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Neighbourhood Density in Spoken Word Recognition: An Eye-Tracking Study

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Abstract: Bilingual acquisition research has so far focused on comparisons with monolingual children in terms of linguistic features, performance on standardised tests, input, etc. In contrast, new methodologies, such as eye-tracking, can offer a more detailed understanding of the way bilinguals use both language systems. Eye fixations provide evidence of online processing. This study investigates spoken word recognition in children and adults. Word retrieval is affected by the number of words that minimally differ from the target (neighbourhood). Previous research found that only bilingual adults activated a similar-sounding competitor from the other language. As children have been found to be sensitive to neighbourhood density from quite early in previous research, similar results might be expected. This study includes 56 subjects (11 German–English bilingual and 12 English monolingual children, aged 8; 21 English monolingual and 12 German–English bilingual adults). The subjects' online processing of competing items for high- and low-density targets was compared. The results confirm that neighbourhood density affects word recognition in adults and children. The bilingual children activated same-language competitors as well as similar-sounding competitors from the other language. Adults and children differed in terms of latencies, and the monolinguals were more accurate than the bilingual subjects.

Keywords: word recognition; eye-tracking; bilingual children

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1. Introduction

While studies on bilingual acquisition have been conducted alongside those on monolinguals, there is still a monolingual bias in bilingual acquisition studies in which monolingual benchmarks are used for bilingual acquisition (Genesee 2003, 2022) and the different languages are seen as separate entities (Calafato 2022). Comparisons with monolingual acquisition can be useful to gain insight into differences but have also led to assumptions that bilinguals have a deficit in specific aspects of acquisition. This has been particularly the case in terms of lexical acquisition (Bialystok et al. 2010; Bylund et al. 2019) but also extends to other areas of linguistic performance.

New methodologies, on the other hand, can offer a more detailed understanding of the way bilinguals use both language systems available. Eye-tracking allows insight into online processing, as eye fixations to a particular stimulus on the screen can be taken as evidence of what is currently being processed. For this purpose, eye-tracking experiments often use a so-called visual world paradigm (Huettig et al. 2011), in which subjects see a visual display on a screen and at the same time hear an auditory stimulus which directs them towards a particular target.

In the current study, the focus is on spoken word recognition. The paradigm makes use of a display of four different pictures and an auditory stimulus which contains the target word. Word retrieval is generally affected by different factors, such as frequency, phonological, and semantic similarity. Frequent words are activated more often and, therefore, are thought to have lower activation thresholds than words with lower frequencies (Brysbaert et al. 2018; Caramazza et al. 2001; Diependaele et al. 2013). Words that are phonologically similar to the target also affect word processing, as the word's initial sound activates a number of possible word candidates (Marslen-Wilson 1987; Goh et al. 2009). Semantic similarity has been found to facilitate word access in lexical decision tasks (Meyer and Schvanefeldt 1971), but in the context of the visual world paradigm, the semantic priming effect interacts with the number of words that are phonologically similar to the target.

1.1. Word Access and Neighbourhood Density

Neighbourhood density is defined as the number of words that differ from the target by one phoneme (Luce and Pisoni 1998). If a target word has a lot of neighbours, it has a dense neighbourhood; words with few neighbours, on the other hand, have a sparse neighbourhood. For example, a target word such as *map* has a high number of neighbours, such as *man*, *mop*, *mat*, *mad*, *lap*, *gap*, *nap*, and *tap*, and, therefore, a high-density neighbourhood, whereas a word like *tree* has fewer neighbours, such as *free*, *three*, and *tray*, and, therefore, has a low-density neighbourhood.

Studies investigating the effect of neighbourhood density on word access have mostly considered related languages. Marian and Blumenfeld (2006) found similar lexical access patterns in German and English due to the structural similarities in both languages. Compared to a non-related language like Spanish, different patterns were found, thus showing that the effects of neighbourhood density can vary across different languages.

Word access implies both the recognition of the word form and the subsequent retrieval of the meaning of the word. This process is described in in the Distributed Cohort Model (Gaskell and Marslen-Wilson 2002). In the model, lexical representations are organised in terms of both phonology and semantics. When we hear words, we have to simultaneously identify the phonemes and match the string to stored patterns in our mental lexicon (Magnuson et al. 2007). As the first phoneme of a word is heard and processed, all the words in the neighbourhood are activated. As subsequent sounds are processed, the initial cohort is reduced, as items that do not contain the phonemes are eliminated. This process continues until the target word is left.

If the neighbourhood density of the target is high, a larger cohort of words is activated. This slows down word recognition (Desroches et al. 2009). On the other hand, a sparse neighbourhood density enables the faster recognition of the target word (Dufour and Peereman 2003).

In a task where words are presented within a context, this also has an impact on the recognition of the target word as the context makes particular word choices more likely. The semantic properties for particular word candidates are activated when a point has been reached where sufficient information is accessible to identify a particular target word after the cohort has been reduced.

Gaskell and Marslen-Wilson (2002, p. 223) give the example of the phoneme sequence/kæptɪ/which can result in two possible word forms, *captain* or *captive*. In this situation, the semantic representations of both words are likely to be activated. If there is only one possible form left, the sequence has reached the so-called uniqueness point (UP).

Neighbourhood density also affects spoken word recognition in speakers who come into regular contact with two languages (Marian et al. 2008). In the context of bilingual speakers, the question is whether the phonemes that are processed activate words from both languages, regardless of the particular language of the auditory stimulus (competition account, Sullivan et al. 2018). Studies of word processing that include target words from one language and phonological competitors from the other language in adults show that this is indeed the case (Blumenfeld and Marian 2007; Ju and Luce 2004; Marian et al. 2008; Marian and Spivey 2003; Marian et al. 2003; Weber and Cutler 2004).

Marian et al. (2008) investigated the effect of phonological similarity on target word access in an eye-tracking task that included 29 bilingual German–English bilingual participants and 15 English monolinguals who were shown a number of arrays of four pictures, in which one of the pictures represented the English target item. One picture was phonologically related to the target and the remaining two pictures were unrelated to both the target and the competitor. In half of the trials, the phonologically similar competitor was from the same language as the target (within-language competition). In the other half of the trials, the phonologically similar competitor was from the other language, in this case German (across-language competition). The target words and the competitors had either low or high-density neighbourhoods. For example, the within-language competitors for a high-density English target word like *dove* are words like *love* and *done*. Across-language competitors are similar-sounding German words such as *Dach* (roof) and *Haff* (lagoon).

It was found that the within-language competitors were fixated more when the target word had a low-density neighbourhood. While the monolingual subjects only activated the within-language competitors, the bilingual subjects fixated on both the within- and across-language competitors. This confirms that in bilingual spoken word recognition, language activation is non-selective, i.e., the cohort that is activated is comprised of words from both the languages of the bilingual. Sullivan et al. (2018) argue that bilinguals experience higher response times compared to monolinguals because words from both languages compete for selection during language processing.

