DESIGNING MOTIVATIONAL GAMES
FOR
ROBOT-MEDIATED STROKE REHABILITATION

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Dedicated to my loving father, Brig. Tariq Sohail

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ABSTRACT

The repetitive and sometimes mundane nature of conventional rehabilitation therapy provides an ideal opportunity for development of interactive and challenging therapeutic games that have the potential to engage and motivate the players. Different game design techniques can be used to design rehabilitation games that work alongside robotics to provide an augmentative therapy to stroke patients in order to increase their compliance and motivation towards therapy.

The strategy we followed to develop such a system was to (i) identify the key design parameters that can influence compliance, prolonged activity, active participation and patient motivation, (ii) use these parameters to design rehabilitation games for robot-mediated stroke-rehabilitation, (iii) investigate the effects of these parameters on motivation and performance of patients undergoing home-based rehabilitation therapy. Three main studies were conducted with healthy subjects and stroke subjects. The first study identified the effects of the design parameters on healthy players' motivation. Using the results from this study, we incorporated the parameters into rehabilitation games, following player-centric iterative design process, which were formatively evaluated during the second study with healthy subjects, stroke patients, and health-care professionals. The final study investigated the research outcomes from use of these games in three patient's homes during a 6 weeks clinical evaluation.

In summary, the research undertaken during this PhD successfully identified the design techniques influencing patient motivation and adherence as well as highlighted further important elements that contribute to maintaining therapeutic interaction between patients and the therapy medium, mainly the technological usability and reliability of the system.

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1. INTRODUCTION

This chapter gives a brief introduction to the subject area and the motivation behind the research. The chapter presents the research questions which the research aims to address, and lists the methodologies used during the course of this research, all of which will be discussed in detail in the following chapters.

1.1 BACKGROUND

Stroke, with a victim, on an average, every 40 seconds in the USA [1] and every 5 minutes in the UK [2], has become one of the leading causes of serious, long-term physical and mental disability. Due to the plasticity of the human brain, stroke survivors often make spontaneous and significant recovery in functionality by working with occupational therapists, physical therapists, and speech therapists, each offered in different capacities depending on how the stroke has affected them. However, in the USA alone, there are over 6 million stroke survivors, most of them living with residual disabilities [1]. In the UK, it has been estimated that there are approximately 3 hundred thousand people living with moderate to severe disabilities as a result of stroke [2]. As the population ages, there is likely to be an increase in prevalence of stroke resulting in a higher demand of rehabilitation measures both in medical and technological spheres.

Hemiparesis, a condition of paralysis on one side of the body, has been the area of focus in post stroke rehabilitation, being the substantial contributor to the disability. With exercise therapy being the only main effective treatment for post-stroke recovery [3], stroke survivors undergo extensive training sessions with physiotherapists in order to regain the functions lost after the brain injury, learn compensatory strategies to reduce the effects of remaining deficits, and establish exercises to help retain the learned skills.

The therapists need to encourage and push the patients to exercise their affected extremities in order to remap muscle control in the brain. These therapy sessions may reduce the victim’s impairment but they are still often left with some residual disabilities which they must learn how to overcome, on their own, to be as independent as possible, adapt their lifestyle and environment, and bring purpose and meaning to life. For some, this may take a long time and be very costly.

Although conventional therapy has shown improvements in the sensorimotor function in stroke rehabilitation, it relies heavily on the therapists’ training and past experience [4]. In addition to that, with an increasing demand of stroke rehabilitation services due to demographic changes [5], it is becoming difficult to provide each patient the optimum time needed with a therapist. These limited resources highlight the need to innovate mechanisms that would prevent decline in rehabilitation services or an increase in its cost.

Another reason to look for alternatives to conventional therapy is the monotonous nature of its exercises, which poses a challenge in maintaining motivation levels for people undergoing therapy. Patients need to continue the exercise regimes at home doing hundreds of repetitions a day, which is tedious and unpleasant. Therefore, motivation to do these is often lost outside the therapy sessions [6]. Also, following a stroke, it is very common for survivors to experience depression, anxiety for their loss and attention deficiencies. For this reason, they may find it difficult to concentrate and actively participate in conventional therapy exercises. It can be hard for the patients to stay focused and attentive due to the monotonous nature of these repetitive exercise routines. Along with the benefit of repetitive exercises, which are useful in restoring some degree of motor functions [7], recent studies have shown that patients seem to further improve as a result of more intense and interactive exercises [8]. Additionally, feedback on performance in training is important to encourage the patients to strive for improvements [9]. In order to address this, more engaging and entertaining exercise environment needs to be designed in order to motivate the patients through the exercise sessions to increase adherence to the rehabilitation training exercises.

Since video games are associated with high-user engagement, studies have aimed to solve this problem by using games and virtual reality (VR) to engage patients into actively taking part in their therapy. Although some of these studies show potential, the games used in these studies are commercial games, which although have rich multimedia content, are designed for people with normal movement patterns requiring movements beyond the abilities of most stroke patients. Those designed specifically for rehabilitation purposes are often merely virtual representations of the physical tasks or are basic and have minimal game design parameters.

Our solution is to find out some of the basic game design techniques and processes used by the commercial game designers in order to hook the players in to playing their games and incorporate them into home-based rehabilitation games designed specifically for stroke patients. This way, patients can be encouraged to exercise independently at home. These games will be customizable to each patient's abilities and needs and also provide an interactive experience. Our aim is not only to diminish the monotony of the therapy exercises, but instead to make them more fun, motivating and engaging.

1.2 RESEARCH QUESTIONS

1. Can the game design parameters used in commercial games affect the motivation of healthy players, their performance, and sustain prolonged activity within a set of rehabilitation games?

2. Do game design techniques and parameters affect rehabilitation games' desirability influencing motivation of stroke patients undergoing therapy, increasing compliance and activity, prolonging duration, and sustaining interest?

Motivation plays an important role in rehabilitation after stroke. The background research supports the idea of using multi-modal games to provide an engaging and interactive platform to motivate people to actively participate in the therapy. Designing games for rehabilitation requires input from both multiple stakeholders such as the medical, bioengineering and game design fields. Investigation on these lines identified that games designed for the specific purpose of rehabilitation can benefit from bridging the gaps between these fields. In this context, we believe that following the same design procedures and techniques used in the gaming industry, along with the advancing technology of rehabilitation robotics, we can create a motivating and an effective environment for therapy.

Three main studies were carried out in the course of this research. The first study aimed to identify and test the effectiveness of some key game design parameters that influence motivation amongst players (Question 1). The second study tested the usability of rehabilitation games designed through player-centric design process with the identified parameters (Question 2). The effectiveness of these games in terms of motivation, amusement, and duration of therapy was evaluated during the third study (Question 2).

While the first study involved healthy participants, the latter two were carried out with stroke patients. Formative evaluations and usability testing were carried out prior to each study to evaluate the performance of the technique implemented for the studies. Ethics approval was obtained at every stage. Participants were briefed about the experimental protocol before giving their consent to take part in the study. The findings and feedback obtained from every study provided direction for further investigations and guided the design and aims of subsequent studies.

1.3 Relation With Script Project

This research was carried out in relation with the EU-FP7 Supervised Care and Rehabilitation Involving Personal Tele-robotics (SCRIPT) Project (http://scriptproject.eu/). The SCRIPT project is a study which is intended to provide distal arm training to chronic stroke patients at their homes. Three games were designed and developed for the SCRIPT System. Formative evaluation of the games was carried out with healthy subjects, people recovering from stroke and therapists to test the feasibility and usability of the system which was followed by a 6-week study with three stroke subjects.

1.4 Contribution to Knowledge

The key contributions of this research can be summarised as:

1. Identification of some key game design parameters including operant-conditioning, scoring, feedback, dynamic difficulty balancing that could be used to motivate and engage stroke patients into actively participating in therapy exercises and influence prolonged activity.
2. Identification of crucial differences in implementation of the game design techniques in games for healthy players and rehabilitation games for stroke patients in particular in order to maximize the therapeutic benefits.
3. Proposed a framework through which rehabilitation game developers can catalogue and document their games' design allowing understanding of the effectiveness of game design parameters with regards to rehabilitation therapy.

4. Evaluated the effects of the different design parameters and on player motivation, player performance, play duration, and game desirability.

1.5 THESIS LAYOUT

1.5.1 CHAPTER 1– INTRODUCTION

This chapter provides a brief introduction to the research and its motivation. The chapter presents the research questions considered, and lists the methodologies used during the course of this research, all of which will be discussed in detail in the following chapters.

1.5.2 CHAPTER 2 – STROKE AND ROBOTICS

The second chapter provides a brief description of stroke, its epidemiology, and its effects. The chapter then discusses the different practices of stroke rehabilitation, their benefits and limitations, to highlight the need for alternatives.

The chapter also presents an introduction to robotics for rehabilitation, listing some of the popular robots used for therapy primarily focusing on the upper-limb, which is the focus of this research.

The chapter also presents a brief introduction to motivation and highlights its importance in rehabilitation.

1.5.3 CHAPTER 3 – SERIOUS GAMES

This chapter gives an introduction of serious games followed by a detailed overview of how different game design parameters, techniques, and processes can influence motivation and enjoyment amongst players. The chapter moves on about the role of games in healthcare as a means to engage patients behaviourally to improve their conditions.

