) has done so within the confines of an alternating runs paradigm. However, the current work (more akin to Jersild's (1927) alternating tasks procedure) can still inform in a broad perspective about the nature of general costs as a direct measure. Measuring at the level of per-trial switch cost fails to take account of the influence of tasks which precede, follow and offer an alternative to the one currently being performed (Kleinsorge et al., 2004). Interpretation of data from Experiment 3 in the current work looking at 'local' cost for the Mixed Category II task (local in terms of a single task but not a single trial) incorporated a measure of the switch *to* the subsequent category as well as production of the word within the current category. The pattern of reverse asymmetry in the Mixed Category II task was seen in the context of this subsequent task switch. As such, this broader measure of switching between two tasks rather than for one task switch in isolation has informed an interpretation of switch cost that indicates a lack of carryover from the previous task. Local cost calculation in Experiment 3 accounted for the time taken to switch *to* the current task, calculating cost from the end of Task A to the end of Task B inclusive. As such, the whole-task contributors of disengaging from the previous task, considering the possible alternatives in terms of task *and* task item (as indicated by Kleinsorge et al., 2004), engaging the appropriate task set and (on occasion) discarding an incorrect choice were all accounted for. Any enduring carryover from Task A would have been captured as a delay to any one of these inclusive processes.

In a wider context the findings of Experiment 5, using non-updating colour name 'categories', can account for the effects of a broad global setting. In that experiment, at the most difficult level of the task (switching between four overlearned sequences) the category 'days' departed from the previously seen trend of producing the greatest number of errors. In this instance it could be construed that performance was affected by the last *'block'* (or difficulty level, switching between three overlearned sequences plus one colour category) which was materially different to preceding trials in all other versions of the Continuous Series II. Every stage of the task for Experiment 5 included four categories, the number of colour categories being balanced against an increasing number of overlearned sequences. The constancy of the 4-category condition would have primed the cognitive system to deal with four categories *per se* from a much earlier stage in the task, thus providing practice at producing ‘days’ embedded within four categories, albeit ones with changing internal demands. Thus the ‘global workspace’ that encompassed the whole task had an effect on the pattern of error production. The number of subsequent categories in a constant 4-category run changed the ‘space’ in which the production of the category days occurred.

In terms of the accessibility of more than one task set for the current response, as previously noted, the existence of mixing costs (Fagot, 1994) further emphasise the importance of global considerations (Kleinsorge et al., 2004). In the alternating runs paradigm mixing costs are the reaction time difference between repetitions in switching blocks and pure task blocks – they represent the cost of mixing tasks together but not switching between them, attributed to having to maintain the availability of more than one task set. Experiment 5 in the current work identified *proximity costs* from performing four tasks together regardless of the need to update (as for the overlearned sequences) – in a comparable way to mixing costs they reflected the cost of switching *between* tasks but not switching *within* tasks as was usual with the Continuous Series II. For the verbal switching task the wider global context accounts for the changing *content* of categories as well as a linear combination of preceding/ alternative/ subsequent tasks – the current item within a task (category) has a direct relationship with the last item produced, the next item produced and the range of alternatives that may be produced in its place, so there is a ‘micro global workspace’ in operation as well. Global options (different responses preceding, subsequently or as an alternative to the current response) at the micro/ local level had been removed showing the differential effect of the more complex updating content in the categories. Maintaining availability of alternative responses within each category (quasi-mixing costs) as well as alternatives for task choice are two separate sources for cost – in terms of global effects each is available to have an effect on the other. Updating of items within a category is a feature of the broader task that must impact switching between categories and vice versa.

1.2 Switching in working memory as opposed to perceptual switching

Task *representation* in the Continuous Series II is entirely reliant upon working memory as there are no externally presented stimuli or task cues. Switching between representations in working memory has been noted as separable from perceptual switching (Wager, Jonides & Smith, 2006). Comparison of switching between overlearned sequences and more memory-reliant semantic categories (the Mixed Category task) with the overlearned sequence-only Continuous Series II (Experiments 1-3) has shown that switch cost is increased, partially dependent upon the greater reliance on working memory for one of the task types[81].

In the verbal paradigm it has been shown that working memory representation is more effective than perceptual presentation. In Experiment 6 the introduction of external explicit (whole word) cues did not reduce switch cost, resulting instead in slower responses (though not significantly so). This was interpreted as the additional need to process the cue without the supportive compound cue effect usually found in explicit cueing studies, where cues are

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[81] Increased switch cost is also sourced to the need to switch between two different verbal domains for the two types of verbal category.

accompanied by confirmatory externally presented stimuli. The compound cue effect in the alternating runs paradigm had been found strong enough to facilitate switching in the absence of reconfiguration (Logan & Schneider, 2010) and so the absence of a definitive compounding stimulus had a negative effect on cost. Previously it has been stated (Altmann & Gray, 2002; Altmann, 2004) that maintaining a fixed task order in memory is more efficient than to continually process external cues, due to the need to transform even the most explicit cue into a task response. The current work certainly supports such an assertion, although the continuous presence of cues in Experiment 6 was aimed to reduce the need to continually process them; cue processing could certainly be carried out anew every time there was a perceptual shift to the cue rather than a physical re-presentation.

However, the fact that cues did not reduce cost would also suggest that, as proposed by Gurd et al. (2002), the Continuous Series II does not present a significant *load* to working memory. If the task was overloading a finite working memory resource then alleviating some of this by naming the tasks to be carried out would reduce the load. Working memory load is dissociable from other implicit switching processes (e.g. Barch et al., 1997). We know also that memory switching, such as is performed in the cue-free Continuous Series II is separable from perceptual switching (Wager, Jonides & Smith, 2007). It would seem that, as costs are not reduced by measures that clearly alleviate memory load, such a load is not contributing excessively to general switch costs in the Continuous Series II. Working memory is a reliable facet for carrying out the verbal task but is not excessively loaded, as proposed by Gurd et al. (2002). Cue processing costs are more of an issue than working memory load. Thus memory reliant accounts of switch cost, such as the task-set inertia hypothesis (Allport, Styles & Hsieh, 1994, page 26 of this document) do not seem so applicable for the Continuous Series II.

Switching in memory is more beneficial for the verbal task than semi-perceptual switching (semi in that cues and not stimuli were externally presented). Preparation for the upcoming response can be facilitated directly after the current response has been made, noted by Monsell & Mizon (2006) to be potentially as effective a preparatory period as that afforded by regular explicit cueing. This is at odds with the findings of Wager, Jonides and Smith (1994) who identified that selecting *both* the correct object and attribute to be switched were impaired with a working memory task but not for an externally presented task. They concluded that attributes (for the verbal task the category item) were inevitably rehearsed upon selection of an object (for the verbal task the category) – all attributes were triggered in the way that all potential items might be triggered for an overlearned sequence (e.g. items Monday through to Sunday for 'days'). However, in the verbal task this is not a detrimental process due to the updating nature of the category items – each time a response is made it needs to incrementally advance from the preceding one. As noted costs relating to task switching and item updating inevitably feed into one another but they must also support each other; knowing that the last *item* produced was 'Tuesday' also flags the fact that the next *task* to be produced is 'months'. The particular nature of the Continuous Series II means that conclusions must be drawn cautiously from dichotomous choice task data.