In the context of the present study, the question is whether these results also extend to monolingual and bilingual children. Neighbourhood density has been found to play an important role in early lexical acquisition, hence it can be expected that children are sensitive to targets with high- and low-density neighbourhoods.

1.2. Lexical Acquisition and Neighbourhood Density

Spoken word recognition in children has been found to correlate with different measures: age of acquisition (AoA), word frequency, neighbourhood density, and vocabulary size (Garlock et al. 2001; Juhasz 2005; Munson 1999). Juhasz (2005) reviewed a number of studies that confirm age of acquisition to be a strong factor in word processing, resulting in higher accuracy ratings and lower latencies for words that are acquired early. One explanation for this phenomenon is the assumption that early-acquired words will be encountered more often by the learner, compared to later-acquired words (Cumulative Frequency Hypothesis, Juhasz 2005, p. 703).

In general, children's processing of spoken words varies in speed and develops in line with their vocabulary and working memory (Marchman and Fernald 2008). Neighbourhood density has been found to play a role in children's early lexical acquisition (Coady and Aslin 2003; Hansen 2017; Stokes 2010; Storkel 2004).

Storkel (2004) investigated different factors that predict the early acquisition of words listed in the MacArthur–Bates Communicative Development Inventory (Fenson et al. 1994). It was found that early-acquired words have dense neighbourhoods and are generally quite short, yet this effect levels off as children acquire more words. For example, the word *cat* is acquired early by children (1;9, Cortese and Khanna 2008); it consists of just three phonemes and has quite a high number of phonological neighbours (words like *cot*, *hat*, *bat*, *rat*, and *sat*). On the other hand, the word *foot* is also early-acquired (2;1, Cortese and Khanna 2008), consists of three phonemes, and has a similar frequency, but the number of neighbours is considerably lower (words like *food*, *fool*, and *boot*).

Stokes (2010) investigated neighbourhood density and word frequency in the early lexicons of a large sample of two-year-old British children, using the British adaptation of the MacArthur–Bates Communicative Development Inventory (Klee and Harrison 2001). She found that neighbourhood density was a better predictor of vocabulary size than word frequency.

Coady and Aslin (2003) investigated the phonological neighbourhoods of words produced by two of the children in the Brown corpus, Adam and Sarah (Brown 1973), between 2;3 and 3;6, as well as their mothers. It was found that words used by adults had a higher number of neighbours than those used by the children, yet the words in the children's expressive vocabulary still had a higher-than-average number of neighbours. This suggests a higher occurrence of words from dense neighbourhoods in children's early receptive as well as expressive vocabularies.

As an explanation for the occurrence of high-density words, it has been suggested that these are composed of phoneme sequences that occur frequently in the language. Metsala (1997) proposed that children's processing of spoken words changes from initially being more holistic to more segmental processing as more words are acquired and similar-sounding lexical items need to be distinguished. However, the high occurrence of high-density words in children's early lexicons suggests a high degree of sound discrimination for frequently occurring sound patterns from early on.

For bilingual children, spoken word recognition has been linked to vocabulary size and the neighbourhood density of words in each of their languages (Freedman and Barlow 2012; Marchman et al. 2010). Freedman and Barlow (2012) investigated phonological complexity and neighbourhood density in single-word speech samples from 15 children with a mean age of 4;11. Five children were classed as monolingual English speakers; five as monolingual Spanish speakers; and five children were German–Spanish bilinguals. No differences between monolingual and bilingual children were found, suggesting that bilingual children can discriminate the sound patterns of both languages in the same way as their monolingual counterparts.

1.3. The Current Study

The current study focuses on neighbourhood density in word retrieval in monolingual and bilingual German–English children and adults in two tasks: a picture-naming and an eye-tracking task.

The early acquisition of high-density words by young monolingual and bilingual children suggests that these might be processed more quickly by children, which would contrast with adults who have been found to react faster to words with low-density neighbourhoods (Luce and Pisoni 1998).

Bilingual children have often been found to lag behind monolingual children in their lexical development, as shown by significantly lower mean scores on standardized tests in at least one of their languages (Bialystok et al. 2010; Bylund et al. 2019; Hoff and Ribot 2017). Such differences in lexical skills are likely to affect accuracy and naming speed in picture naming, as well as the processing of lexical items in the eye-tracking task.

On the other hand, bilinguals have more developed cognitive skills in comparison to monolinguals (Bialystok 2010, 2018). The contact with another language, as well as switching languages, has been found to lead to enhanced skills in executive functions, particularly inhibitory control and conflict resolution (Barac et al. 2014). This could result in a better performance in the eye-tracking task, wherein subjects are asked to select a target picture in line with a spoken word in the presence of a competitor.

To get a clearer idea of bilingual children's processing of lexical items, the child subjects were given a picture-naming task consisting of high- and low-density items. This was then followed by an eye-tracking task which included high- and low-density target items as well as within- and across-language competitors, similar to Marian et al.'s (2008) study on bilingual adults. Given that the adults were found to activate cross-language competitors, the question is whether bilingual children process words in a similar way and thereby also show the parallel activation of both languages.

A study by Von Holzen and Mani (2012) included a group of 17 German–English bilingual children aged 1;9 and 3;7 and compared them to a group of 17 monolingual German children of the same age using a preferential looking paradigm. For some of the target items (target–prime condition), the word of a presented competitor picture either overlapped in sound with the English target word (*blue*–*glue*) or with the German translation equivalent (*blue*–*Kuh* (cow)). For the monolingual children, there was no difference in recognising the targets across conditions. The bilingual children, on the other hand, found it easier to recognise the target in the within-language target–prime condition and more difficult for the across-language target–prime condition. This result is taken as evidence that bilingual children indeed activate both languages in spoken word recognition from early on. Further evidence for the parallel activation of both languages comes from the observed "cognate facilitation effect" in picture naming that has been observed in adults as well as children (Costa and Caramazza 2000; Poarch and van Hell 2012; Schelletter 2002).

The current study investigates the effect of neighbourhood density on spoken word recognition in both bilingual and monolingual children and adults using an eye-tracking task. While previous studies have mostly studied monolingual and bilingual adults, the present study addresses the question of whether the same effects can be observed in school-age children who have grown up with two languages, as well as comparing monolinguals and bilinguals and adults and children with regard to their word processing.