1.5.4 Chapter 4 – Games for Health

The chapter presents a review of some of the current games used for stroke rehabilitation and finally proposes a framework for cataloguing rehabilitation games.

1.5.5 Chapter 5 – SCRIPT System

As explained above, part of this PhD is aligned with the developments in SCRIPT project and use of SCRIPT rehabilitation system. Three games designed by the author have been incorporated into the project, to benefit from evaluation with stroke subjects. The chapter provides an introduction to the SCRIPT project and its objectives. The chapter also details the system's hardware, software interface, and the games it comprises followed by a brief overview of the clinical trials carried out testing the systems usability and compliance.

1.5.6 Chapter 6 – Game Development

Chapter 6 provides a detailed description of the rehabilitation games developed for the purpose of this research; The Marble Maze Game, Run Jack Run, and Burger Hub game. The description includes the design and development procedures and the game parameters built in the games.

1.5.7 Chapter 7 – Game Design Parameters

Chapter 7 presents the initial investigation addressing how some of the identified game design parameters affect the motivation of the players. A pilot trial testing the usability of this game is followed by an experiment evaluating the design parameters incorporated in the Marble Maze game and their effects on motivation and performance of the players, healthy individuals. Lastly, analysing the quantitative and qualitative results of the study, the potential benefit of these parameters for the use of rehabilitative purposes are observed and discussed in the chapter.

1.5.8 Chapter 8 – Game Design Procedure

This chapter presents insight to user-centric game design procedures and its benefits, expanding the concept of game design in order to increase user enjoyment. The iterative design as presented in Chapter 3 is elaborated in this chapter and applied to the developed games. The design process of the three games is explained and the modifications resulting from the iterative cycles are listed.

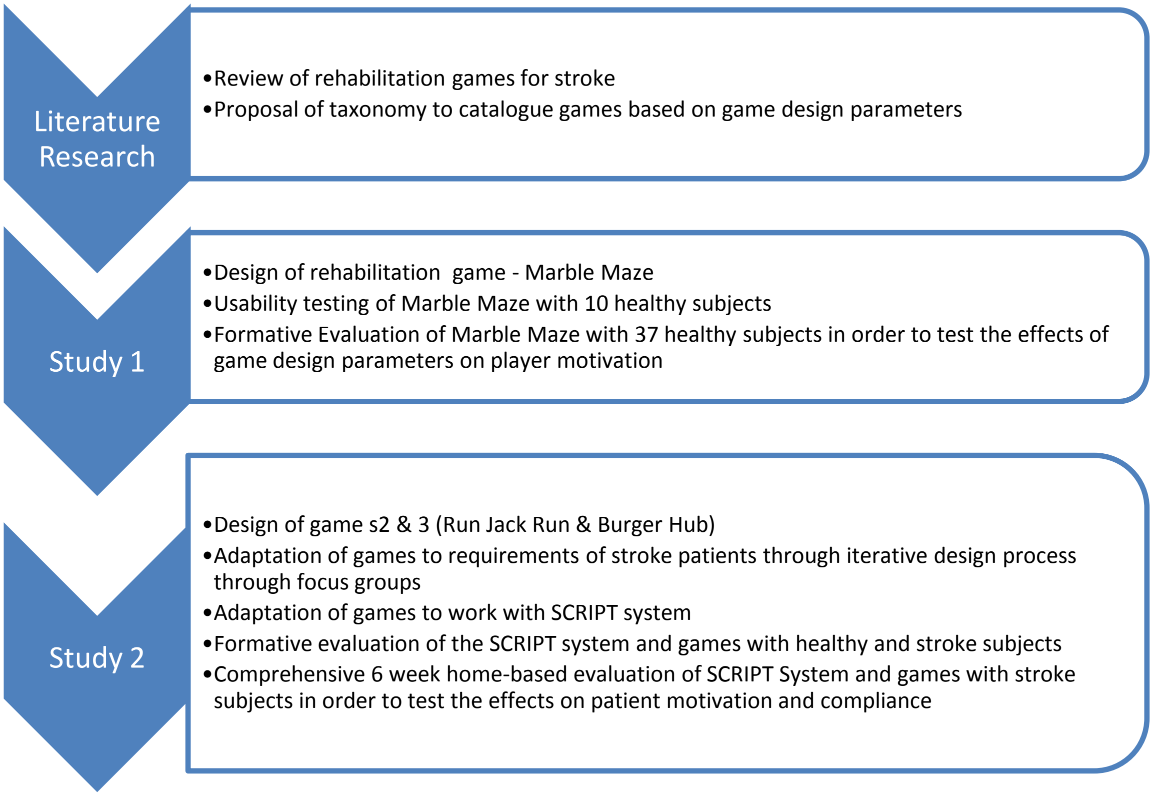
The chapter details the results of formative evaluations conducted with healthy subjects, stroke patients, and health-care professionals in order to test the usability and the effectiveness of the player-centric design. The qualitative and quantitative data collected during this process and the changes resulting from them are also presented and discussed.

1.5.9 Chapter 9 – Motivational Stroke Rehabilitation Games

Based on the developments presented in earlier chapters, three games were incorporated into the SCRIPT system and underwent home-based evaluation during a 6-weeks period by 3 patients. This chapter presents the results from this experiment evaluating feasibility of using games designed within this research, in patients' home. The qualitative and quantitative results are then discussed and their significance highlighted.

1.5.10 Chapter 10 – Conclusions

This chapter presents the conclusion of the research carried out followed by the limitations of the current research, and the future direction the research could focus on.



1.6 Publication List

The work reported in this thesis contributed to publications listed below which include a peer-reviewed international conference paper, a journal article and a poster presented at a conference. A second journal paper based on the content of Chapter 3 has been submitted. The first author of these articles conducted the research studies and produced a first complete draft of the articles. The co-authors guided and supported during the design, development and evaluation process of the studies and also provided feedback on the drafts of the articles. The reference to each article in the list below is followed by a brief description of its relation-ship with this thesis.

1. N. Shah, A. Basteris, and F. Amirabdollahian, "Design Parameters in Multimodal Games for Rehabilitation," *Games Health J.*, p. 131221070208007, Dec. 2013.
2. N. Shah, F. Amirabdollahian, and A. Basteris, "Designing motivational games for stroke rehabilitation," in 7th International Conference on Human System Interactions (HSI), 2014, pp. 166–171.

2. STROKE

The chapter provides a brief introduction to stroke, its common effects, and some of the popular therapeutic approaches currently being implemented to counter the effects of stroke. The chapter follows on to explain why there is a need to look for augmentative tools for the current rehabilitative approaches and lists some of the technological systems addressing this need. The chapter also provides a brief introduction to motivation and its influence on the effectiveness on rehabilitation therapy.

2.1 Introduction

Stroke is a leading cause of death with around one out of four people having stroke dying of it [2]. Those who survive are often left with severe impairments; typically paralysis on one side of the body, which if not cared for may result in permanent disabilities. Different therapeutic approaches are currently available but the effectiveness of each of which are still questionable. The advancements in technology in recent era have given birth to many augmentative methodologies adding and sometimes comparing to the conventional therapies. This research aims to identify some of the existing work in this area, which is used to position this work in the correct context and also to highlight the significance of our chosen approach.

2.2 Stroke and its Effects

Stroke, or *cerebrovascular accident* (CVA), is the rapid loss of brain function due to interruption of blood supply to the brain. Stroke may be caused due to two reasons; haemorrhage or ischemia.

Figure 2-1- Ischemic Stroke

Ischemic stroke, accounting for 87% of the strokes [10], occurs due to an obstruction within a blood vessel supplying blood to the brain. These obstructions may be caused when a blood clot, cerebral thrombosis, forms and blocks blood flow to part of the brain. Part of a blood clot formed in other parts of the body, referred to as cerebral embolus, may also sometimes break loose, enter the blood stream to the brain causing ischemic stroke.

Haemorrhagic stroke occurs when a weakened blood vessel ruptures causing leakage of blood in the brain tissue or the brain surface. This causes lack of blood supply to the brain and a build-up of blood which puts too much pressure on the brain [10]. Although, haemorrhagic strokes are less common, yet they are responsible for more than 30% of all stroke deaths [11].

Figure 2-2 - Haemorrhagic Stroke

In either case, as soon as blood supply to the brain is interrupted, oxygen deprivation causes immediate brain cell damage. The location and the size of the lesions created and the type of stroke determine the kinds of symptoms the patient will suffer, often in loss of abilities controlled by that area of the brain.

Around one in four people who have a stroke die of it [2]. If not fatal, stroke may result in some permanent motor disabilities, typically hemiparesis or hemiplegia which ranges from weakness to full paralysis of one side of the body. Other physical disorders include *spasticity* of muscles (unusual tension and stiffness of muscles), *apraxia* (inability to execute purposeful movements), *and hemi-neglect* (neurophysical condition in which, after damage to one hemisphere of the brain, a deficit in attention to and awareness of one side of space is observed). Cognitively, stroke survivors may suffer from *memory loss*, *aphasia* (inability to understand or formulate speech), *agnosia* (inability to recognise shapes, objects, or persons), sensory disturbances, *attention deficits* and/or *limitation on one side of the visual field*[12].