1.3 Interpretation of errors made during task switching

Errors made during verbal task switching were of two types, within-category (incorrect updating of an item e.g. Monday-Tuesday-*Thursday*) or between-category (incorrect order of categories e.g. 'Numbers-*Months-Days*' instead of 'Numbers-Days-Months'). Interpretation of these errors was aligned to Kahneman's (2011) two-system approach to thinking. System 1 (fast and automatic) equated to within-category item errors and System 2 (effortful, slower and executive) to between-category task errors. Other work

(Arbuthnot & Frank, 2000) linked item errors to working memory and task errors to executive functioning. For the Continuous Series II a lack of perseveration (repeating of the last task) for between-category errors in all Experiments was a marked departure from the Arbuthnott and Frank findings (perseveration was seen in the results for neurological patients in Experiment 1). This was interpreted as evidence for greater presence of reconfiguration than inhibitory processes at play during the task. Unlike the Arbuthnott and Frank study participants were always able to switch task, although not always to the correct one – again this presents as evidence for the positive crosstalk between item updating and task changing. This mimics the measures taken by Gilbert and Shallice (2002) in their PDP model of switching to avoid perseverative errors by constantly updating the start state of the trial.

Crosstalk between item and task update is also manifest in results from Experiment 5 where between category errors are eliminated in the non-updating arbitrary colour categories. Switching between categories only becomes problematic when the content of those categories becomes complex and itself requires updating at every category repeat. However, rather than indicating between-category errors are in fact memory related rather than executive this is interpreted as an artefact of task design for this experiment – the repeating colour categories do not present a sufficient amount of executive content as a task to trigger executive errors. This again echoes the assertion of Altmann and Trafton (2004) that tasks need to have sufficient ecological validity as real-world activities in order to measure executive processes during task switching. Thus while the content of task categories may not directly cause between-category errors it does have to be of a type that requires executive processes to be engaged in order for the opportunity for errors to arise. However, in Kahneman’s model there is communication between System1 and System 2. System 1 takes things at face value, which could be another reason for the profusion of within-category errors. The responses are of the correct category so are taken to be the correct responses[82]. This is a detrimental effect of the fast thought system. Errors in System 1 are slow to be detected by System 2 and so may present as System 2 errors if System 2 processing is on the basis of System 1 output. Intuitive automatic System 1 responses are taken for rational System 2 responses and so an error in System 1 (perhaps a pervasive error) could lead to a System 2 error. Mapping of error types between each other would be more informative about this relationship.

One aspect of error production that is task related is the clustering of errors in the category 'days' when the task is at its most difficult level. This was found to be a feature of task type and not of task order as revealed by the variance on category order in Experiment 4. That accuracy costs should be related to the type of tasks being performed indicates that some portion of the general costs calculated for the Continuous Series II are task-related rather than switch-related costs. The increased errors were attributed to the relative 'weakness' of the category 'days' when subjected to proximity effects of three additional categories – the repeated common suffix 'day' in category items was found to obscure the route to item selection in this setting, impeding item production and resulting in a greater number of errors. These increased errors for 'days' (noted also in Experiment 3) were unusually not seen in Experiment 5, which utilised arbitrary colour categories to keep the number of categories constant at four for all levels of the task. In that instance the change in global space to four categories on preceding levels of the task was interpreted as priming the system for proximity effects.

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[82] Referred to by Kahneman (2011) as the 'halo effect', acknowledging something that seems positive and automatically adding to it for consistency.

A particular phenomenon related to between category errors is their tendency to 'switch back' to the correct response (see Chapter 2) – often sequencing errors will occur in clusters of four as two categories will swap over (e.g. *'Days-numbers'* instead of 'Numbers-days') and then after a few iterations will swap back again, seemingly undetected by the participant. It has been noted that self-initiated repairs of phonological errors are very often in response to inner rather than overt speech (Nooteboom, 2005); if the same can be said about content errors of the type seen here then the role of inner speech as a self-cueing device in the Continuous Series II is further reinforced. Given the seemingly automatic nature of the switch back to the correct categories it can be said that cueing by inner speech is particularly effective as it does not seem to be consciously referred to, unlike external utterances such as those noted by Monsell (2005); Baddeley, Chincotta and Adlam (2001) state that repetition of overlearned sequences require little attentional demand so the associated inner speech prompting would similarly follow as a low demand function.

1.4 Verbal switching, reconfiguration and carryover accounts of task switching

It is proposed by Rogers and Monsell (1995) that switch costs relate to additional processing steps required to reconfigure the cognitive system to carry out the upcoming task. Reconfiguration is completed in response to the presentation of stimuli, affecting an external component to control. The alternating runs paradigm used by Rogers and Monsell incorporates a cue for the upcoming task – allowing sufficient time to prepare for the task after the cue has been presented results in a reduction of switch cost as reconfiguration has been completed during the cue-to-stimulus interval (CSI). However, the persistence of a residual switch cost even at the longest CSI has lead others (e.g. Allport & Wylie, 2000) to speculate that switch costs are determined by carryover of preceding task activation and task retrieval processes. Differing task requirements (in the case of Stroop stimuli where a coloured word can trigger either word reading or colour naming) lead to task-set conflict and wrong-task retrieval – the task-set associated with a recently carried out task is triggered and it is settlement of this conflict which leads to switch costs rather than proactive anticipatory reconfiguration.

In Experiment 2 the absence of perseverative between-category errors suggests successful inhibition of the previous task set – activation for the previous category did not endure into the subsequent one, with errors instead mostly indicating the wrong task had been switched to. Error types were not equated as indicators of carryover in Allport's original work (Allport et al., 1994) which instead used a general measure of accuracy. Allport did not determine the source of errors (for example, in the same way as Arbuthnott & Frank (2000) or Gurd (1995)) and so did not directly relate them to the carryover process. Interpretation of verbal between-category errors in this manner lends itself ideally to identification of the type of processes at work, something not readily afforded by the calculation of general switch cost. Switch cost in the verbal task instead appears to be caused by active reconfiguration of task set as evidenced by the successful but erroneous switch made in between-category sequencing errors.