Based on the outline above which summarised the context of this study in terms of neighbourhood density as an important factor in the access of words in both monolingual and bilingual subjects, as well as children's acquisition of lexical items, this study investigates the following research questions:

1. Does the neighbourhood size of target words affect the accuracy and speed of retrieval in monolingual and bilingual children in the picture-naming task? Is there a difference between monolingual and bilingual children?
2. Does the neighbourhood size of the target words affect the activation of same-language competitors in monolingual and bilingual adults and children in the eye-tracking task?
3. Does the neighbourhood size of target words affect the activation of cross-language competitors in bilingual adults and children in the eye-tracking task? With regard to these questions, the following outcomes are expected:

H1. *Given the finding that neighbourhood density plays a role in children's early vocabulary, it is expected that the children will retrieve the target words with a high neighbourhood density faster and more accurately than the target words with a low neighbourhood density. Differences in lexical knowledge are likely to affect accuracy ratings as well as latencies. Hence, it is expected that the bilinguals will differ from the monolinguals on both accuracy and naming speed.*

H2. *It has been found that monolingual and bilingual adults activate low-density, same-language competitors. It is expected that all the groups in the sample will activate the low-density, same-language competitors. In line with this assumption, lower accuracy ratings, higher latencies, and a higher rate of competitor eye fixations are expected for the low-density targets.*

H3. *Adult bilingual subjects were found to activate across-language competitors. It is expected that this finding also extends to children, such that only bilingual adults and children activate low-density, across-language competitors. As a result, lower accuracy ratings, higher latencies, and a higher rate of eye fixations are expected for the across-language targets for the bilinguals only.*

2. Materials and Methods

2.1. Picture Naming Task

To investigate the first question, the monolingual and the bilingual children were given a picture-naming task consisting of 48 black-and-white line drawings of the target words used in the subsequent eye-tracking tasks on a computer screen. The drawings were mainly taken from the international picture-naming project database (Szekely et al. 2004) and were based on the normed picture set suggested by Snodgrass and Vanderwart (1980). By testing the children on the target words in a picture-naming task first, it was possible to establish a baseline measurement of their initial knowledge of the target words, as well as making it easier to process and comprehend the words during the subsequent eye-tracking task.

The target items were categorised as having a high or a low neighbourhood density based on the number of words that differ from the target by one phoneme but have the same phoneme positions. The number of neighbours for each target word were determined using the Clearpond database (Marian et al. 2012). The target words were constrained by a need to represent them in picture form. The target items, together with their phonological neighbours in both English and German, are listed in Appendix A. The target items that are classed as having a high-density neighbourhood have an average of 33.6 same-language and 38.7 total number of neighbours. Those that are classed as having a low-density neighbourhood, on the other hand, only have an average of 11.9 same-language neighbours (12.9 in total). The cut-off point between the high- and low-density items was 23 neighbours.

The list of target words also includes frequency ratings (derived from Clearpond) as well as age-of-acquisition ratings for monosyllabic words (Cortese and Khanna 2008). No correlation was found between the total number of neighbours and the age-of acquisition ratings.

In order to ensure that the group of high-and low-density target items did not differ by frequency or AoA ratings, an independent-samples *t*-test was carried out. This showed no significant difference between the frequencies and AoA ratings of high- and low-density items. The total number of neighbours between the high- and low-density items differs significantly though: $t(46) = 11.1$, $p < 0.001$.

Picture Naming Participants and Procedure

A group of 24 children, aged 8, was tested: 12 English monolingual children from a school in Hertfordshire, UK (6 males and 6 females) and 12 German–English bilinguals attending the German school in London in the UK (7 males and 5 females). The subjects were selected via opportunity sampling. Parental questionnaires revealed that among the group of bilinguals, while all subjects were exposed to German from birth, the onset of exposure to English varied from birth to 6 years. This means that half of the bilingual children can be classed as simultaneous bilinguals, with parents speaking their respective native language to the child, while the remaining 6 bilingual children can be classed as sequential bilinguals, with German as their L1 and a later onset of English, their L2.

The children were tested individually and presented with 48 black-and-white line drawings of the target words. Some of the targets were used in the subsequent eye-tracking task. The children were asked to name the targets. Latencies and accuracy for high- and low-density target words were measured. The bilingual children were additionally tested on a set of high- and low-density targets in their other language, German.

2.2. Eye-Tracking Task

To investigate the second and third questions, the adult and child subjects participated in an eye-tracking task, using an SMI RED 250 eye-tracker. For the experiment, the psycholinguistic package Superlab X5 with eye tracker support was used (Cedrus). The task made use of a visual world paradigm (Huettig et al. 2011) consisting of a set of four pictures as well as an auditory stimulus which included the target word.

For each item, the participants first saw a cross in the middle of the computer screen (1000 ms), followed by an array of four black-and-white line drawings of objects at the same time as hearing a generated audio file "where is" (1000 ms), which was followed by the target word.

The four pictures in the array consisted of the target word, a phonologically overlapping competitor with the same phoneme onset and two pictures representing unrelated words. Half of the competitors were phonological neighbours from the same language as the target word (within-language), and the other half were from the other language of the bilinguals, German (across-language).

There were 32 stimuli in total, which formed a subset of the items used for the picture-naming task (see Appendix A). Items that were classed as high-density had a total number of neighbours between 30 and 58. Items that were classed as low-density had a total number of neighbours between 4 and 23. The items for the eye-tracking task are listed together with the competitor and distractor items in Appendix B.

Eye-Tracking Task Participants and Procedure

A total of 56 subjects took part in the experiment. There were 23 children, aged 8 (12 monolinguals and 11 bilinguals); they were the same children that took part in the picture-naming task, except for one female bilingual child for whom the eye tracking did not work very well. Additionally, 21 monolingual adults, who were students at the University of Hertfordshire, and 12 German–English sequential bilinguals, who were recruited among Erasmus students and staff, also took part.

The reaction times were measured from the onset of the target word until the subjects clicked the mouse to indicate the target picture. The eye fixations were calculated from the onset of the target word, over a period of 1500 ms.

For the statistical analysis of the data, an Aligned Rank Transform (ART) procedure (Wobbrock et al. 2011) was performed and an ANOVA was applied to the transformed variables, as not all the key assumptions of normality and the homogeneity of variances were met.

3. Results

3.1. Picture -Naming Task

In order to assess the effect of neighbourhood size on word retrieval in monolingual and bilingual children, Table 1 gives an overview of the accuracy ratings and latencies. Accuracy in this context refers to correct word retrieval when shown a picture of the target item. The subjects' correct responses were assigned a score of "1"; incorrect or no responses were scored as "0". Reaction time was measured from the onset of the picture to the correct response. The results are summarized in Table 1.

Table 1. Picture naming accuracy and latencies for monolingual and bilingual children.

Measures/Group	High Density	Low Density	ANOVA
Accuracy (SD)			
Monolinguals (n = 12)	**0.83** (0.07)	**0.73** (0.05)	
Bilinguals (n = 12)	**0.65** (0.18)	**0.60** (0.16)	
All (n = 24)	**0.74** (0.16)	**0.67** (0.13)	F = 9.6 **
Reaction Times [ms] (SD)			
Monolinguals (n = 12)	**2280** (327)	**2197** (303)	
Bilinguals (n = 12)	**2600** (581)	**2798** (392)	
All (n = 24)	**2451** (502)	**2480** (437)	F = 0.86

The F-values indicate the difference for the variables Accuracy and Reaction Times and include significance levels. ** $p < 0.01$.