2.3 STROKE THERAPY

Reduction in the extent of neurological impairments can result from natural neurological recovery, where functioning muscles are used to accomplish a motor function through reorganisation and /or through the development of new neural pathways due to brain plasticity, where a different part of the brain takes over and a different set of muscles are recruited to achieve the motor tasks [13]. This may cause some motor abilities to be regained, but in order for the patients to fully return to their normal independent life, they may have to go through physical and occupational therapy which further help to reduce the effects of these disabilities. Based on the time elapsed after stroke, patients may be classified as being in acute (initial weeks), sub-acute (between weeks and six months) or chronic (past three or six months) stage[14].

Therapy helps recover redundant neural pathways that do not include damaged brain tissue through extensive exercises requiring hundreds of repeated motions on every day basis [15]. It has been observed that intensive and repetitive exercises are useful in providing the brain sufficient stimuli to remodel itself and provide better motor control [7], [8]. In addition, it is important for stroke patients to exercise their affected limbs and continue using them outside therapy in order to reach enough repetitions which is usually ignored by most of the patients due to a number of reasons including lack of motivation, unpleasant sensations associated with exercises, social and cultural expectations, lack of knowledge of the benefits of the exercises[16], and environmental factors such as the effect of being in hospital[17].

The rehabilitation of the upper-limb is challenging yet crucial. Various therapeutic techniques and approaches are currently available but their effectiveness is still questionable and no therapeutic advantage of one approach over the other has been demonstrated. Although there are many documented therapeutic interventions for stroke, some are considered to be more commonly practised than others.

The Bobath technique, name after its inventors Berta Bobath (physiotherapist) and Karel Bobath (a psychiatrist/neurophysiologist), is a broad and ever-evolving approach to neuro-rehabilitation. The concept of this technique is to prepare the patient for functional activity by hindering abnormal movement patterns while promoting and facilitating normal movement patterns, thereby enhancing quality of movement [18]. Formerly, this was achieved by the therapists placing the patients in ‘reflex-inhibiting postures’ to provide the feeling of normal movements in order to reduce spasticity. The therapist acted as the problem-solver and the decision maker guiding the patient, who was relatively a passive recipient, through patterns of movements. However, since the carry over to functional tasks was limited, the approach has evolved more towards focusing on optimization of the function itself rather than the preparation of the function [18], [19]. While Bobath’s technique has made significant contribution to stroke rehabilitation and it is perhaps the most widely used technique specially in the UK [20].

In contrast to the Bobath concept, which focused predominantly on passive treatment, Carr and Shepherd proposed a motor-relearning program for stroke rehabilitation based on promoting an active role for patients. This approach focused on the concept that to regain movement to perform ADL functions, the relearning process of the impaired people is similar to that of the non-impaired ones. The training involved task-specific and context-specific activities; functional tasks in functional settings [18]. Patients are encouraged to practise both physical and mental tasks extensively, under the therapist’s supervision as well as independently at home.

Challenging the prior belief that the apparent loss of strength following stroke was a problem of dysfunctional postural reflex mechanism rather than muscle force [19], recent studies have shown strength and circuit training have a positive effect on muscle strength [21]. The belief that strength training influences unwanted effects of increasing muscle tone and increased spasticity were also not supported by the literature and were found to few and minor only [21].

Other neurodevelopmental approaches like Brunnstrom, Rood and proprioceptive neuromuscular facilitation have also been coined but are less often used. Several studies reviewed the traditional physiotherapeutic approaches but due to methodological differences, have highlighted the lack of evidence in favour of efficacy of one approach over the other [22], [23].

Other approaches take a different approach towards the rehabilitation for example, electrical stimulation of the muscles by applying electrical current to the skin in order to elicit muscle contraction, maintain the range of motion and reduce spasticity [18]. This technique is suitable for individuals with muscles too weak to generate any observable contractions themselves.

Another important aspect for effective therapy is to make sure that the patients are encouraged to use the impaired limb to carry out the task rather than the unaffected limb, a phenomenon often observed in stroke patients [24]. Patients try to compensate for the limited motion of the impaired limb by moving their other body parts, often without being even aware of it, affecting the therapy the impaired limb receives. Constraint-induced movement therapy (CIMT) is another approach, which reflects on the same concept of limiting the use of unaffected limb by retraining it and maximizing the use of the affected limb through exercises. Now, however, some studies have reported patients to have benefitted from this technique [24], [25], a survey carried out has suggested that this technique may sometimes make patients apprehensive about participation in such therapy regimes. The survey of patients and therapists revealed that this demanding treatment may be unacceptable and some even argue it to be deemed unethical. Although, this technique may have some benefits, further research is required.

2.4 NEED FOR AUGMENTATIVE THERAPIES

Most of these techniques are based on motor learning to induce neural plasticity in order to acquire new functions and compensate for impairment. These changes are greater if the practice is meaningful, repetitive, and intensive [26]. Hence, it is recommended that an organized care is provided through cyclic process involving assessment, goal setting, intervention and reassessment. The constant limitation of resources, however, restrains this from happening. Almost all of these conventional therapies require interventions with a physiotherapist which, due to the growing number of people and subsequently growing number of stroke patients, there will be limited access to therapists. Moreover, the therapists also require good skills, training, and past experience [4].

Stroke is one of the leading causes of death and the largest cause of disability and since stroke mortality has decreased in recent years due to improved care immediately after the incidence of the stroke and early and more accurate diagnosis, the demand for the rehabilitative services is very high. It has been estimated that care costs the NHS approximately £3 billion a year in England [2] and about $38.6 billion a year in USA [27]. However, through effective therapy most patients could partially regain enough motor control to use their limbs for ADL tasks [28], this is usually not the case. Due to the limited resources, patients do not receive the required amount of therapy and between 50% to 75% of stroke patients fail to regain functional use of their impaired upper limb [29]. The recovery of the upper extremities often is slower as compared to that of the lower limbs [30] and usually starts with the shoulders and over time moving towards elbow, wrist, and finally hand and fingers.

In spite of much advancement in research, the mechanisms of brain recovery are still unclear but evidence has shown that there is a greater scope of recovery in acute and sub-acute stages [31]. However, in order to prepare patients for discharge, inpatient rehabilitation is mostly focused on walking and mobility rather than upper-limb therapy which is often left for therapy delivered in patient’s home [32], which is also limited to a certain period of time. The rush to discharge the patient early has prompted a shift towards encouraging functional movements by learning compensatory techniques, which although attends to disability reduction, occurs at the expense of impairment reduction [33]. Following discharge, people have expressed unmet needs in relation to rehabilitation services and exercises at home [34].

This lack of services leaves behind some impairments unaccounted which limits the patients' functional autonomy making it difficult to perform ADL, which in turn impacts negatively on their overall quality of life [35].

2.5 REHABILITATION ROBOTICS

In the recent years, there has been a paradigm shift in rehabilitation with the focus on empowering the patient with the provision of therapy outside of the acute settings [32]. This, along with the various constraints of conventional therapy, has increased interest in providing therapy to patients in more novel ways. It has been recognised that face-to-face therapy with the therapist is not the only way to deliver therapy and application of emerging technologies to contribute to tele-rehabilitation has been endorsed. A system is needed that can help health care professionals provide safe, quantifiable, reproducible physical activities in an engaging and an interactive manner.

A large number of studies and research centres have developed various technologies that can provide additional support and exercise mediums for patients. Amongst these technologies are robotic devices that can physically assist patients during practice and provide a safe and controlled environment to deliver therapy to patients. With the earliest referenced manipulator developed dating back to early 1960s [36], over the years, robot mediated therapy has evolved to the point where various products are commercially available. While the efficacy of some of these systems is still being evaluated and are in a more experimental stage, some have shown the potential to provide valuable opportunities for patients to learn perceptual motor skills in an enriched environment.

These rehabilitation robotic systems can provide high-intensity, repetitive, task-specific and interactive treatment of the impaired limb. Another positive aspect to robot-mediated therapy is its potential to measure the patient’s abilities objectively. With conventional therapy, patient evaluation is done subjectively, which makes it difficult to monitor treatment effects. Rehabilitation robots coupled with sensors have an advantage of measuring and monitoring the patients’ forces and movements providing high quality feedback as insight to treatment. Feedback of the performance plays a central role in the acquisition of skills during therapy [37]. The highly accurate information provided as feedback can be used as a basis for error-correction for the next trial and thus can be used to achieve more effective performance as the practice continues [38].

Rehabilitation therapy robots include an array of various devices supporting impaired limbs through training exercises. Rehabilitation of gait receives utmost focus in sub-acute stages as it plays a main role in the independent living. As conventional training is a laborious process and often requires more than one therapist, rehabilitation robotics aim to automate the process reducing the number of therapists required. Design and efficacy of these devices is being actively researched on and some are already available commercially.

In order to address the lack of focus on upper-extremities, which are often neglected in the sub-acute stage when there is a good scope of recovery, several robots for upper-limb rehabilitation have emerged. Although the ultimate goal of these robotic devices is to train the upper-limb, the design of these devices may differ depending on the training strategy they are built for. Some designs encompass hi-tech complex approaches resulting in a high quality and accurate product providing more control over the therapy such as physical assistance while some take low-fidelity approaches providing simpler and cheaper alternatives.

There are three categories of upper-limb devices used in the literature:

Arm support devices work on the principle of supporting the weight of the patient’s arm compensating it against the gravity, making it easier for patients to make controlled movements easily. These devices usually utilize cable suspensions and are simply designed but offer a limited control over the joints.