In Experiment 5, where the Continuous Series III included arbitrary non-updating colour categories, the link between task content and switch cost (much more costly for overlearned sequences) initially suggested reconfiguration as an unlikely cause of switch cost in all forms of the Continuous Series task. A major assumption of the reconfiguration account is that the time needed to reconfigure (which switch cost is said to represent) is independent of properties relating to the tasks (Chamberland & Temblay, 2011). There is a functional distinction between executive processes and task processes. However, the nature of the content in the verbal switching task (overlearned sequences) may provide a caveat to this. The lack of attentional demand required by recitation of overlearned sequences (Baddeley, Chincotta & Adlam, 2001) suggested separation of task related load and attentional switching processes – it is possible to recite such sequences with minimal attentional input. This would suggest that there is after all separation of task related load (recitation of the sequences) and attentional switching processes, due to the ‘special’ nature of the tasks. Thus a reconfiguration based source for switch cost cannot be precluded. Between-category sequencing errors again show support for this reconfiguration based cost. Such errors could reflect a blocking of the phonological loop, due to recitation of overlearned sequences as suggested by Baddeley et al. (2011).

Further evidence in support of a reconfiguration-based account comes from the Mixed Category II task, which alternated switching between overlearned sequences and semantic categories and showed a result of reverse asymmetry when local per-category switch cost was compared in Experiment 3. Asymmetry typically occurs in Stroop-type tasks where it is harder (more costly) to switch to the easier task (e.g. Allport, Styles & Hsieh, 1994) and is said to show enduring carryover of activation for the – reverse asymmetry presents as more intuitively being harder to switch to the more difficult task (e.g. Monsell, Yeung & Azuma, 2000) and refutes the carryover account, linking asymmetry to the relative ability of tasks to interfere with each other rather than a widespread repeatable effect. In the Mixed Category II task it was less costly to switch to the easier task type of overlearned sequences, deemed to be such due to their faster repetition during the non-switching condition and less reliance on verbal working memory. As such there was no evidence of carryover of activation from the preceding harder task type of semantic category production; the pattern of reverse asymmetry tied in more with the supposition of relative strength of interference (Monsell, Yeung & Azuma, 2000) – the semantic category task did not exert sufficient interference with the well embedded overlearned sequence task and so the more intuitive reverse asymmetry of being easier to switch to the easier task was displayed, contesting the existence of a uniform and reliable carryover of activation from the last task.

In non-switching baselines for the Continuous Series II[83], processing would be somewhat similar to non-switch trials in the alternating runs paradigm (see Figure 21A). Stimulus onset and encoding would be represented by foreknowledge of the task. Identification would be a confirmatory process. Response selection would very likely take longer as there are a range of possibilities – checking against the last response made would need to be carried out[84]. Response executing would be identical (see Figure 22A). During switching, the process would be somewhat different, but still comparable to that proposed for the TSR hypothesis (see Figure 21B). Foreknowledge and confirmation would be a more dynamic process as there would be up to four potential possibilities, in the absence of overt stimulus onset. This stage would involve template checking (see Figure 2B). Response checking also takes on a more dynamic role as this has to be done for both task and item. These would be areas where general cost for the Continuous Series II would be lengthier than cost for the alternating runs paradigm. Task (or ‘stimulus’) selection has already occurred at the earlier template checking stage but additionally it needs to be checked against the last task carried out (separate from checking against the template). This second levels of checking

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[83] Where categories are recited in order at speed

[84] For the semantic categories in the Mixed Category II task this would need to be checking against all previous responses made.

occurs after the ‘stimulus’ (the task) can be said to have arrived from the template checking stage.

Endogenous control is implicated during switching to oversee template checking, response checking and response selection in light of the need to switch away from the previous response made. Reconfiguration occurs in the attention shift from one task to the next, which must occur at all of these three stages. Breakdown of the reconfiguration process (posited as an effortful, executive, System 2 failure) can result in a failure to switch correctly and production of the wrong category. This failure can occur in checking the template, in checking the response or in selecting the response. As stated by Monsell (2003) such reconfiguration may also involve inhibition of the previous task set as well as activation of the upcoming one. Evidence from the current work would suggest that inhibition is successful in the verbal task (as evidence by the lack of perseverative between-category errors) but that failure can occur in subsequent activation.