Table 1 shows higher accuracies for targets with a high neighbourhood density for both monolingual and bilingual children. Taking accuracy as the dependent variable, a 2 × 2 (Density × Group) ANOVA shows that both Density and Group are significant: $F(1,22) = 11.3$, $p = 0.003$ and the estimate of the effect size (ηp^2) is 0.34 for Density, $F(1,22) = 13.2$, $p = 0.001$ and $\eta p^2 = 0.34$ for Group.

Latency, on the other hand, did not differ by neighbourhood density. A 2 × 2 (Density × Group) ANOVA shows that for latency as the dependent variable, $F(1,22) = 0.23$, $p = 0.64$ and $\eta p^2 = 0.01$ for Density. The variable Group, on the other hand, is significant: $F(1,22) = 8.5$, $p = 0.008$, $\eta p^2 = 0.28$.

The results show that for the group of children tested, neighbourhood size affects accuracy, but not the speed of retrieval in picture naming, thereby confirming the first part of hypothesis H1 for accuracy, but not retrieval speed. The fact that accuracy is higher for targets with a higher number of neighbours is in line with the finding that children's early vocabulary has been found to contain high-density words (Coady and Aslin 2003; Hansen 2017; Stokes 2010; Storkel 2004).

In order to investigate whether children's latencies were affected by one of the other factors, neighbours, item frequency, and the age-of-acquisition ratings (Cortese and Khanna 2008) were correlated with children's reaction times for each picture. The results are presented in Table 2.

Table 2. Spearman-rank correlations for neighbourhood, frequency, age of acquisition, and latencies.

	Neighbours	Frequency	Age of Acquisition (AoA)	Monolingual RT	Bilingual RT
Neighbours	1	0.176	−0.158	0.039	−0.142
Frequency	0.176	1	−0.537 **	−0.405 *	−0.271
AoA	−0.158	−0.537 **	1	0.461 **	0.259
Monolingual RT	0.039	−0.405 *	0.461 **	1	0.628 **
Bilingual RT	−0.142	−0.271	0.259	0.628 **	1

RT—reaction times per picture; ** Correlation is significant at the 0.01 level (1-tailed). * Correlation is significant at the 0.05 level (1-tailed).

Table 2 shows that there is a significant negative correlation between frequency and AoA, such that items with higher frequencies tend to have lower AoA ratings. Monolingual, but not bilingual, latencies were significantly correlated with AoA ratings and negatively correlated with frequency. This result is not surprising, given that AoA ratings tend to be based on monolingual children's trajectory of lexical acquisition. On the other hand, there was a significant positive correlation between monolingual and bilingual latencies, showing congruency between the latencies in both groups.

The second part of H1 predicts differences in both accuracy and reaction times for monolingual vs. bilingual children due to differences in lexical knowledge between the two groups. This was confirmed by the significant difference for both accuracy and reaction times between the monolingual and bilingual children. The overall difference in accuracy between the groups was 0.15 (0.78 for the monolinguals and 0.63 for the bilinguals) and 460 ms for reaction times (2239 ms for the monolinguals and 2699 ms for the bilinguals).

The difference in accuracy for the high- and low-density targets is also stronger in the monolingual group (0.1) compared with the bilinguals (0.05). In the latter group, the children that had simultaneous exposure to both languages showed higher accuracy ratings (0.75 for high-density targets and 0.685 for low-density targets), whereas the children who started English later (sequential bilingual children) did not show a difference in accuracy between the high- and low-density targets (0.54).

The differences in lexical knowledge can also be seen as resulting in higher retrieval times. The children who acquired both languages simultaneously showed latencies of 2422 and 2655 ms for high- and low-density items, respectively, whereas the sequentially bilingual children showed latencies of 2728 and 2903 ms.

3.2. Eye-Tracking Task

In order to investigate the effect of neighbourhood on the activation of same-language and across-language competitors, as outlined in questions 2 and 3, accuracy, latencies, and eye fixations for both conditions were measured and compared. Accuracy in this context refers to the correct identification of the target via a mouse click. Reaction times were measured from the onset of the auditory word to a mouse click. Accuracy and latencies are compared for high- and low-density items in the within-language condition in Table 3 below.

Table 3 shows high accuracy ratings for all the groups for both the high- and low-density target items, yet latencies show differences by group as well as density.

A 2 × 4 (Density × Group) ANOVA with Accuracy as the dependent variable shows that $F(3,52) = 0.67$, $p = 0.42$, $\eta p^2 = 0.013$ for Density but $F(3,52) = 7.7$, $p < 0.001$, $\eta p^2 = 0.31$ for Group. Post-hoc tests revealed that the monolingual adults are significantly more accurate than the bilingual children and adults.

Taking Latency as the dependent variable, a 2 × 4 (Density × Group) ANOVA shows that $F(3,52) = 8.03$, $p = 0.007$, $\eta p^2 = 0.13$ for Density and $F(3,52) = 15.64$, $p < 0.001$, $\eta p^2 = 0.47$

for Group. Post-hoc tests reveal that the monolingual adults are significantly faster than both the groups of children.

Table 3. Accuracy and latencies for all groups in the eye-tracking task, within-language items.

Measures/Group	High Density	Low Density	ANOVA
Accuracy (SD)			
Adults (n = 33) **			
Monolingual adults (n = 21)	**1** (0)	**0.99** (0.04)	
Bilingual adults (n = 12)	**0.9** (0.12)	**0.92** (0.11)	
Children (n = 23)			
Monolingual children (n = 12)	**0.97** (0.08)	**0.97** (0.08)	
Bilingual children (n = 11)	**0.92** (0.12)	**0.92** (0.10)	
			F = 0.29
Reaction Times [ms] (SD)			
Adults (n = 33)			
Monolingual adults (n = 21)	**1316** (195)	**1365** (296)	
Bilingual adults (n = 12)	**1501** (351)	**1548** (344)	
Children (n = 23) **			
Monolingual children (n = 12)	**1632** (389)	**1848** (277)	
Bilingual children (n = 11)	**2275** (791)	**2306** (572)	
			F = 6.43 *

The stars in the first column indicate significance levels for subgroups as measured by post-hoc tests, the F-values in the ANOVA column indicate the difference for the variables Accuracy and Reaction Times and include significance levels. * $p < 0.05$; ** $p < 0.01$.

While neighbourhood density does not seem to affect accuracy ratings in the within-language condition, all the groups show higher reaction times for the low-density target items, which is in line with H2. At the same time, reaction times vary by group, showing that the bilinguals are slower than the monolinguals and the children are slower than the adults.

Figure 1 shows the competitor fixations for the high- and low-density targets for all the groups from word onset to 1500 ms after word onset.