Exoskeletons (or external skeletons) are devices which are placed over the arm and/or hand. The exoskeletal devices offer more control over the joints of the limbs and with further addition of powered actuators at the joints, offer greater control and range of motions.

End-point manipulators or end-effector based robots are another type of robots which can assist in upper-limb training to stroke patients. The patient’s hand or forearm is connected to the end-effector of the robot which can then be used to move the arm around in 3D workspace. Compared to the exoskeleton devices, the end-point manipulators have simpler designs but the control of the joints and range of motions is limited.

Since the PhD focuses on upper-limb rehabilitation after stroke, some of the most popular rehabilitation robots for upper-limb stroke rehabilitation designed are described below:

2.10.1. *MIT-MANUS* has been developed at the Massachusetts Institute of Technology, MIT; is commercially available as InMotion2, Interactive Motion Technologies Inc., Cambridge, Massachusetts. The robot provides 2DOF (degrees of freedom; ability to make a movement, translation or rotation around an axis in space) passive motion on horizontal plane for elbow and forearm. . The device is designed for safe, stable and compliant operation in close physical contact with patients. They key feature of the device is its back drivable hardware and impedance control. This unique configuration allows the robot to be able to generate sufficient forces to move the patient's arm but at the same time be sensitive to forces applied by the patient. This leaves the patient in control of the movements, hence being engaged in therapy [39]. The robot allows therapists to record and monitor mechanical quantities such as force applied, velocity and position.

The MIT Manus has been subjected to many clinical evaluations including one by Volpe et al. which reported that although all 56 patients improved, patients who used the robot for 1 hour per day had significantly greater recovery in impairment measures than the control group patients treated through the conventional therapy measures and used the robot only for 1 hour per week. There was however, no difference between groups for Fugl-Meyer score [40].

In addition to the 2DOF of the device, further 3DOF can be added by attaching an extra module to the end of the planar module allowing wrist motions which allows wrist flexion-extension, pronation-supination, and abduction-adduction. The wrist module can be mounted on the Manus or be used as a standalone device. A study compared the results of rehabilitation of 36 patients with the robot. The patients were divided into two groups, each receiving 36 sessions of therapy for 6 weeks. The first group trained the shoulder-elbow for the first 3 weeks and then wrist for the next 3 weeks, while the second group received wrist training for the first 3 weeks and shoulder-elbow for the next. Results of both the groups were observed to have improved but they suggested that training the more distal wrist first appears to lead to higher skill transfer to the more proximal segments then vice versa [41].

2.10.2. *MIME (MIRROR IMAGE MOVEMENT ENABLER)* developed by Stanford University and Veteran Administration, Palo Alto is a robotic device for shoulder and elbow neuro-rehabilitation in stroke patients. The device consists of a 6DOF robot manipulator (PUMA 560, Staubli Unimation Inc., Duncan, South Carolina) attached to a splint, which applies forces to the paretic limb to move it in range of motions and orientations in a three-dimensional workspace. A robot is equipped with a six-axis sensor which measures the forces and torques applied by the patients.

The device works in four different modes: passive, active-assisted, active-constrained, and bilateral. In passive mode, the robot guides the patient's arm through a predefined trajectory without any input to be applied by the patient. In the active-assisted, the movement towards a certain target has to be initiated by the patient which is then assisted to completion by the robot. In the active-constrained mode, the robot resists the movement of the patient by applying a viscous resistance and spring-like opposing forces perpendicular to the direction of the desired movement. The device works in both unilateral and bilateral mode. In the bilateral mode, the user attempts bilateral mirror image movements while the device assists the affected arm in the mirror image position and orientation of the stronger arm.

A study using the MIME device recruited patients in the sub acute phase and were divided into 4 groups. Each group received fifteen 1-hour sessions over 4 weeks. The first group received neurodevelopmental therapy (NDT) targeting the proximal upper limb while other three groups received robot-assisted treatment with one group receiving bilateral, one with unilateral, and last group received combined unilateral and bilateral treatments. Only the combined training group had significantly greater gains compared to the NDT group. However, the gains in both groups were equivalent at the 6-month follow-up, suggesting that the combined training is at least as effective as equivalent amount of conventional therapy in sub-acute and chronic stroke patients, but it may accelerate the recovery rate on similar scales [42].

Other studies with 21 subjects training with the robot also presented positive results. The subjects were divided in two groups, each attending 24 1-hour sessions over 2 months period. The results showed significant by greater Fugl-Meyer scale score for shoulder and elbow activity and improved percentage strength in shoulder and elbow movements as compared to the control group patients [43].

2.10.3. *ARM-GUIDE (Associated Rehabilitation and Measurement Guide)*

by Rehabilitation Institute of Chicago and University of California - Irvine is a device consisting of a specially designed splint attached to a linear track actuated by a DC motor. The hand/forearm of the patient is strapped to the specially designed splint which slides along the linear constraint. The motor drives a chain drive attached to the splint in order to move the arm. The arm's position is measured by an optical encoder attached to the motor while a six-axis load cell mounted between the splint and the linear constraint measures the forces applied by the arm. The orientation of the track can be changed according to requirement to provide different pitch and yaw angles allowing reaching in different workspace regions [44]. It has 4DOF which can work in both active-assistance and active-constraint mode. The device is also statistically counterbalanced so the patient does not experience any static loading of the arm due to the weight of the device.

A group of 10 subjects receiving training with the ARM Guide were compared to a control group of 9 subjects. Both training groups performed an equal number of reaching movements to identical targets in every 45 minutes sessions, three times a week for 8 weeks. The robot-trained group however, received mechanical assistance to complete the desired movement. Subjects trained with the ARM Guide were observed to have improvements in gains, which were equivalent to the control group, that translated into improvements in time taken to carry out functional tasks and also improved movement smoothness [45].

2.10.4. *DRIVER SEAT (DRIVER'S SIMULATION ENVIRONMENT FOR ARM THERAPY)*, developed at VA Palo Health Care Systems Rehabilitation Research and Development Centre is a car steering simulator equipped with specially designed steering wheel to measure forces applied by each arm of the patient. Driver's Seat is a 1DOF robotic device with a split-steering wheel which measures position and force related performance. The electric motor which is used to provide assistive or resistive forces [46]. The device measures the forces generated by each arm of the patient independently. The device is designed to encourage patients to use their paretic limbs through bimanual exercises.

The device operates in three different modes: passive movement, active steering and normal steering. In the passive mode, most of the steering is done with the less impaired hand while the impaired hand is moved passively. In the active-steering mode, most of the driving is done by the impaired-hand while the forces by the contralateral limb are discouraged by partial restraint. In the normal steering mode, the subjects are instructed to practice coordinated driving by actively steering with both hands in order to improve the force symmetry.

A study comparing the effects of active-steering and normal steering involving a group of 8 patients with chronic stroke and a group of 8 healthy subjects, showed that in stroke subjects, force cues in active steering mode significantly increased productive torque activity in steering directions up and against gravity with the impaired upper limb [47].

2.10.5. *BI-MANU-TRACK* by Reha-Stim (Berlin, Germany) is a computerized motor-driven arm trainer which allows bilateral training of fore-arm pronation-supination or wrist flexion-extension. The device can be used in passive mode where both the arms are moved by the robot, active mode where the non-affected arm actively moves the handle while the robot guides the impaired arm in a mirror-like fashion, or an active mode with resistance where the paretic arm has to overcome pre-set, initial isometric resistance to allow bilateral movement. The device movements can be set to be either mirrorsymmetric or parallel with speed, range of motion (ROM), and resistance individually set depending on the patients' abilities.

A study involving 42 patients with chronic stroke compared the results of Bi-Manu-Track bilateral upper limb training with therapist-based bilateral upper limb training and control treatment. The Bi-Manu-Track group had increased shoulder flexion compared with the therapist-based bilateral upper limb training and control groups [48].

2.10.6. *REHA-ROB THERAPEUTIC SYSTEM* was developed by Budapest University of Technology and Economics to support upper limb physiotherapy for patients with spastic hemiparesis. The system takes a unique approach towards coordination of joint movement. The system comprises of two unmodified industrial robots which work simultaneously to practice passive physiotherapy for upper limb. The therapists program the system by teaching it movements entering the order and repetitions of these movements which the robot then executes providing passive shoulder and elbow physiotherapy. In contrast to the systems which provide goal-directed movements, the REHA-ROB system aims to provide high number of slowly executed movements with a constant velocity to decrease spasticity, reduce muscle hypertonia and increase the range of shoulder and elbow motion [49].

Thirty patients with the spastic hemiparesis due to stroke took part in a study with the system. The patients were divided into two groups, each receiving 30 minutes of Bobath therapy sessions for 20 consecutive work days. The robotic group received an additional 30 minutes of robot-mediated therapy on the same 20 days. Both groups showed improvements in the shoulder-elbow subsection score of Fugl-Meyer test and FIM test, reduction in elbow flexor spasticity, and increased elbow range of motion [49].

2.10.7. *NEREBOT (NEURO-REHABILITATION-ROBOT)*, designed at the Padua University, Italy, is a novel device for upper limb rehabilitation based on direct-drive wire actuation. The 3DOF device benefits over the other devices due to its reduced complexity, lower cost, and a higher degree of safety and reliance. The robot can assist shoulder and elbow flexion-extension, adduction-abduction, pronation-supination, and circular movements. Each exercise is programmed by the therapists by manually moving the patient's arm through a series of way points recording movements which the robot subsequently reproduces during therapy sessions. A virtual 3D representation of the arm is displayed on a screen which informs the patient of the desired movements to be carried out.