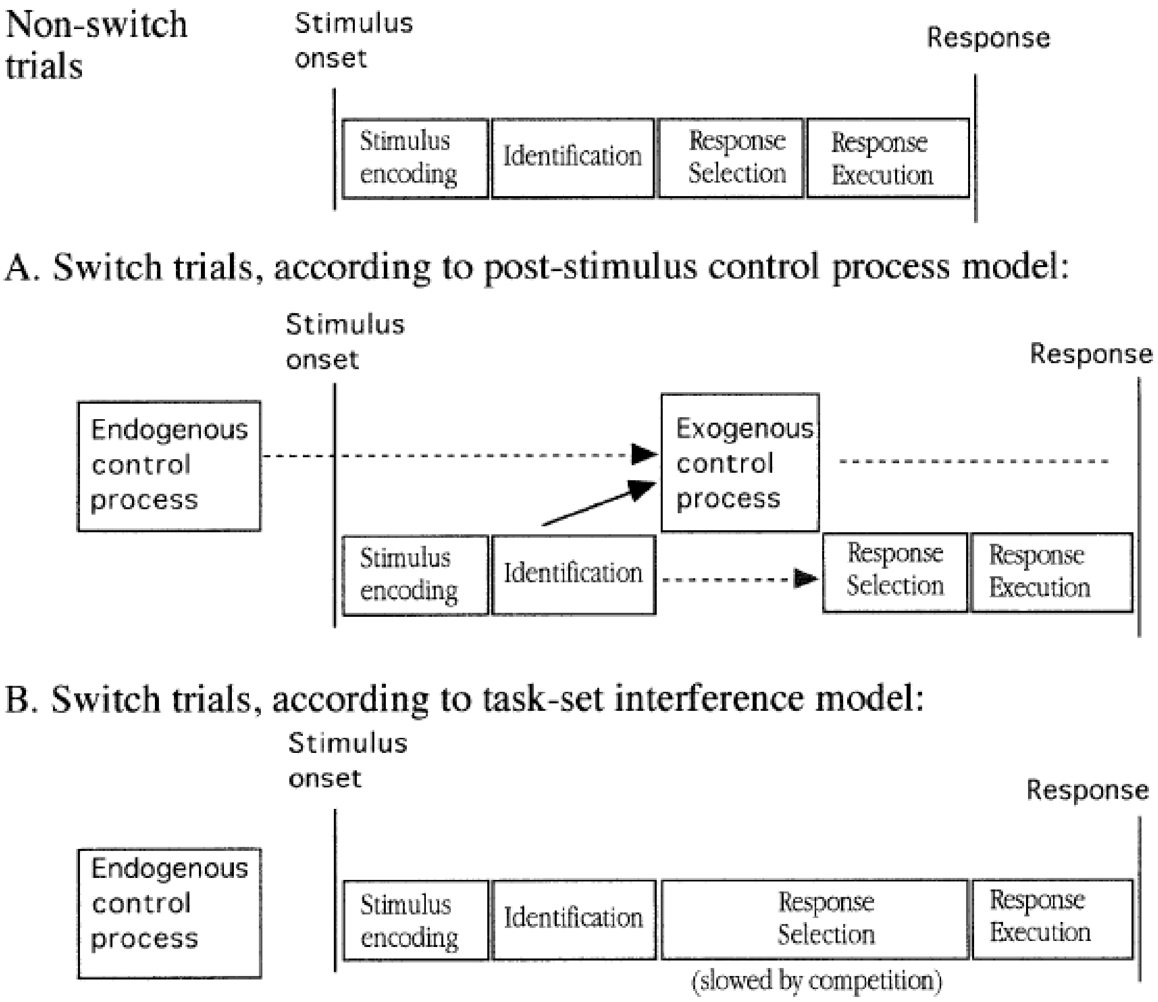

Figure 21 Representation of the task-set reconfiguration (TSR) account, where an extra process takes place on switch compared to repeat trials and of the task-set inertia (TSI) account, whereby carryover of priming from previous trials slows response. Taken from Monsell, Yeung & Azuma (2000)

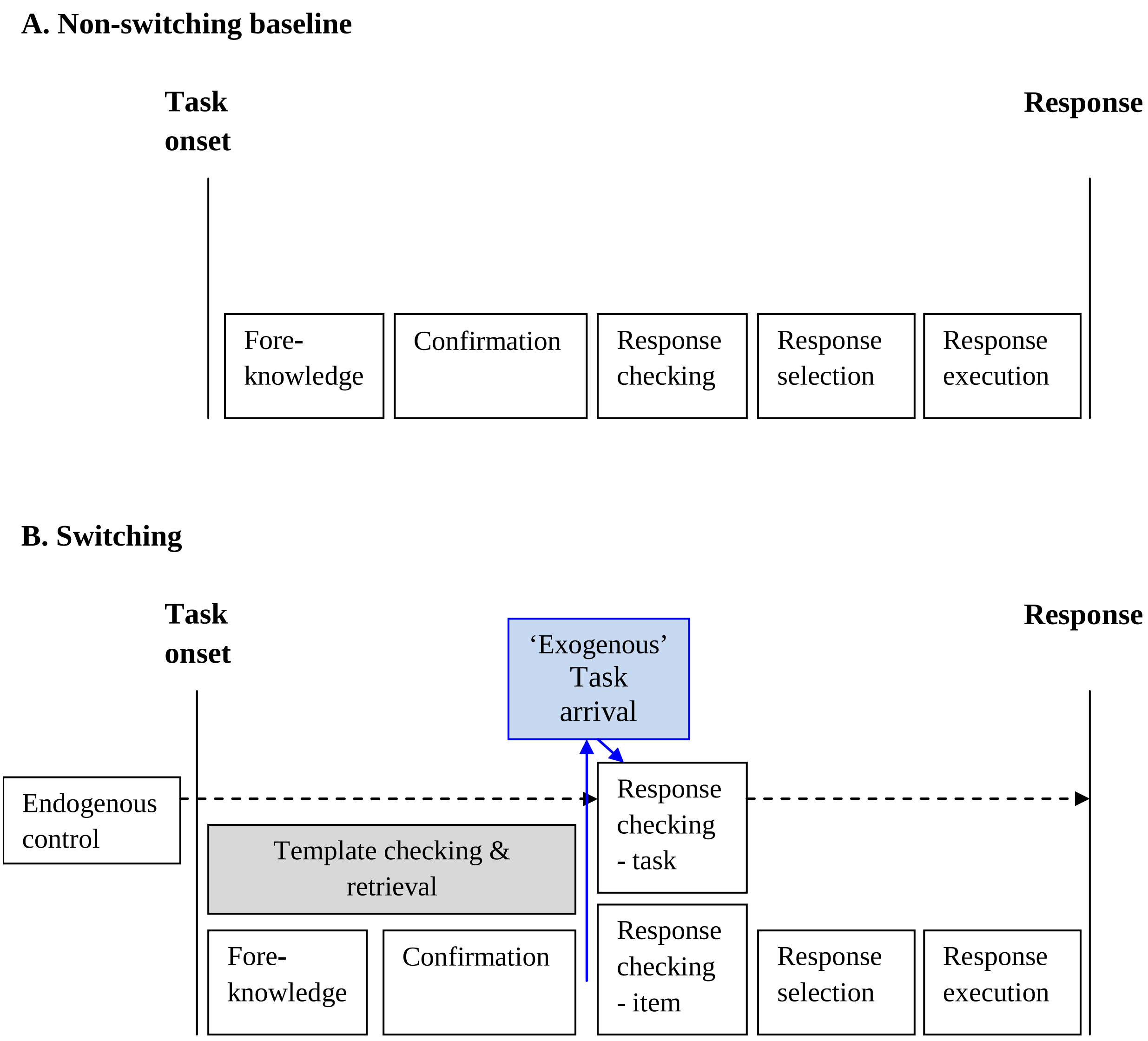

Figure 22 Application of a modified version of TSR to Continuous Series II switching. Stimulus encoding and identification encompasses confirmation against template checking in memory, resulting in arrival of the 'exogenous' stimulus (task). Further checking occurs post-arrival, with identical response selection and execution

Exertion of endogenous control, albeit more dynamically and in a way that is more time costly, is therefore clear in the Continuous Series II. However, one element of the TSR hypothesis that appears absent from verbal switching is the arrival of an external stimulus to complete reconfiguration – the source of residual cost. This thesis has previously spoken about the ‘arrival’ of stimuli in the verbal task – however, this surely is under the influence of *endogenous* control, by virtue of retrieval of task order from memory. Does this present a problem for a TSR interpretation of the Continuous Series II? At first glance it would seem there is no scope for an exogenous completer in the Continuous Series II. Control of task (or ‘stimulus’) *arrival* is top-down and intentional. However, could it be argued that once the task has been endogenously retrieved it is exogenously available to be responded to? The task (or ‘stimulus’) is there to be responded to in the same way as if it had been presented externally. It is only the method of its arrival that is different.