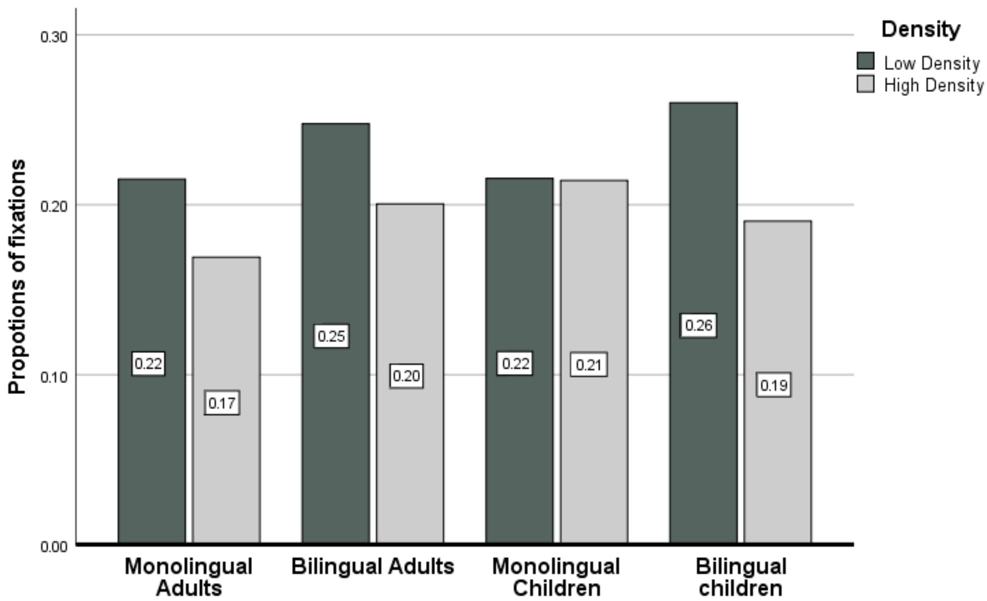

Figure 1. Proportions of competitor fixations for high- and low-density targets, within-language.

A 2 × 4 (Density × Group) ANOVA showed that Density was significant: $F(3,52) = 16.6$, $p < 0.001$, $\eta p^2 = 0.23$. There were no significant differences between the groups. In order to verify that the competitor is activated in the trials, the fixations to the competitor need to be compared to distractor fixations.

Figure 2 shows the proportions of eye fixations for targets and distractors for the high- and low-density targets from 300 ms after word onset up to 1500 ms for all groups.

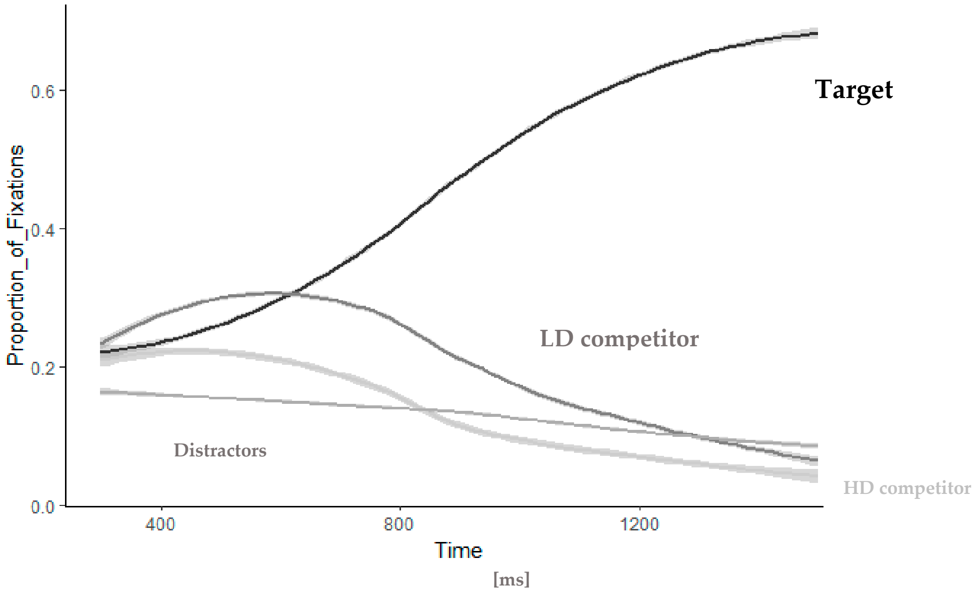

Figure 2. Proportions of fixations to target items, competitors, and distractors, within-language.

The target and distractor fixations in Figure 2 are summarized for the high-and low-density conditions but the competitor fixations are separated by density competitor fixations. LD competitor represents the competitor fixations in the low-density condition, whereas HD competitor represents the competitor fixations in the high-density condition.

A 2 × 2 × 4 (Density × Competitor vs. Distractor × Group) ANOVA for the within-language condition showed that Density and Competitor vs. Distractor, as well as the interaction between the two were significant: $F(1,52) = 11.5$, $p = 0.001$, $\eta p^2 = 0.18$ for Density and $F(1,52) = 84.5$, $p < 0.001$, $\eta p^2 = 0.62$ for Competitor vs. Distractor.

The fact that Density as well as Competitor vs. Distractor were significant but there were no significant differences between the groups confirms that neighbourhood density does indeed affect the activation of same-language competitors in monolingual and bilingual adults and children, though the effect size is small. H2 is therefore confirmed for eye fixations as well as latencies, but not for accuracy ratings.

Let us now turn to the final question relating to the across-language condition. Table 4 gives accuracy and latencies for the condition.

For the across-language condition, the accuracy ratings are similar for the monolingual children and adults but lower for the bilingual subjects, particularly for the low-density targets. A 2 × 2 (Density × Group) ANOVA with Accuracy as the dependent variable shows that $F(1,52) = 7.6$, $p = 0.008$, $\eta p^2 = 0.12$ for Density and $F(3,52) = 21.4$, $p < 0.001$, $\eta p^2 = 0.55$ for Group. Post-hoc tests reveal, in particular, that the monolingual adults and children do not differ in terms of accuracy, yet both the bilingual adults and the bilingual children differ significantly from the monolingual groups.

For Latencies, a 2 × 2 (Density × Group) ANOVA shows that $F(3,52) = 3.05$, $p = 0.086$, $\eta p^2 = 0.06$ for Density and $F(3,52) = 29.5$, $p < 0.001$, $\eta p^2 = 0.63$ for Group. Post-hoc tests reveal that the bilingual children are different from the other groups.

As far as H3 is concerned, it seems that the group of bilingual children, in particular, show differences in accuracy and latencies for the high-and low-density targets in the across-language condition, thereby partially confirming hypothesis H3.

Table 4. Accuracy and latencies for all groups in the eye-tracking task, across-language items.