A study involving 17 patients during acute phase of stroke receiving 4 hours per week for 25 weeks additional therapy with the robot reported improved scores of Fugl-Meyer, and increased deltoid and bicep strength in comparison to 18 patients in the control group. At 3- and 8-month follow-ups, the statistically significant effects of robot-mediated therapy were maintained [50].

2.10.8. *T-WREX (THERAPY WILMINGTON ROBOTIC EXOSKELETON)* is a passive arm orthosis designed to enable patients with significant arm weakness to achieve intense training without supervision of the therapist. The 5DOF, body-powered device provides movements in a large workspace while compensating for the effects of gravity, reducing the effects of muscle weakness due to dystrophy. The device is linked to a computer interface with games specifically designed to simulate functional tasks. The instrumentation of the device allows it to be used as an input device and is equipped with a pressure-sensitive hand grip which enables hand grasps to be detected and incorporated in the virtual tasks.

A pilot study to test the feasibility of using the T-WREX as a training tool was conducted with five chronic stroke patients. The patients trained with the robot for 45-minutes, 3 times a week for 8 weeks. The degree of gravity compensation was gradually decreased through the training sessions so the patients were training with greater effects of gravity acting on the arm. Statistically significant improvements in arm movement (measured by Fugl-Meyer score) were reported. Three of the patients demonstrated significant improvements in free-reaching away from the body while two patients demonstrated significant improvements in grip strength [51].

2.10.9. *THE GENTLE/S* system was developed to provide challenging and motivating therapies to stroke patients through level exercises and be in control of their therapy. The GENTLE/S system comprises of a 3DOF robot manipulator (Haptic-Master, Moog FCS, The Netherlands) with a 3DOF passive gimball which allows pronation-supination of the elbow as well as flexion-extension of the wrist. The patient's arm is placed in an elbow orthosis suspended from an overhead frame and on the gimball using a wrist splint. The movement therapies are programmed on the robot which then guides the arm through these reaching and withdrawing movements. Visual feedback is provided on a screen depicting the current and the target position of the arm.

The robot works in three modes: patient passive, patient active-assisted, and patient-active. In the patient passive mode, the robot guides the paretic arm of the patient through a series of set points in the workspace while patient remains passive. In the patient active-assisted mode, the patient has to initiate the movement by providing a nominal force in the correct direction to make the robot move. In the patient-active mode, the patient is told to reach a target position on his/her own. The robot remains passive, unless the patient deviates from the pre-defined path which then guides the arm back to the correct path.

The GENTLE/S clinical trial with 31 hemiparetic patients in the chronic stage of stroke compared the robot with sling-suspension exercise. Both the groups showed improvements in Fugl-Meyer scores but there was no evidence of any one being better than the other, however, this maybe because of the limited exposure time of only 4.5 hours of robot-mediated therapy per subject [52]. A later study with 20 stroke patients demonstrated that the robot therapy appeared to speed up the recovery rate [53].

Figure 2-3 - The GENTLE/S System

As an extension to the GENTLE/S system, the GENTLE/G System incorporates a grasp assistance robot which allows a further 3-passive-DOF to facilitate the orientation of the hand and 3-active-DOF for grasp and release of the hand. Software was developed to manage data collection, control of the robots, and simulate interactive virtual worlds for exercising arm reach and hand grasping of objects. A randomized study with 4 stroke subjects compared the results of robot-mediated therapy with the conventional therapy reported higher gains in robot-mediated phase [8].

2.10.10. *ARMIN*, developed at the ETH (Eidgenossische Technische Hochschule) Zurich and the University of Zurich, Switzerland, is an arm exoskeleton designed for patients with movement impairments. It has 6-active-DOF which assists patients with moving the shoulder joint in 3DOF, the elbow joint, lower-arm pronation-supination, and wrist flexion-extension. The control algorithms allow position control of the device and also interacting forces between the robot and the patient. A graphical interface presents different training programs allowing passive mobilization, active gaming therapies and active ADL training through virtual scenarios. In passive mobilization mode, the patients arm is moved by the robot through a predefined trajectory. In the active gaming mode, the patients are presented with tasks in a game-like scenario which they have to accomplish with the support of the robot. In the active ADL therapy mode, the patients train real life tasks like eating, cooking, setting up the table etc. [54].

With further advancements in technology, more and more devices are coming to surface showing potential results in robot mediated therapy, each with its own appropriate strategy to actuate the motion of relevant body part(s) to train for restoring motor functions. The great advantage of robot mediated therapy is its capability to provide highly safe, feasible, personalized and standardized rehabilitation protocols with the option of having multitude of quantifiable [55].

2.6 MOTIVATION

Although home therapy using rehabilitation robotics provides a prospective alternative to conventional therapy, the lack of motivation of actually using these technologies outside the therapy settings still remains a constraint. As discussed earlier, the movements involved in the therapy exercises are usually repetitive; which may seem monotonous and boring in nature to some. Furthermore, in addition to concentration and attention deficiencies, stroke patients often experience depression and anxiety due to the drastic change in their lifestyle. For this reason, it is not only hard for patients to stay focused and attentive towards the therapy, they also feel disheartened and give up on home exercises.

In order for the patients to get better, physiotherapists persuade patients to continue their exercises at home but a survey shows that only 31% of the patients do so as recommended [16]. People who do not complete home exercises as recommended often cite slow progress and lack of motivation as impediments [56]. As recovery usually happens in plateaus, it is easy to lose faith in exercises after observing no improvement for a long time [57]. Therefore, finding motivating and effective ways to encourage people with hemiparesis to perform therapeutic exercises at home is crucial in helping them achieve complete recovery where they regain lost motor control and become more independent.

Although there's no certain definition of motivation, a general definition reflecting the consensus of variety of psychology textbooks states that motivation is an internal state or condition that serves to activate or energize behaviour and give it direction [58]. It is a general understanding that motivation is involved in the performance of all learned responses; that is, a learned behaviour will not occur unless it's energized [59]. However, the major issue is of explaining the phenomenon of what causes motivation. Various theories have been presented by many psychologists trying to explain the concept but there has been very little agreement upon identifying the motives underlying behaviour [60]. Contrary to some theories, which believe that motivation is a unitary phenomenon, some theories state that people not only have different levels of motivation but also different kinds of motivation. This orientation of motivation concerns the underlying attitudes and goals that give rise to the action [61].

In Self Determination Theory (SDT), Deci & Ryan distinguish between the different types of motivation based on the different reasons or goals that result in a certain behaviour, classifying them in two basic distinctions; intrinsic and extrinsic motivation [62].These are further discussed in the following sections:

2.6.1 Intrinsic Motivation

Intrinsic motivation refers to doing something due to inherent satisfaction, interest and enjoyment in the task itself, existing within the individual without any external pressure or desire of a reward. The phenomenon, first acknowledged in experimental studies of animal behaviour, discovered that playful and exploratory actions were driven solely out of curiosity and interest without any external reward [63].

According to some authors, intrinsic motivation is classified as natural motivational tendencies, critical to cognitive, social and physical development and exists within an individual while others argue that it exists in the relation between the individual and the task itself. In one sense, it is the motivation a person gains from the task engagement, while the other defines it as motivation in terms of the task being interesting [61].

2.6.2 Extrinsic Motivation

Extrinsic motivation, on the other hand, comes from outside the person, referring to the performance of an activity in order to attain a separable outcome. Extrinsically motivated tasks may be complied with resistance or disinterest with the individual being externally propelled into an action, or alternatively, with an attitude of willingness reflecting on the individual’s acceptance of the value of task on hand [61]. This difference can be used as an effective strategy to promote the learning process of an individual by making the task more active and volitional.

According to an American psychologist B. F. Skinner, all behaviours are motivated by rewards. Through this experiment, Skinner coined the concept of *operant conditioning*. The basic principle of operant conditioning is simply that frequency of behaviour will increase if it is rewarded and that it will decrease if it is punished [64]. Since operant conditioning maintains that all behaviours are motivated by awards, intrinsically motivated activities are said to be the ones for which the reward is within the activity itself.

3. Serious Games

With the role and importance of motivation on the effectiveness of stroke rehabilitation understood, we move on to present some possible solutions to address the limitations discussed in the previous chapter.

This chapter gives a brief introduction to the use of games in the field of healthcare. The chapter presents an insight to various parameters, techniques, and procedures used in game designing to influence motivation, enjoyment, and engagement.

3.1. INTRODUCTION

With the impressive growth of the video game industry in the past years, the use of these games for health, education, training purposes has become a popular trend amongst game designers, educators, and marketing firms. Games which are designed for a primary purpose other than entertainment are defined as serious games[65]. The emergence of serious games as viable niche in the multi-billion dollar gaming industry, represents opportunities for these video games to be used outside the scope of entertainment [66].