Exogenous control is “…bottom-up, involuntary, automatic, and stimulus driven…” (Rubin & Koch, 2006, p.1034). According to Rogers & Monsell (1995) task set reconfiguration cannot complete until the stimulus appears. The appearance of the stimulus triggers the task sets associated with it. In the Continuous Series II searching days of the week is not activated until the task ‘days’ is presented to the system. The stimulus (or the task) itself prompts an individual to perform actions that are associated with it. This happens regardless of prior top-down intention and can indeed conflict with prior intention. The preponderance of perseverative errors in patients with frontal damage illustrates a failure to respond to exogenous control – this is a failure to respond to a stimulus attribute (Rogers & Monsell, 1995). Indeed, such errors are seen in Experiment 1 (Chapter 3) in the single case series of neurological patients. In the case of bivalent stimuli exogenous control can evoke an inappropriate response which has to be overcome by endogenous control. The current verbal task does not use bivalent stimuli but several responses are prompted by each stimulus by virtue of their sequential nature. The arrival of the stimulus (task) in the process after template checking, and before subsequent item and task checking against the last response, constitutes exogenous control as presented in the TSR hypothesis (See Figure 22B in comparison with Figure 21).

2 Limitations

2.1 Task-related costs

A number of costs identified in relation to the verbal switching tasks are task related rather than indicative of the switching process. These costs are error costs and so outside the remit of a holistic general measure of *reaction time* switch cost, other than the degree to which error commission and recovery contributes to that cost. Evidence of task related costs limits the extent to which results can be interpreted as indices of executive control processes. Experiment 5 shows that between-category errors in the Continuous Series III task (using a constant 4-categories with decreasing numbers of arbitrary colour categories) only occur when the content of those categories are sufficiently complex as to trigger executive processing on the content. Results from Experiments 3 and 4 indicate the possibility of a task-related artefact in the increased rate of errors for the category ‘days’ at the highest level of task difficulty, which occurred wherever the category was placed within the task order; increased error production was attributed to suffix repetition (‘day’) for category items, weakening the effectiveness of task and item maintenance.

2.2 Calculation of general switch cost

While the inclusion of effects from the 'global workspace' (Kleinsorge et al., 2004) undoubtedly add holistic and ecological value to the overview of behaviour during verbal task switching, the calculation of general switch cost is necessarily limited in the degree to which specific contributors to overall cost can be identified. The inclusion of local 'per category' switch cost (see Experiment 3) refines this to an extent but in hindsight would be more informative if based on the inter-task gap alone rather than including last-task production costs. Experiment 5 would have been better able to attribute cost as task or switch related in response to differing task content with these measures. Additionally the Continuous Series II more closely follows the alternating tasks design proffered by Jersild (1927), resulting in a subtractive measure of switch cost compared to non-switch cost (see page 18). This has been criticised on the basis of differential numbers of tasks having to be held in working memory for switching and non-switching conditions, an issue addressed by the alternating runs paradigm (Rogers & Monsell, 1995 – see page 24 of this document). The continuous category-as-task design of the Continuous Series II does not lend itself directly to an alternating runs approach[85] and so any potentially additional costs from the alternating tasks design must be absorbed and acknowledged within the measure of general costs, balanced against the advantages of using a holistic measure of all costs involved in switching and more everyday real-time tasks (Altmann & Trafton, 2004). Per-trial measures may be more flexible in allowing for analysis of within-trial factors such as the response-to-stimulus interval, but global contributors (which undoubtedly factor into any measure of cost) are lost by this method. The methodological limitation here is how far comparisons can be made between verbal task switching experiments and other studies (such as the interpretation of

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[85] Although see section 'Direction for future work' for a suggestion as to how an approximation of this might be achieved.

verbal task switching in terms of reconfiguration and carryover explanations), though given the wide range of methods and tasks employed in the field this is not an unusual problem.

3 Directions for future work

3.1 Applying the alternating runs paradigm to verbal switching

To further investigate the conclusions drawn from the current work the task could be investigated using a local-switch cost alternating runs paradigm. Using experimental software the task could be presented on an incremental basis, with a visual cue presented before each response is due. Voice-activated timing via a microphone would measure the cue to response interval. This would not allow for manipulation of the response to stimulus interval (RSI) as in traditional experiments but it would allow for more accurate measurement of the time taken to produce a response. The cue signifies the switch to be made and does not require another level of stimulus (it would be difficult to foresee what such a separate stimulus would be). This would be of particular benefit for the Mixed Category II task (Experiment 3, Chapter 5). The task could be presented with repeats embedded in the mixed task block in the format A-A-B-B (Number, Number, Day, Day…), extended for the more difficult levels of switching (Number, Number, Day, Day, Month, Month…). This would not be identical to the original alternating runs paradigm but would allow criticisms of the Continuous Series II to be addressed.

3.2 Analysis of pre- and post-error responses

An analysis of pre- and post-error responses in relation to those errors would assist in determining both the cause and effect of incorrect responses and setting error production in the wider context of processes underlying switch cost. Post-error slowing during task switching has been reported in various age groups (Themanson, Hillman & Curtin, 2006; Gupta, Kar & Srinivasan, 2009). This is akin to Altmann's post-interruption resumption lag (Altmann & Trafton, 2004), although the intended analysis would focus more on the nature of the response that the time taken to execute it. Many individuals completing the Continuous Series II commit errors in clusters. Mapping these to the surrounding pattern of self-corrections and subsequent additional errors will give a more complete picture of verbal task switching behaviour. In particular the relationship between self-corrections and errors can be explored – error repair can be delayed i.e. further responses are made before the error is addressed, or they can be immediate. Self-corrections are often of the type specified by Levelt (1989) as instant, where the replacement response is the first word of the repair – however, unlike Levelt's observations error repairs are not always conservative in that additional utterances to replacement target responses are sometimes made. Delayed self-corrections could suggest a degree of enduring carryover as awareness of the error responses continues into production of subsequent categories. The lack of conservatism in error corrections would again suggest that in at least some instances carryover of a previous task set occurs as the repair of the error requires disambiguation between responses, as evidenced by the unusual (according to Levelt) additional utterances. Such indicators of task set carryover in an otherwise reconfiguration biased account of switch cost during verbal task switching warrant further analysis.

3.3 Introduction of planned interruptions

The effect of interruptions on complex tasks has been shown to result in a ‘resumption lag’, a reduction in RT for a period after the interruption. Post-interruption responses take time to build up into a competent set in memory on which to draw for subsequent responses (Altmann & Trafton 2004, 2007), taking several seconds and task responses to complete. This has been described this as the need to reconstruct context in the original complex task (Altmann & Trafton, 2007). Anecdotally a number of participants carrying out the Continuous Series II experienced self-imposed interruptions when their mobile telephones went off unexpectedly during the test session (any such sessions were excluded from final analysis). A similar type of slowing to that recorded by Altmann was seen, with individuals taking time to build up ‘momentum’ in the task after the interruption[86]. Slowing was often accompanied by a repetition of the last few responses seemingly in an effort to regain the correct placement in categories and items. It is proposed that planned interruptions are added to the Continuous Series II, either by use of a telephone or by a confederate knocking on the door and entering the room. Recent work (Stoet et al., 2013) used a telephone call to interrupt task switching between planning tasks. Either method could be used to deliver an interrupting task such as a simple arithmetic problem, making the interruption more comparable to that used by Altmann – he interrupted a computer game with a superimposed screen displaying a classification task (Altmann & Trafton, 2007). The time course of actions following the interruption would reveal whether the recovery matched Altmann’s model of subsequent post-interruption responses (and their subsequent representations) building up to a reconstruction of the original task environment.