Measures/Group	High Density	Low Density	ANOVA
Accuracy (SD)			
Adults (n = 33) **			
Monolingual adults (n = 21)	**0.96** (0.06)	**1** (0)	
Bilingual adults (n = 12)	**0.83** (0.11)	**0.8** (0.11)	
Children (n = 23) **			
Monolingual children (n = 12)	**0.99** (0.04)	**0.96** (0.06)	
Bilingual children (n = 11)	**0.97** (0.12)	**0.8** (0.2)	
			F = 7.9 **
Reaction Times [ms] (SD)			
Adults (n = 33)			
Monolingual adults (n = 21)	**1459** (222)	**1483** (212)	
Bilingual adults (n = 12)	**1551** (265)	**1523** (277)	
Children (n = 23) **			
Monolingual children (n = 12)	**1842** (302)	**2222** (516)	
Bilingual children (n = 11)	**2146** (288)	**2458** (546)	
			F = 6.8 *

The stars in the first column indicate significance levels for subgroups as measured by post-hoc tests, and the F-values in the ANOVA column indicate the difference for the variables Accuracy and Reaction Times and include significance levels. * $p < 0.05$; ** $p < 0.01$.

Let us turn to eye fixations in the across-language condition. Figure 3 details competitor fixations for both high-and low-density across-language targets.

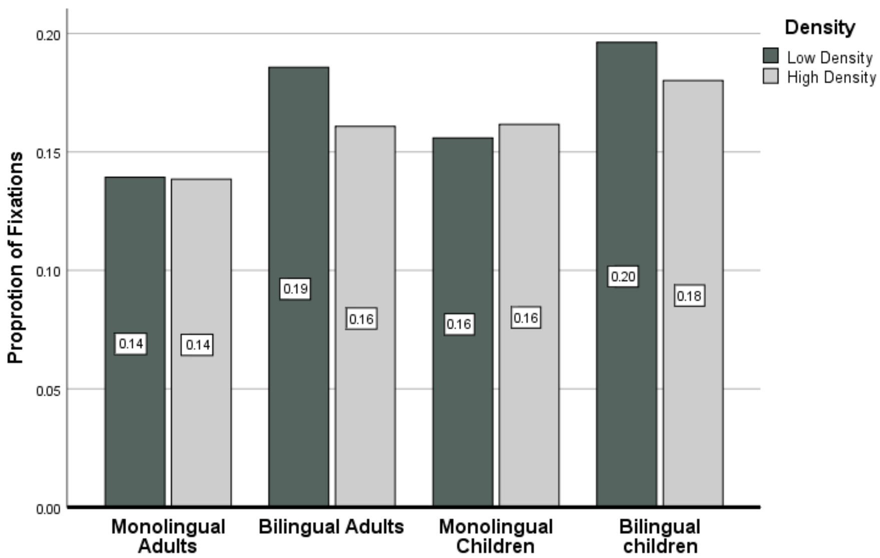

Figure 3. Proportions of competitor fixations for high- and low-density targets, across-language.

Figure 3 shows that both the bilingual groups fixate more on the competitor in the low-density condition compared to the competitors of the high-density targets. Comparing the monolingual and the bilingual subjects, a 2 × 2 (Density × Language Group) ANOVA showed that only Group was significant: $F(1,54) = 8.3$, $p = 0.006$, $\eta p^2 = 0.13$.

In order to see whether the competitor is activated in the trials, Figure 4 shows the proportions of eye fixations for the targets, competitors, and distractors from 300 ms after word onset up to 1500 ms for the monolinguals and the bilinguals separately. Again, the high- and low-density conditions are taken together, except for competitor fixations, wherein LD competitor represents the competitor fixations for the low-density targets and HD competitor represents the competitor fixations for the high-density targets.

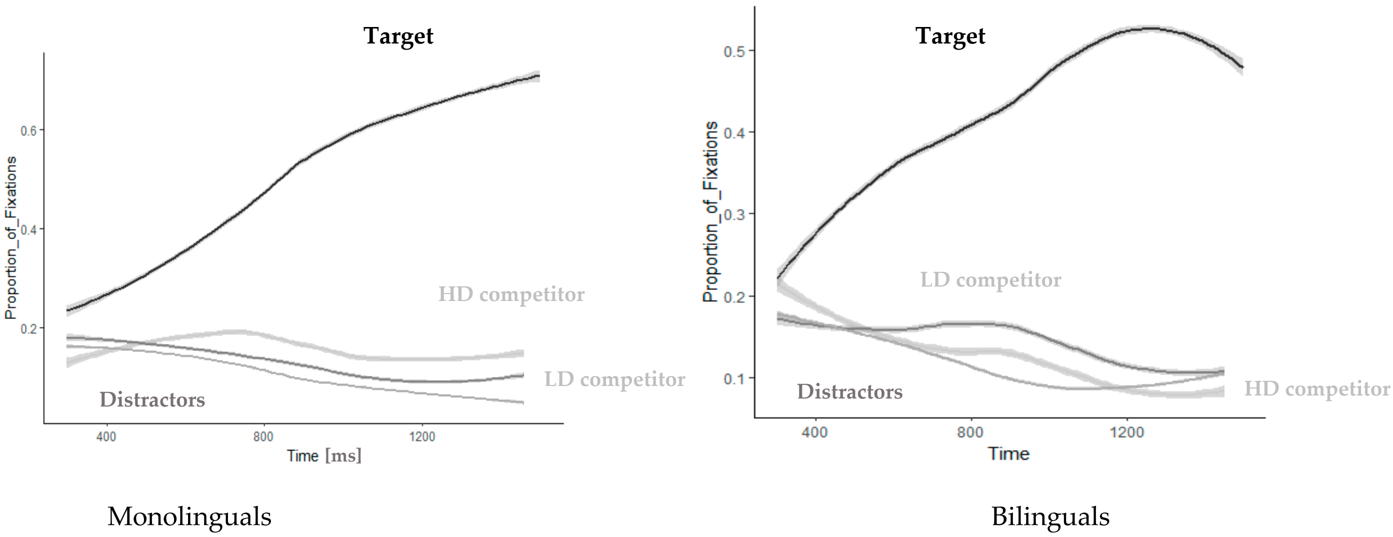

Figure 4. Proportions of fixations to target items, competitors, and distractors, across-language.

Based on the significant difference between the monolinguals and the bilinguals, the groups are considered differently for this analysis to test H3. First, we analyse the monolinguals' activation of competitors and distractors in the across-language condition. A 2 × 2 × 2 (Density × Competitor vs. Distractor × Group) ANOVA shows no significant differences. This suggests that neither the monolingual children nor the monolingual adults tested here activated cross-linguistic competitors. The fixation to competitors were at similar levels to competitor fixations for both the high- and low-density targets.

For the second analysis, both bilingual groups are compared regarding the proportion of fixations of competitors and distractors in both conditions. A 2 × 2 × 2 (Density × Competitor vs. Distractor × Group) ANOVA shows that Competitor vs. Distractor is significant: $F(1,21) = 10.3$, $p = 0.004$, $\eta p^2 = 0.32$. In addition, the interaction between Density and Competitor vs. Distractor is also significant: $F(1,21) = 6.47$, $p = 0.019$, $\eta p^2 = 0.227$. There was no difference between the bilingual children and the bilingual adults.