3.2. GAME DESIGN

Games, defined as an activity or sport played according to some rules[67], are designed for one primary purpose: player enjoyment. Enjoyment, however, has a deeper root in psychology[68] and may arise from many characteristics of a game. However, defining what these characteristics exactly are has been subject of some debate. Most literature explaining the factors that foster player enjoyment or entertainment experience refers to the games' interactivity [69], [70]. Malone (1980) defined the characteristics that make a game engaging as the challenge, fantasy, and curiosity induced by the game [71]. deFelix and Johnston suggest that dynamic visuals, interaction, rules, and a goal are the essential components for a game to be enjoyable. Gredler (1996) states that task-reinforcement structure, strategy, and complexity of problem solving are essential for an effective game design [72]. Marc Prensky expands this list by adding adaptability, feedback, and storyline [73]. Another study, investigating the design factors perceived as important in creating cognitive and perceptual fun, indicates satisfaction, challenge, imaginativeness, and vividness as the derivatives of enjoyment in a computer game [74].

Although many of these theories and models have been developed to conceptualize and explain the phenomenology of enjoyment, the so called *Flow Theory* stands out. Flow Theory is based on the premise that the elements of enjoyment are universal, providing a general model that summarizes the concepts common to all when experiencing enjoyment [75]. In an attempt to explain happiness, Csikszentmihaly introduced the concept of Flow in the mid-1970's, which has since become fundamental to the field of positive psychology [76]. Flow is a state of consciousness expressed as the optimum experience so gratifying that people are willing to do the task on hand without concern of some external reward [75]. Analysing these concepts of Flow, Sweetser & Wyeth introduced a new model called *GameFlow*, based on an eight-element model of Flow in order to define a model that can be used to design, evaluate, and understand enjoyment in games [77]. The GameFlow model consists of:

1) Concentration
2) Challenge
3) Skills
4) Control
5) Clear goals
6) Feedback
7) Immersion
8) And social interaction

In addition to these, the usability of games is another important factor which can affect the interaction of users with the game. The current literature on usability of games presents many heuristics for designing and evaluating games focusing on three aspects of usability in games: interface (controls and display), mechanics (of the game world) and gameplay (problems and challenges) [78], [79]. Game interface is the medium through which the player interacts with the game. Game mechanics are the environment physics of the game, which are developed through a combination of animation and programming. Game play is the process by which a player reaches the goal of the game. The design, testing and evaluation of all three are critical for the game to be both, functional and satisfying.

A comprehensive review of the literature was conducted to determine the key parameters and elements of game design that affect player motivation and enjoyment. Through the analysis of these game characteristics, we identified the key parameters that make the game engaging and enjoyable, ultimately motivating players into playing the games for long durations.

3.2.1. Game Play

Game play, perhaps, may be the most important part of a game. Game designers and game publishers alike are adamant that game play is the deciding ingredient of a good game [79]. A game's gameplay is the degree of and nature of the interactivity that the game includes [69]. It consists of a set of challenges following a storyline, a set of actions that can be performed by the player to overcome these challenges [80] and other entities within the virtual environment, in response to the player's actions or as autonomous course of action that contribute to the liveliness of the virtual environment [81]. Gameplay is generally considered the overall experience of playing the video game and excludes the graphics and the sound.

One of the most important of aspects of the gameplay of a successful game is that it should lead to the creation of meaningful play [82]. Playing a game means making choices and taking actions given that they abide by the rules of the game space. Each action in turn results in an outcome driven by the game engine. Meaningful play relates the actions of the players and the choices they make with the outcomes of those actions and their effects on the overall context of the game. The consequences of every action should be discernible as to leading towards or away from winning. With only the environment designed, the flow of the game should entirely depend on the sequence of choices made by the player, the non-playing-characters and/or the AI game engine. The player's choice of actions should not just have an immediate effect on the game, but should also consequently affect later parts or the overall context of the game's progress. In this manner, the player drives the game according to his/her will by making certain choices or taking specific actions while the game engine and the non-playing-characters give rise to a new set of meanings as an effect of those choices and actions.

As an acknowledgment of these effects, feedback cues from the game prompt the player to signify if correct or incorrect action was taken. Often some form of performance measure such as numerical score or progress bars are maintained and presented in the form of aural, visual or haptic cues informing the player of his/her performance. The correct sequence of choices resulting in incentive benefits for the player, such as upgraded level in the game and the player losing some benefits as a result of wrong actions taken in game, keep the player motivated and captivated to the game.

3.2.2. Genre

Like most media, video games also have genres. The genre of a game is a general descriptor of the style of gameplay of the game with a purpose of defining and categorizing games in terms of having a common style of perspective, interaction, objective etc [83]. Video games are usually divided into different genres and subject to individual choice and preferences. It is very challenging to define what genre makes a game motivational and engaging since there is no common likeable game. Similarly, games designed for rehabilitation encompass a wide variety of genres of games providing the users with a library of different games to choose from depending on their personal liking and level of impairment. *Action-Adventure*, *Arcade* and *Sports* are some of the most common genres found in rehabilitation games. A brief description of some of these common genres is listed in the Appendix IV – Game Genres.

However, understanding who the intended gamers are is very important from a design perspective. Bateman and Boon [84] discuss that the design of the game should reflect upon the desires and needs of the audience, complimenting their taste. Some game design models attempt to understand the players by identifying common characteristics or habits of their target audience. Salen and Zimmerman [82] and Fullerton et al. [85] refer to these as the iterative design method and argue in favour of inviting feedback from players early on in the design stages. ‘Iterative’ refers to a process in which the game is designed, tested, evaluated and redesigned throughout the project. Also, designers of rehabilitation games should also involve subjects with stroke into the choice of their preferred genre.

3.2.3. Challenge vs. Skills

Another principal aspect of game design is adapting the level of challenge to the player's skills [82]. In order to keep the game interesting it is important that the player is consistently provided with challenging tasks while at the same time avoiding over-challenging him/her prevents potential frustration. The balance between these two conditions is difficult to achieve considering the inter-individual variability in terms of skills.

The traditional way of achieving this is by gradually increasing the level of difficulty. Starting with simpler and easier tasks, giving the user time to familiarize with the game and develop the essential skills. The difficulty could be increased when a certain in-game task is achieved, a certain score is reached, or a certain level of training skill is acquired. The motor skill taxonomy, proposed by Gentile [86], provides a desirable template for designing such rehabilitation programs by systematically classifying motor skills and movements based on their increasing complexity according to two dimensions of physical actions; environmental context and action function. The taxonomy is a good means of becoming aware of the skill characteristics that make skills distinct from, as well as related to, other skills. It is also an excellent guide for establishing practice or training routines [86]. Rehabilitation games can focus on one element of the taxonomy and gradually increase the complexity of the tasks based on the patient's progression.

In addition the game's difficulty level can be adapted online based on the player's performance. Depending on the genre of the game, this could be achieved by either adding/removing some of the challenges/rewards the player is presented with or by increasing/decreasing the pace of the game based on how well the player is progressing in the game.

In this way, although the game could start with standard settings, its difficulty will be automatically adjusted depending on how well the player is performing. If a person with weaker motor functionality fails to do a certain task, the game will automatically decrease the level of difficulty for that particular task for subsequent number of trials until the player is able to complete the task, provided it does not fall below a defined threshold. Not only will this keep the patient motivated, it will also allow players with weaker capabilities to move forward within the levels of the game. The same goes for the people with better motor functionality, with the game increasing the level of difficulty if the player is performing well in the game, not making the game too easy and boring for the player.

Since the training regimes are intended for patients with different level of motor abilities, each task can present a different level of challenge depending on its complexity, its environment and the individual abilities. The Challenge Point Framework proposes that learning is related to the information arising from performance, which should be optimized along functions relating the difficulty of the task to the skill level of the performer [87]. Increasing the task difficulty may increase the learning potential, but may also decrease the performance of the individual. Thus, the Challenge Point Framework proposes means to determine the optimal challenge points for motor learning and configure the difficulty of the game such that the learning is maximized and decrement in performance in practice is minimized.

3.2.4. Goals /Achievements

The current literature on motivation proves that clear, specific, and difficult goals lead to enhanced performance[88]. Clear, specific goals allow individuals to perceive goal-feedback discrepancies, which are seen as crucial in triggering greater attention and motivation. Studies have shown that individuals with specific goals have higher performance and typically work harder to meet the challenge than those without goals [89].

The same principles are important in game design. Even a rich, responsive environment may be unappealing unless it provides an appropriate goal to the user. Simple games should provide obvious and compelling goals, with the help of sensory cues, for a more appealing approach. Also, it is important that the players are able to identify and monitor their performance in order to tell how close they are to achieving the goal [71].

Good computer games often make use of multiple levels of goals where there is one basic goal of accomplishing something in the game world, while there is another meta-goal to achieve the basic one efficiently. Some games use speeded response feature which is a type of meta-goal where the player races against time to achieve the basic goal of the game before the time runs out. Similarly, some games have sub-goals where the individual works towards the sub-goals before actually moving on to the basic goal of the game [71]. The term 'achievements' or a similar concept, has recently become popular after adoption by major gaming platforms like Microsoft Xbox Live (http://www.xbox.com/) and Valve Steam (http://store.steampowered.com/). These achievements are awarded to players when a certain level of skill has been acquired. It aims to motivate players by rewarding them with achievement badges for their efforts.

3.2.5. Feedback

One of the very important aspects of user interaction with the game is feedback. Feedback in games is designed to evoke correct behaviours, thoughts or actions. In motor skill rehabilitation, providing feedback to the patient can influence the learning process [90]. Feedback sometimes is provided by the sensory information that arises in response to natural consequences of a certain movement made. This type of feedback is categorised as intrinsic feedback[91], and it implies a person's own perception of the result of movement mediated by the sensory input such as vision, touch, audio, etc. The additional feedback provided to the performer from external sources, such as the therapist or the game interface, is regarded as extrinsic feedback [91]. Extrinsic feedback includes knowledge of the results, which presents the information about the outcome of the performance, as well as the knowledge of the performance, which provides the information about the characteristics of the movement itself.