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[86] Self-corrections, comprising of a pause and reiteration of a response or cluster of responses, also constitute interruptions (Levelt, 1989) although don’t offer the possibility of control in the same way.

3.4 Verbal task switching using cues in an older adult sample

A pilot study using the cued version of the Continuous Series II (Experiment 6, Chapter 8) on older adults was carried out as preparation for the current work. Individuals aged 60 years and older were reluctant to continue with the task once they started committing errors, instead opting for early cessation. Some commented that they found cues distracting – given the greater reliance on verbal self-cueing in older adults (Kray, Eber & Lindenberger, 2004; Kray, Eber & Karbach, 2008) this could shed more light on the underlying processes of the verbal task. As aging is known to deplete executive functioning (Rabbitt, 1968) it is presumed that there are fewer ways in which a person is able to affect a switch between one task and another, so resulting in greater switch cost and less accuracy. Use of cues should therefore benefit this population but in some individuals seem to clash with reliance on self-cueing. Perseverative errors are more common in an older population (West, 1996); during switching this is possibly due to problems with set shifting rather than initiating rule-based behaviour or monitoring of performance. The lack of perseveration in the verbal task has been attributed to successful inhibition of the previous task set (Experiment 2); administration of the task to a sample who are more likely to experience difficulties with inhibition would give more scope for successful application of cues.

3.5 Gender differences in verbal task switching

Much popular interest has been engendered by recent work (Stoet et al., 2013) which highlights a female advantage in executing planning tasks during switching. Samples used in the current work were largely female so no gender comparison was possible. However, those individuals who excelled at the task were all male – general switch cost has been found to be faster for males (although no differences were found on specific task costs) (Reimers &

Maylor, 2005). Despite the popular assumption that women excel at multitasking the question is under researched in the literature. The current work took the stance that any factors relating to gender differences were varied and as such did not present a consensus view that gender would be a significant variable. However, the anecdotal finding that faster accurate completion of the verbal task was a male trait warrants further investigation, particularly in light of the discussion surrounding work by Stoet et al. (2013). Work using real-time switching tasks (completing word search and Sudoku puzzles) found females performed comparably to males and indeed were *less* likely to switch in a self motivated switch condition (Buser & Peter, 2011). Findings on gender effects for more complex switching tasks are varied and further analysis using the Continuous Series II would add to the as yet unclear picture of this variable, clouded as it is by popular assumption.

4 Final Conclusion

The Continuous Series II offers a multi-component general measure of switch cost over conditions of increasing task difficulty, encompassing switch, proximity and task specific costs and preceding, subsequent and alternative task responses. The task is suitable for individuals with a range of neurological deficits and is stable under a number of different manipulations. As such it is a useful tool for the measurement of switching over time for a more complex real world task.

The measure of general switch cost reflects strategies and processes applied over the time course of the task. A degree of preparation and control of localised switches occurs globally – the structure within which switches are embedded affects them at a local level.

General costs over subsequent trials (Experiment 5) as well as within a single trial have been shown to have an effect on performance, expanding the scope of influence within the task. In this way proximity of additional tasks or categories has been shown to have a similar effect as mixing costs. Additionally measures of per-category cost (Experiment 3) show the effect of the task being switched to; the global workspace in which tasks and switches are embedded contribute to all measures of cost.

Reliance on switching in working memory as oppose to perceptual switching is successful for the Continuous Series II, although there are limitations on the degree to which comparisons can be made between tasks relying on these two faculties. Memory load is not excessive and this is not a limiting factor for the task, bringing into question the suitability of carryover-based accounts of switch cost. Introduction of external cues (Experiment 6) failed to enhance performance on the task as the additional processing of cues was not cancelled out by compound stimuli as would be the case in more regular cueing experiments. The preparatory period afforded by the structure of the task in the non-cued condition was sufficient to allow adequate preparation. The naturally updating nature of categories within the overall task facilitated attribute selection once the individual task (category) had been selected, indicating that verbal switching of overlearned sequences lends itself to working memory reliance.

Error patterns suggested inhibition of previous task sets were being completed successfully and so indicated reconfiguration as a more likely source for switch cost. Crosstalk between item and category updating, rather than direct equation of within-category errors with memory and between-category errors with executive processes, was evident within the task. Certain aspects of error production, such as the lack of between-category errors found in colour categories for Experiment 5 and general clustering of errors around the category ‘days, were noted as task artefacts – task related factors have already been noted as limiting the general applicability of findings from the verbal task.

Overall, switch cost in the verbal task appears to be determined by active reconfiguration of task set rather than passive carryover of previous task set activity, something which has not previously been proposed for the task. The general lack of perseverative errors between tasks suggests there is no enduring conflict between task sets to be resolved. As task and attentional processes are taken to be separable the link between task content and switch cost seen in Experiment 5 does not preclude a reconfiguration account. Reverse asymmetry in the local cost comparison of Experiment 3 further served to refute any carryover of preceding task set activity. Cautious acceptance of a reconfiguration basis for switch cost can be made, with the caveat that a lack of comparable finite per-switch cost measures for the verbal task limits the extent to which comparisons can be made between the verbal paradigm and alternating runs studies. However, at this time reconfiguration offers a far more convincing basis for switch cost than a passive carryover account.

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APPENDIX A: INSTRUCTIONS FOR VERBAL TASK SWITCHING

1. Baseline measures

Original task/ Order effects (Experiment 4) / Cues (Experiment 6)

“When I tell you to start, I’d like you to recite numbers from 1 to 20 as fast as you can. When you get to 20, start again immediately at 1 and keep repeating that sequence over and over as fast as you can until I tell you to stop. Do you have any questions? Are you ready? Go!”

[Repeat for days (sequence running from Monday through to Sunday), months (January to December) and letter of the alphabet (A to Z)]

Mixed task (semantic categories and overlearned sequences, Experiments 1-3)

[Follow previous instructions for overlearned sequences and following instructions for semantic categories]

“When I tell you to start I’d like you to tell me as many different types of animal as you can think of – they can be any animals and in any order, but don’t repeat yourself. I’d like you to try and do this as fast as you can and to keep going until I tell you to stop. Do you have any questions? Are you ready? Go!”

[Repeat in exactly the same way for all required semantic categories.]