Taken together, the results confirm hypothesis H3. Neither of the monolingual groups have been found to activate the competitor in the across-language trials. Only the bilingual groups show significantly higher fixations on the competitor picture compared to distractors in the low-density condition.

4. Discussion

The aim of the current study has been to examine the role of neighbourhood density in word recognition in both monolingual and bilingual children and adults. Based on the findings that high density words are frequent in children's early vocabulary, it was expected that children's picture naming would be in line with the findings for early acquired words (Coady and Aslin 2003; Hansen 2017; Stokes 2010; Storkel 2004).

This was partially confirmed. Neighbourhood density was found to have a significant effect on accuracy in children's picture naming, but not on retrieval speed. The children were more accurate in naming high-density items but showed similar latencies for high- and low-density target words. The monolingual children's picture naming latencies were found to correlate with the AoA ratings, in line with a number of previous studies (Juhasz 2005; Morrison et al. 1992; Schröder et al. 2004).

While children's early vocabularies tend to contain high-density words, this does not mean that high-density lexical items in general have earlier AoA ratings. The averages of the items rated for age of acquisition in Tables A1 and A2 are similar. The similar average latencies for high-and low-density items are in line with the expectation that items with similar AoA ratings would be retrieved within a similar amount of time.

As was also predicted in H1, the bilingual children were significantly slower and less accurate in both conditions compared to the monolingual children. While the lower accuracy can be explained in terms of vocabulary differences (Bialystok et al. 2010; Pearson et al. 1993; Schelletter 2016), the reasons for the longer latencies are not obvious and different explanations have been put forward (Sullivan et al. 2018). These are in terms of a lag in frequency and the activation of both lexical systems (competition account).

A frequency lag in the bilinguals assumes that individual words in each of the bilingual's languages are accessed less often, hence the connections between the concepts and the word forms are weaker and the thresholds are higher, thus resulting in higher latencies. The competition account assumes that the word forms in the two languages of the bilingual compete and that word access is non-selective. Even when bilinguals are presented with auditory words in one language, similar-sounding words from the other language are still activated, as shown by Marian et al.'s (2008) eye-tracking study, where bilingual adults activated across-language competitors.

The second task aimed to determine whether Marian et al.'s findings for the within- and across-language activation of competitors also extends to monolingual and bilingual children (H2 and H3). All the subjects activated within-language competitors of the low-density targets more than those of the high-density targets and also showed higher latencies for the low-density targets, thereby partially confirming H2. Accuracy, on the other hand, did not differ for the high- and low-density targets in this condition. For the children, this could be due to the prior picture-naming task, in which they were required to produce the names of the target items represented in the pictures. Alternatively, it could also be due to the different nature of the two tasks. While the picture-naming task required the subjects to retrieve the name based on the represented picture (productive task), in the eye-tracking task, the subjects heard the target and had to respond by clicking on the target picture (receptive task).

The results of the across-language condition confirmed H3, as only the bilingual subjects were found to activate the across-language competitor. This is in line with previous findings (Marian et al. 2008). It also shows that bilingual children of the age included here are sensitive to competitors within and across languages, similar to adults and younger children (Von Holzen and Mani 2012).

On the other hand, only the bilingual children showed lower accuracy ratings and higher latencies for the low-density items. One reason for the lower accuracy ratings was due to some children clicking on the competitor rather than the target picture. This suggests that in these cases, the strength of the competition exceeded that of the target item and does not seem to be in line with the finding that bilingual children have enhanced inhibitory control.

However, enhanced skills in executive functions have been found to be related to the length of time of exposure to another language (Bialystok and Barac 2012). Given the varying onset of L2 English in the group of bilingual children, their skills in executive functions and inhibitory control, in particular, can be assumed to differ. In particular, the child with the latest onset of English (6 years) was found to have the lowest accuracy rating for low-density targets in the across-language condition, choosing the competitor over the target for a number of items. This was accompanied by fixations on the competitor picture.

By integrating eye-tracking in this study, it has been possible to shed more light on the way bilingual subjects, including children, utilise both language systems during online processing. In the case of cross-language competition, as explored here, the similarity between auditory words in the two languages of the bilingual, which are both represented in the display, clearly leads to a competition. This is in line with non-selective access as well as the assumption that the initially activated cohort in word access (Gaskell and Marslen-Wilson 2002) consists of items from both languages for bilingual speakers. Subsequent processing involves the reduction of the cohort, including the removal of items from the non-selected language.

5. Limitations of the Study

The data were collected using portable eye-tracking equipment that could be taken to schools and used with the children in a suitable classroom. Due to time constraints within the organisation of the school day, it was difficult to assess more learners within the selected age group or learners from a different age group at the time of testing. As a result, the sample size for bilingual and monolingual children is quite small.

The bilingual children were selected by opportunity sampling. They all attended the German school in London and had language skills in both languages. However, it was only through the parental questionnaires that details of the children's language background could be ascertained. While all children were exposed to German from birth, the group was not homogeneous, as the onset of English ranged from birth up to the age of six, thereby consisting of simultaneous as well as sequential bilinguals. Further studies should include enough children to be able to compare both sequential and simultaneously bilingual children.

The number of included test items for the eye-tracking task was kept low to take account of children's more limited attention span. The bilingual children were also tested with an English and a German version of the experiment.

6. Conclusions

In this paper, the results from two studies were reported: a picture-naming task to investigate the effect of neighbourhood density on word retrieval in school-age monolingual and bilingual learners and an eye-tracking study to compare the online processing of competing items for high- and low-density targets in monolingual and bilingual adults and children.

Neighbourhood density was found to affect processing in both tasks. For picture naming, the monolingual and the simultaneously bilingual children were more accurate at naming high-density target names, though no significant difference for retrieval speed was found (Vitevitch 2002). Words with a high neighbourhood density contain frequently occurring phoneme sequences that children learn early (Storkel 2004).

In the eye-tracking task, on the other hand, neighbourhood density was found to affect the activation of a particular phonological competitor, which was represented as part of an array of four pictures. If the target word had a higher neighbourhood density, there was a lower degree of the activation of the represented competitor. This is in line with previous findings (Marian et al. 2008) and shows that the competitor has a greater influence at the stage of word retrieval when processing is close to reaching the uniqueness point (Gaskell and Marslen-Wilson 2002).

The bilingual children's results were like those of the bilingual adults, in that both within- and across-language competitors were activated. Error patterns reveal that the children selected the across-language competitor over the target in some cases. This could be related to the language status of the children, as the bilingual participant group includes both simultaneous and sequential bilinguals A larger dataset that controls for the language status of the children and includes more age groups would be needed to investigate the issues in more detail.

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Institutional Review Board Statement: The study was approved by the Social Sciences, Arts and Humanities Ethics committee of the University of Hertfordshire under protocols HUM/SF/UH/02704 and HUM/SF/UH/02704(1).