Feedback, providing information on correct and incorrect actions, can provide encouragement and motivation to be persistent in learning a certain skill and may also speed up the learning process [90]. Feedback may be of positive or negative kind; informing the player of the repercussions of their actions by indicating the degree of ‘correctness’ or ‘wrongness’ of an action. In this way, the player is guided to respond correctly thus steering him towards success. This not only motivates the player, it also keeps the player engaged and hooked to the game.

It is important that the feedback flows naturally from the game, unfolding in an orderly and a well sequenced fashion and not be too distracting while at the same time being noticeable enough to not go ignored. Also, it has to be constant and continuous so that the player does not have to wait for it while also having some element of surprise to it containing some twists to keep it interesting. Finally, the feedback should be coherent to the context of the game; congruent with the actions on screen as well as with the storyline of the game unfolding it as the player progresses in doing the ‘right’ actions.

Video games are even termed as ‘Virtual Skinner Box’. Through his original experiment, Skinner coined the concept of “operant conditioning”. The basic principle of operant conditioning is simply that frequency of behaviour will increase if it is rewarded and that it will decrease if it is punished [64]. Operant conditioning is a type of learning in which an individual’s behaviour is modified by providing a reward structure through reinforcement schedules in order to elicit specific controlled behaviours. Operant conditioning not only affects the kinds of choices players make during the course of a game, but also their general motivation to continue playing [82]. The same behavioural approach is used in some game designs with core game mechanics being based on simple reinforcement schedule [92]. Similar to the design of gambling casinos, where small wins or rewards keep the player engaged while punishments keep the game challenging enough, games use similar techniques to make the game interesting. Progression in game levels, power ups, and boosters are used in various games to invoke and reinforce correct behaviour, whereas losing game lives or player inventory are examples of punishments to discourage incorrect behaviour. The more certain the players are that something good or interesting is going to happen soon, the harder they will play. Similarly, when they are punished with some negative consequence of their actions, they will try to avoid them to prevent such things to happen [93].

3.2.6. Scoring

Obtaining high score is one of the most easily recognizable hooks and often provides an urge to do better and better in the game to break the record score of someone else or even one's own score. This 'hook' can also keep the players engaged in the game for long periods of time [94]. Score is often measured in an abstract quantity of units associated with a correct behaviour of the player. Achieving score may lead to progression in the game unlocking new levels of challenges or often in arcade games, gaining an extra in-game life or power up boosters. In some games, score may be an optional side component of the game with no immediate relevance to the progression of the game, however, achieving the 'high-score' and trying to beat that score in subsequent play becomes an extra challenge to offer replay value [95].

3.2.7. Graphics/Immersion

'Immersion' is an increasingly popular term in the game design community, referring to using technologies that engage the game player's minds via sensory stimulations and providing a sense of presence in the game environment [65]. Sensory channels include rich visual graphics, spatial sounds and haptics which can be used to engage players, evoke emotions and influence a certain state of mind.

Visual aesthetics, referring to the graphical innovation that affects how the game is visually perceived by the player, plays an important role in the game design [96]. Although it is widely accepted that gameplay is more relevant than graphics, first impressions are also very important [97]. Photorealism is the current visual preference as it is easily measurable against reality and realistic visuals become a broadly applicable barometer of quality [98]. Thus a highly realistic game not only gives an impression of skillful technology but also of immersion [99]. With the evolvement of graphic technology, recent games have focused on visual realism and immersion but a recent study encourages game designers to use alternative, more artistic rendering styles, such as non-photorealistic rendering. These stylized graphics can employ a more interpretive aesthetics and establish a visually unique environment which can immediately stand out visually and thematically in a game.

These styles are suggested to assist in evoking emotions and establishing certain moods [97]. Using basic graphical elements (such as dimensionality, perspective, colour, presentation, realism) and principles of art as building blocks to create a consistent visual style through iteration can play an important role to set the immersive environment of the game which can influence the over-all appeal of the game and the length of time one plays a game [99].

While vision is regarded as the most important sense of apprehending an environment, sound has certain advantages over sight. Stereo sounds used in games can surround the listener, blending him with the game environment by providing the player with information outside the visual frame. This not only enriches the user experience but adds to the sense of immersion in the game world [100]. Different sounds and speech delivered with an emotional attachment can toy with the player’s emotions and motivate the player to want to play [101].

4. GAMES FOR HEALTH

This chapter presents a literature review of games used for stroke rehabilitation followed by a proposal of a framework to catalogue these games for future reference and to allow for achieving evidence for usefulness of different game design techniques within the games for health field.

4.1. INTRODUCTION

Serious games have recently become popular in the field of medicine as a means to engage patients behaviourally to improve their health outcomes. Some of the earliest reports of using games as physiotherapy have shown these to have huge therapeutic benefit. Serious games have been used in rehabilitation for several purposes, such as to train movements of a patient with Erb's palsy [102], to increase hand strength [103], as physiotherapy for patients with arm injuries [104] and to distract and relieve pain for burn victims undergoing physical therapy [105]. In the right context, serious games and in some cases, even commercially available off-the-shelf games that are repurposed to meet a certain behavioural goal in healthcare, have shown to have a positive therapeutic benefit to a large range of different subgroups [106], [107].

4.1.1. GAMES FOR STROKE

As discussed in the previous chapter, finding motivating and effective ways to encourage post-stroke patients with impairments to perform therapeutic exercises at home is crucial in helping them achieve a more complete recovery and to become more independent. Since video games are associated with high user engagement, numerous studies designed and tested games specifically for engaging stroke patients in their rehabilitation exercises. These games require the patients to perform certain motor tasks to play, which results in reasonably efficient exercise regimes [108].A potential benefit of serious games is the possibility of home-based rehabilitation systems remotely monitored by a therapist/health care professional.

A number of research centres have developed varying technologies that can provide additional support and exercise mediums for patients. These include commercially available gaming consoles, motion analysis systems and robotic devices.

The commercial release of motion controlled videogames (e.g. Nintendo Wii, Microsoft Kinect) has made it possible for such games to be used also for rehabilitation. With gradual improvement of motor function, the games developed for these consoles could be setup at the patient's home allowing the patient to undergo controlled rehabilitation therapy at home by performing pre-recorded exercise routines and the performance monitored by a health care professional.

Some of these off-the shelf games for such hardware platforms, such as Nintendo Wii and PlayStation Eye-Toy, have been tested with patients and have shown some potential for stroke rehabilitation [109]–[112]. Not only are these affordable, but are also easy to set up at clinics and homes. However, many of these do not comply with the requirements of subjects with stroke where limited range of motion or lack of adequate grasping force impedes the game play. Also, while the traditional video games report on game scores, rehabilitation processes are informed by feedback on patients' physical status, i.e. active and passive range of motion, which is often not provided in commercial video games.

"On the other hand, there are games designed and developed specifically for stroke rehabilitation which although are suitable for patients with limited movements but are often very basic in design and have a very low appeal to the users. Some of these games have proven to be suitable for effective therapy, however, their ability to sustain the interest of patients during extended exercises remains questionable. This is partially due to combining games with the interactive medium such as a robot or a hand-held device, but also due to less standardized forms for reporting and measuring engagement and motivation.

There is a possible two-way exchange between the conventional video game designs to address stroke patient's needs, or for the rehabilitation game designers to deploy success factors used by commercial games.

Most of the rehabilitation games have focused more on the clinical constraints and have not taken into account game-design principles. As a result, rehabilitation games lack the appeal of the commercial games because of their limited graphics and gameplay and eventually become boring.

To date, a growing number of games have been developed for various platforms, usually robotic devices or interactive virtual reality systems that can physically interact with patients during practice and provide a safe and controlled environment for their treatment. They also feature sensors which allow monitoring limb motions, making it possible to generate an instrumental assessment of patients' skills and recovery. With the ability to measure movement details and, in some systems, the ability to assist the movement of the arm in specific sequence of motions, these systems pair up with serious games effectively resulting in a reasonably efficient rehabilitation system.

4.2. Review For Games of Stroke

In order to evaluate the state of games for post-stroke rehabilitation of the upper limb and their relations to aspects of game design techniques, we conducted a review of these games. We considered whether and to which extent the design of these games included principles which are traditional in video gaming.

4.2.1. Methods

Inclusion criteria and literature search

We included studies in which participants were required to move the upper limb to control a game. Articles were included if focusing on the game itself (i.e. describing why the authors had developed such a game and hypothesized its effectiveness in rehabilitation) rather than on other components such, for instance, the hardware used to control a game. Articles were included also if the rehabilitation of the upper limb was not the primary aim, but the performance of such games was hypothesized to improve psychological aspects of the post-stroke experience such as motivation.

We limited our scope to the last ten years, due to the rapid advancements in the field and its technologies.

The literature search was limited to abstracts of articles written in English and included in the following electronic databases: IEEE, Pubmed, and Google Scholar. The search terms used were a combination of 'serious games', 'virtual reality', or 'games' and ‘rehabilitation’, ‘stroke’, ‘motor control’, or ‘motivation’. Furthermore, other relevant papers were also included through the references of the resulting papers.