Dummy categories (Experiment 5)

[Follow previous instructions for overlearned sequences and following instructions for semantic categories]

"When I tell you to start I'd like you to repeat the word 'red' over and over as fast as you can – I'd like you to keep going until I tell you to stop. Do you have any questions? Are you ready? Go!"

[Repeat in exactly the same way using the colours blue and green.]

2. Switching

Original task/ Order effects (Experiment 4) / Cues (no cue condition, Experiment 6)

Practice:

"What I'd like you to do now is to alternate between telling me words from two of the categories I have just asked you to repeat – I'll explain how I want you to do this. The two categories are going to be numbers and letters. The idea is to keep each category in the correct order as you have just done, but to alternate between telling me a word from each one – number, day, number, day. For example, 1/ Monday/ 2/ Tuesday/ 3/ Wednesday and so on.

Let's try that out – starting with 1 and Monday, I'd like you to recite numbers and days in order but alternating between the two. The days will have to keep cycling round (as you did previously) as there are only seven of them, but this time the numbers will just keep going up and up – there is no need to stop at twenty as you did before. So when you get to "7/ Sunday" the next number will be '8 and the days will have to start again at 'Monday'. Do you have any questions? Are you ready? Go!"

[Allow the participant to go through ten iterations of the task order. If they are having difficulties or misunderstand the instruction allow them to continue for another ten. At this stage, either before or after attempting the practice session, it may be necessary to refer the participant to a printed version of the correct responses, highlighting the incremental change in the number sequence and the point where the day sequence starts to repeat.]

Full task:

"Now I would like you to try that again but this time carry on for longer – I will tell you when to start and when to stop. There are a few rules for this longer version. I'd like you to try and complete the task as fast and as accurately as you can. I won't be giving you any feedback while you are doing this, so I cannot indicate whether your responses are correct or not. However, even if you think you've made a mistake try to keep going for as long as you can. This time I don't want you to start with '1' and 'Monday' – I'd like you to start with the number '6' and the day 'Tuesday' and to keep each category in the correct order from that point onwards. For example, the response would be "6/ Tuesday/ 7/ Wednesday/ 8/ Thursday" and so on. Do you have any questions? Are you ready? Go!"

[It may be necessary to clarify that numbers and days are not tied to each other i.e. the starting point of 'six' and 'Tuesday' is permissible as the number six is not bound to Thursday as the sixth day of the week]

"Now I'm going to make the task a little harder. I'd like you to do the same thing again but this time using three categories – numbers, days and months. I'd like you to start now with the number '4', the day 'Friday' and the month 'October'. Remember to try and do this as fast and as accurately as you can, and to keep going until I tell you to stop. Do you have any questions? Are you ready? Go!"

[Instructions are repeated with the addition of the category 'letters' for four category switching, using the start points 'nine', 'Wednesday', 'February' and 'eight'. The cues version of the task follows the same category order and use the same start points at each stage of the task. The order effects version uses a different category order for each of its five conditions. When switching between four categories, all versions of the order effects task use the same start points, although categories are necessarily in varying orders]

Dummy categories (Experiment 5)

Practice:

"What I'd like you to do now is to alternate between telling me words from two of the categories I have just asked you to repeat – I'll explain how I want you to do this. The two categories are going to be numbers and the colour red. The idea is to keep numbers in the correct order, increasing by one every time (one, two, three...), but to alternate between telling me a number and saying the colour 'red' – number, red, number, red. For example, 1/ red/ 2/ red/ 3/ red and so on.

Let's try that out – starting with one and red, I'd like you to recite numbers as you did before but saying the word 'red' in between each one. Do you have any questions? Are you ready? Go!"

[Allow the participant to go through ten iterations of the task order. If they are having difficulties or misunderstand the instruction allow them to continue for another ten. An additional short practice session is required for this version of the task as switching between overlearned sequences is not introduced until the second stage of the task, unlike all other versions]

Practice when two overlearned sequences introduced:

"I'd like you to try that again but this time with three categories – numbers, letters and the colour red. So this time you need to keep both the numbers and the letters in their correct orders, followed by the colour red – number/ letter/ red/ number/ letter/ red. For example, 1/ A/ red/ 2/ B/ red/ 3/ C/ red and so on.

Let's try that out, starting with 1, A and red. Keep the numbers and letters in the correct order and alternating between the three word categories. And don't forget to say red! Do you have any questions? Are you ready? Go!"

[Allow the participant to go through ten iterations of the task order. If they are having difficulties or misunderstand the instruction allow them to continue for another ten. At this stage, either before or after attempting the second practice session, it may be necessary to refer the participant to a printed version of the correct responses, highlighting the incremental change in the number sequence and the point where the day sequence starts to repeat.]

Full task:

“Now I would like you to try that again but this time for longer and with more word categories – I will tell you when to start and when to stop. There are a few rules for this longer version. I’d like you to try and complete the task as fast and as accurately as you can. I won’t be giving you any feedback while you are doing this, so I cannot indicate whether your responses are correct or not. However, even if you think you’ve made a mistake try to keep going for as long as you can. We are using four categories this time, a mixture of the sequential categories and the repeated colour names – they will be ‘numbers’, ‘red’, ‘green’ and ‘blue’. So the numbers will have to be kept in the correct order but the colours stay the same every time. Unlike before, the numbers aren’t going to stop at 20; they’ll just keep going up and up. I’d like you to start with the number ‘3’, followed by ‘red’, green’ ‘blue’. For example, the response would be “3/ red/ green/ blue/ 4/ red/ green/ blue” and so on. Do you have any questions? Are you ready? Go!”

Instructions for increased OS categories:

“Now I’m going to make the task a little harder. I’d like you to do the same thing again but this time using two sequential categories and two colours – ‘numbers’, ‘days’, ‘blue’ and ‘red’. I’d like you to start now with the number ‘6, the day ‘Tuesday, followed by ‘blue’ and ‘red’. The numbers will keep going up as before but the days will have to cycle round as there are only seven of them – the colours still repeat every time. Remember to try and do this as fast and as accurately as you can, and to keep going until I tell you to stop. Do you have any questions? Are you ready? Go!”

[Instructions are repeated using the categories ‘numbers’ (start point ‘4’), ‘days’ (start point ‘Friday’), months (start point ‘October’) and repeated category ‘green’. The final version of the task uses no repeated colour names and is the same as for the original instruction].

APPENDIX B: PARTICIPANT RECRUITMENT LEAFLET

Would you like to take part in psychology research into multi-tasking?

Students and staff welcome ☺

- We are investigating how people are able to carry out several different tasks at once - for example, like typing an email and talking on the phone at the same time.
- The study takes about 30 minutes to complete and involves reading and reciting different types of English words under different conditions

Everyone (non-psychology students & staff) who takes part will be entered into a draw to receive one of two prizes of £20

Due to the nature of the task, we are currently recruiting right handed people who have English as a first language, with normal hearing and no speech or language problems. Full details given at the study website.