Informed Consent Statement: Informed consent was obtained from all the subjects involved in the study, or from their guardians.

Data Availability Statement: The data presented in this study are not publicly available as they have been submitted as part of dissertations by individuals within the institution. Please send any requests to the corresponding author.

Conflicts of Interest: The author does not declare any conflicts of interest.

Appendix A

Table A1. Items in the picture-naming task for high neighbourhood density [1].

Item	Word Length (Phonemes)	Freq (Per-Mill)	Phonological Neighbours, Same-Language	Phonological Neighbours, Cross-Language	Total Neighbours	Age of Acquisition (AoA)
Bell	**3**	**39.33**	**41**	**17**	**58**	**2.8**
Tail	**3**	**23.9**	**49**	**4**	**53**	**3**
Bowl	3	21.5	45	5	50	**3.1**
Bone	**3**	**26.1**	**44**	**6**	**50**	**3.1**
Corn	**3**	**14.2**	**42**	**8**	**50**	**2.8**
Duck	**3**	**24.7**	**42**	**5**	**47**	**2.4**
Bike	**3**	**25.9**	**32**	**14**	**46**	**2.6**
Ham	**3**	**11.5**	**43**	**2**	**45**	**3.6**
Rack	**3**	**7.8**	**44**	**0**	**44**	**4**
Road	**3**	**111.9**	**42**	**0**	**42**	**2.8**
Hoop	**3**	**2.7**	**25**	**15**	**40**	**3.5**
Bird	3	45.5	39	0	39	**2.3**
Cake	3	45.1	35	3	38	**2.6**
Towel	**3**	**14.2**	**25**	**13**	**38**	
Map	**3**	**31.8**	**35**	**2**	**37**	**3.4**
Cook	**3**	**45.6**	**23**	**9**	**32**	**3.1**
Tear	**3**	**27**	**30**	**1**	**31**	**3**
Doll	**3**	**24.7**	**30**	**0**	**30**	**2.4**
Coin	**3**	**9.7**	**22**	**8**	**30**	**3.1**
Witch	3	27.6	28	1	29	**3**
Goat	3	10.5	23	3	26	**2.6**
Dog	3	192.8	25	0	25	**2.2**
Vase	3	3.8	20	5	25	**3.7**
Plane	4	95.5	22	1	23	**3.2**
Average	**3.0**	**36.8**	**33.6**	**5.1**	**38.7**	**3.0**

[1] Items in bold are target items in the eye-tracking task.

Table A2. Items in the picture-naming task for low neighbourhood density [1].

Item	Word Length (Phonemes)	Freq (Per-Mill)	Phonological Neighbours, Same-Language	Phonological Neighbours, Cross-Language	Total Neighbours	Age of Acquisition (AoA)
Low Density						
Tree	**3**	**65**	**22**	**1**	**23**	**2.5**
Swing	**4**	**26**	**19**	**1**	**20**	**2.8**
Hood	**3**	**15.4**	**19**	**2**	**20**	**3.6**
Tailor	**4**	**4.2**	**19**	**3**	**20**	
Horse	**3**	**92.9**	**18**	**4**	**19**	
Fawn	**3**	**0.7**	**18**	**11**	**19**	**4.8**
Belt	**4**	**24.4**	**18**	**14**	**19**	**3.3**
Mower	**3**	**1.5**	**15**	**3**	**16**	
Tooth	3	13.6	13	6	14	**2.3**
Cloud	**4**	**11.7**	**12**	**5**	**13**	**2.8**
Knife	3	46.8	12	7	13	**3**
Table	4	105.6	12	0	13	

Table A2. *Cont.*

Item	Word Length (Phonemes)	Freq (Per-Mill)	Phonological Neighbours, Same-Language	Phonological Neighbours, Cross-Language	Total Neighbours	Age of Acquisition (AoA)
Saddle	4	7.8	10	0	11	
Stairs	4	23.8	10	0	11	**3.2**
Bench	**4**	**9.67**	**9**	**1**	**10**	**3.4**
Snail	**4**	**1.8**	**9**	**0**	**10**	**3.1**
bottle	**4**	**50.7**	**9**	**0**	**10**	
Bridge	**4**	**45.7**	**9**	**0**	**10**	**3.2**
Dress	4	87.2	9	1	10	**2.6**
Kitten	**5**	**4.7**	**8**	**15**	**9**	
Floss	**4**	**2**	**6**	**5**	**7**	**3.6**
Glove	4	10	6	0	7	**3.2**
Church	3	69.7	6	0	7	**2.7**
Ankle	**4**	**8**	**3**	**0**	**4**	
Average	**3.7**	**30.4**	**12.1**	**3.3**	**13.1**	**3.1**

[1] Items in bold are target items in the eye-tracking task.

Appendix B

Table A3. Items in the eye-tracking task, within-language.

High Density				
Target Item	**Competitor**	**Distractor 1**	**Distractor 2**	**Total Neighbours**
Bell	belt	onion	ghost	58
Tail	tailor	biscuit	soap	53
Bike	book	parachute	frog	46
Road	rope	eye	moon	42
Towel	tower	magnet	squirrel	38
Map	man	banana	crib	37
Tear	deer	peas	mattress	31
Doll	dog	carrot	ladybird	30
Low Density				
Target Item	**Competitor**	**Distractor 1**	**Distractor 2**	**Total Neighbours**
Tree	tray	wing	milk	23
Swing	sling	egg	ball	20
Hood	hook	feather	elephant	20
Cloud	clown	glove	bucket	13
Bench	beach	hoof	palm	10
Snail	snake	bag	present	10
bottle	beetle	fork	lion	10
Bridge	brick	hamster	candle	10

Table A4. Items in the eye-tracking task, across-language.

High Density				
Target Item	**Competitor**	**Distractor 1**	**Distractor 2**	**Total Neighbours**
Bone	Bein (leg)	pig	mushroom	50
Corn	Korb (basket)	needle	goat	50
Duck	Decke (blanket)	foot	strawberry	47
Ham	Hemd (shirt)	stairs	pot	45
Rack	Rock (skirt)	hut	crocodile	44
Hoop	Hupe (horn)	leaf	toe	40
Cook	Krug (jug)	ruler	dress	32
Coin	Kinn (chin)	wolf	saddle	30

Table A4. *Cont.*

Low Density				
Target Item	**Competitor**	**Distractor 1**	**Distractor 2**	**Total Neighbours**
Tailor	Teller (plate)	bear	corn	20
Horse	Hose (trousers)	bride	comb	19
Fawn	Foen (hairdryer)	tent	star	19
Belt	Bett (bed)	sledge	globe	19
Mower	Mauer (wall)	cherries	owl	16
Kitten	Kissen (pillow)	nose	lamp	9
Floss	Floss (raft)	beetle	mushroom	7
Ankle	Angel (rod)	chair	pencil	4

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