Psychology students - please sign up via Sona so you can receive course credit. Cash draw is in lieu of course credit for non-psychology students and staff only.

For more information on the study, participant profile and to sign up, please go to:

http://www.surveymonkey.com/s/HFKXCV5

Or contact me on:

f.essig@herts.ac.uk

APPENDIX C: PARTICIPANT INFORMATION SHEET

Researcher: Fiona Essig

Phone: 01707 284 761

E-mail: f.essig@herts.ac.uk

Affiliation: School of Psychology, University of Hertfordshire

Introduction

I am a PhD student conducting research assessing task-switching skills. Task-switching is something we all do frequently in our everyday lives, often without realising; for example, if you are reading a book and hear someone call your name, your attention switches from reading the book to listening to the person calling you.

If you consent to take part you will initially be asked a few questions about your background. Then you will then be asked to carry out some verbal tasks involving explanation or repetition of various words. Following this you will be asked to switch between different language tasks (full instructions will be given before we begin). The session will be audio recorded for transcription purposes. There is no right or wrong way to do the tasks and you cannot pass or fail. No judgement will be made about you based on your performance. Please be assured that you can withdraw from testing at any time without explanation, should you wish to do so. All participation is anonymous and confidential; no information that could identify you will be stored along with any of your scores. Participation records (including any audio recordings) will be destroyed at the earliest possible opportunity. **It is expected that testing will take approximately 30 minutes.**

At the end of the session you may ask for more details about the experiment, although it will not be possible to give feedback on your individual scores. If you have any questions at a later date or would like to discuss anything about the study, please feel free to contact me (details above).

This study has been approved by the Ethics Committee of the School of Psychology under delegated authority from the Ethics Committee of the University of Hertfordshire – Protocol no. PSY 10/05/FE

If you have any questions before we begin please ask. Thank you for your participation.

APPENDIX D: PARTICIPANT CONSENT FORM

The nature and purpose of the assessment procedures to be used have been explained to me and I have had an opportunity to discuss this with the researcher. I understand that I have the right to withdraw my consent at any time and without giving a reason, and that my participation will be anonymous.

I **do / do not** (delete as necessary) voluntarily consent to take part in this research.

Name (participant) . . . .

Signed . . . .

Date . . . .

I **do / do not** (delete as necessary) voluntarily consent to this testing session being audio recorded.

Signed (participant) . . . .

Date . . . .

Signed (researcher) . . . .

Date . . . .

APPENDIX E: DEBRIEFING SCHEDULE FOR VERBAL TASK SWITCHING

[Instructions to researcher are given in square brackets. If at any stage the participant indicates that they require more or less information, give as necessary]

"We are interested in is how people manage to carry out a number of tasks at once (multi-tasking). We are also interested in what happens when multi-tasking becomes more difficult, which is why the number of word categories you had to switch between increased every time. One thing that is particularly useful is looking at the type of errors people make and what happens after an error – do people make more errors, slow down or manage to go back to performing the task correctly? Do they notice when they make an error or think they've made one when they haven't? Obviously we can't tell people we are interested in that at the beginning as it may affect the results; the last part of the task (switching between four categories) is where we expect most people to make errors, as it is quite difficult to switch between doing four different things"

[Deliver the following passage as appropriate to the version of the test used]

"By using different types of cues / dummy (colour) categories / changing the order in which the categories are presented / asking people to repeat the task several times we hope to learn more about the underlying processes used during multitasking behaviour and whether presenting the task differently makes it more or less difficult."

"We won't be able to tell any of these things until we have finished the study and looked at everybody's results together"

[If necessary reiterate that results are anonymous]

[If more information is requested – e.g. "Why are you interested in this?", then continue as follows]

"Other researchers have investigated how long people take to switch between different tasks, and have suggested several theories of how people manage to switch their attention between different things. We are suggesting a slightly different theory of how that might happen, particularly when switching between different language based tasks; the results from tests like the one you have just completed will hopefully support that theory."

[If necessary explain further why you weren't able to disclose this at the beginning of the study. May be omitted in the case of participants who are psychology students]

"In psychology we have to be careful not to give too many clues about the tasks we are asking people to do in case it affects their performance. For example, people who are told beforehand that they are going to be doing a memory task might remember more items than if they were not told what the task was for"

"Do you have any more questions?"

"Thank you for giving your time to take part in this study, it was very much appreciated. Goodbye"

APPENDIX F: TRANSCRIPTS OF TARGET AND NON-TARGET UTTERANCES FOR THREE PARTICIPANTS

KEY

Valid response **Non-word utterance** **Word utterance**

Self-correction **Error**

Participant TW27L Continuous Series II 4-categories

"9… Wednesday…February… H… 10… Tuesday… March… I…11… Wednesday… April… J… 12… Thursday… May… K… 13… **13**… Friday… June… **no, June-June-June-June-June, K –** L… 14… Saturday… **14… Saturday**… July… M… 15…Sunday… August… N… 16… Monday… September… O… 17… Tuesday… October… P… 18… Wednesday… November… Q… 19… Thursday… December… R… 20… **January – no it's not, is it? It's 20, days of the week, 20**… **Monday**… January… S… 21… Tuesday… February… T… 22… Wednesday… March… **V**… 23… Thursday… **May – no,** April… W… 24… **24-24**… **Wednesday**… **June**… X… 25… Thursday… July… **25**… Friday… August… Z… 26… Saturday… A… 27… Sunday… October… B"

Participant TW28L Continuous Series II 4-categories

"9… Wednesday… February… H… 10… Thursday… March… I… 11… Friday… April… J… 12… Saturday… **June**… K… 13… Sunday… July… L… 14… **Sunday**… August… M… 15… **Sunday**… September… **M**… **erm**… **15**… **Saturday, Sunday**… Monday… **September**… N… 16… **October, no it's a day next, Saturday, Sunday**… **Monday**… October… O… **15**… **um**… Tuesday… November… P… 16… **December- no, it's the days of the week, it's not September**… **Monday**… **November**… 17"

Participant TW28R Continuous Series II 4-categories

"9… Wednesday… February… H… 10… Thursday… March… I… 11… Friday… April… **April – what was it after that? April**… J… 12… **Sunday**… May… K… 13… Monday… June… L… **13**… 14… Tuesday… July… M… 15… **Friday**… August… **J**… 16… Saturday… September… K… 17… Sunday… October… L… **L**… **17**… **I**

don’t know what I was up to, 17 – I’ll say Tuesday… November… M… 18… Wednesday… December… N… 19… Thursday… January… O… 20… Friday… February… P… 21… **Friday**… March… Q… 22… Saturday… April… R… **26**… **lost it – 26**… **Saturday**… **August**… **T**… 27… Sunday… September… **T**… **26**”