CLASSIFICATION OF GAME CHARACTERISTICS

We focused on several features of the reviewed games, which were classified according to some of the game design parameters discussed earlier in the chapter. Some of these, shown in Table 4-1, were available for all studies, allowing a systematic process.

Table 4-1 – Game Design Parameters

Hardware	The system (e.g. motion analysis, robotic device) for which the game has been developed
Genre	The genre of the game, classified according to a videogame taxonomy as arcade, racing, sport, simulation, etc.
Graphics	Whether the game uses 2D, 2.5D (i.e. 2D characters on a 3D background) or 3D graphics
Movements	The dimensions of the workspace in which the player has to perform the required movements to play the game.
Haptic Feedback	The game provides haptic feedback.
Dynamic Difficulty Balancing	The game’s difficulty is automatically adapted to the player’s performance.
Multiplayer options	There is the possibility of competing or collaborating with others.

4.2.2. Results

After applying filters for games for upper limb rehabilitation 60 articles were identified. 45 of these articles were excluded either because articles did not include description of the games or mostly focused on the hardware used. Also, a number of articles were discarded since the games were merely virtual representation of the physical tasks presented to the patients, having very poor gaming aspect. As a result 15 studies were included in this review. Some studies used multiple games, hence in total 27 games were included.

Table 4-2- Classification/comparison of Games for Stroke Rehabilitation

Game	Hardware	Genre	Graphics	Dynamic Difficulty Balancing	Movements	Multiplayer options	Haptic Feedback	References
WiiSports	Nintendo Wii	Sports	3D		3D	Competitive and Collaborative		[109]
Cooking Mama: Cook Off	Nintendo Wii	Simulation	2D		3D	Competitive		[109]
Under the Sea	WiiMote	Arcade/Role-play	3D	✓	1D/2D	Collaborative		[113]
Helicopter/ Handcopter	WiiMote/ Webcam	Arcade	2D	✓	1D			[113][114]
Baseball Catch	Webcam	Sports	3D		2D			[113]
Garden	Webcam	Simulation	3D		2D			[113]
Rabbit Chase	Webcam	Arcade	2D	✓	2D			[6]
Arrow Attack	Webcam	Arcade	2D	✓	2D			[6]
FurballHunt	Webcam	Arcade	2D		2D			[115]
EyeToy: Play & EyeToy: Play 2 (Kungfoo, Wishy Washy, Goal Attack, Mr. Chef, Dig and	Playstation EyeToy	Multiple Genres: Sports, Role-play, Sports, Simulation, Simulation and Sports.	2D		2D			[111]

HomeRun)								
Goalkeeper	1-DOF motor based haptic device	Sports	2D		1D		✓	[116]
Air Hockey	The Rehabilitation Gaming System (RGS) using Microsoft Kinect	Arcade/Sports	3D	✓	3D	Competitive		[117]
Breakout Therapy	Logitech Wingman Force feedback Pro/JavaTherapy	Arcade	2D		1D		✓	[118]
Memory Game	TheraMem	Arcade	3D		2D			[119]
Catch the Orange	5DT Ultra DataGloves	Simulation	3D		3D			[120]
Fishing Game	5DT Ultra DataGloves	Simulation	3D	✓	3D			[120]
Whack the Mouse	5DT Ultra DataGloves	Arcade	3D	✓	3D			[120]
The Blood Cell Game	HapticMaster	Sci-fi	3D	✓	3D		✓	[121]
Car Racing Game	Stressball Haptic Device	Racing	3D		2D		✓	[122]
Circus Challenge	Sixense	Action/ Adventure	3D		3D			[123]

Animal Feeder /Fruit Catcher	IGER (Microsoft Kinect, Nintendo Wii, Novint Falcon/ Omni)	Adventure/ Simulation	3D	✓	3D/ 3D		✓ (only for Novint Falcon/ Omni)	[124]
27 games	**12 different platforms**		**8 2D, 13 3D**	**9 YES (33 %)**	**3 1D, 14 2D, 10 3D**		**5 YES (18.5 %)**	

Table 4-2provides a summary of a subjective analysis of games used in the studies selected.

4.2.3. Discussion

With major focus on evaluating the effectiveness of games in rehabilitation, there has been poor or no attention to the design of the games, and to the extent the patients influenced it. Most of the articles reviewed (45 out of 60) had very little information about the games and had minimum or no game design techniques built into them.

With the intention to inform the rehabilitation community, we have identified some aspects used in commercial games which the rehabilitation games can benefit from and motivate patients into playing more. These can be utilized in describing the games used or implemented during a project.

GENRE:

Amongst the reviewed studies, 10 games are reported to have carried out usability testing of the games with healthy and stroke subjects, but only one of them report involving patients in the design process of the games.

Challenge/Skills:

Amongst the reviewed games, only 9 have reported to have dynamic difficulty balancing. For some of the games, it has been reported that once the players got used to the game, they could get bored. Hence, the automatic difficulty adjustment feature addressed this problem. It was observed that it provided more challenge and enabled less boredom [113]. It is however important to highlight that how the game difficulty is changed, (e.g. by speeding it up or increasing the task's cognitive load) should be clearly described in order to allow future comparison between studies.

Movements

Motion mapping is essential for the player to have full control over the game and be able to play the game more naturally. Since not everyone is familiar with video games, it is hard for them to adapt to such movements. It was also reported that patients had problems understanding indirect motion mapping[113]. It was observed that patients found such movements, like mapping vertical motion to move the game character horizontally, confusing. This should be taken into account while designing the game interface such that the input motion is similar to that of its effects in the game. This not only allows the player to be more comfortable as the movements are more natural, but also reduces the learning time and allows for the patients to get accustomed to the controls of the game a lot quicker.

In addition to the cognitive process of perceptual-motor training, motor skill also has an important role in rehabilitation therapy. The physical tasks to be carried out during exercises should require patients to train and practice their motor skills in varying conditions, to develop the motor schemata versatile enough to meet the situations they encounter in daily life [125], [126]. These tasks can require large number of repeated actions to make progress towards recovery. In order to encompass these requirements and attain therapeutic benefits, the rehabilitation games need to be based on the movements or interactions that have specific therapeutic targets. These further rely on our knowledge of therapeutic interactions and mechanisms used to encourage re-learning. While some of this knowledge is available in clinical literature, a part of this relies on developments in the field of therapeutic human-robot interaction. This field entails the mechanisms exploited by robots in order to induce plasticity, for example concepts such as error minimisation or error augmentation [127].

It has been observed in some of the reviewed studies, that games that encourage patients to move through their full motion range and extend it even beyond their limits are the ones with the most therapeutic benefits [113]. Games can be used to engage the player into gradually extending their range of motion by occasionally positioning the target point of the game just outside the player’s comfort range of motion but within the clinical safe range. The occasional stretching technique distracts the patients from the discomfort and pains related to the extension of their limits resulting in therapeutic benefits. Participants in studies of three weeks or longer have shown improvements in their motor control, increase in range of motion and improvements in their game performance [128], [129].

It is important for effective therapy to make sure that the patients are encouraged to use the impaired limb to carry out the task rather than the unaffected limb, a phenomenon often observed in stroke patients [24]. Patients try to compensate for the limited motion of the impaired limb by moving their other body parts, often without being even aware of it, affecting the therapy the impaired limb receives. A potential solution to this is that of eliminating any environmental factors encouraging such compensatory motion [113].

Every game designed for stroke rehabilitation is often designed with the same central element: the player. However beneficial the game design may be, it is useless if the player is not comfortable or willing to play it. The off-the-shelf games mentioned earlier may be very entertaining but they may not be suitable for early stages of rehabilitation with patients having very little voluntary motor control and movement range. Although commercially available gaming consoles like Nintendo Wii or PlayStation EyeToy do not require very accurate movements, they do have high requirements in term of movement amplitude and agility. A calibration procedure is a suitable approach to make the range of motion personalized [113]. This is done by using example motions to identify user motion range where the patients would move their arm in a workspace and the system would record the movement range. This proved to be helpful in calibrating the motion ranges for each user. Similar methods could be used to set a starting point for each patient and it could be gradually increased, with a therapist's supervision, to improve the motion range of the patients.

MULTIPLAYER OPTIONS:

Many commercial games have introduced multiplayer options in their games to promote collaborative and competitive gameplay. This may be with friends and family or strangers over the internet. Either way, multiplayer games are a medium of social interaction between people and exploit this to motivate the player to adhere to the game. Studies suggest that online videogames allow social interaction and relationship building amongst players [130] and increase family closeness [131]. Since stroke patients often experience social isolation which in turn negatively effects their quality of life and mortality rate [132], this choice can have a potential advantage.

Multiplayer option in rehabilitation can be used to promote social interaction and motivate stroke patients to exercise more. Games with competitive gameplay create a sense of challenge for the players. Working towards a certain in-game task or competing against other players, they form a sense of relationship with the fellow players and the game being a common interest between them draws them towards it again and again [94]. However, it is also notable that we do not advocate using only multiplayer or single player approaches. Similar to the gaming industry, we think a diverse population of stroke patients can benefit from a range of available choices, all of which will aim at improving their cognitive or physical status.

Amongst the reviewed games, only four of the games supported multiplayer options and amongst those four, only two have been played by multiple players at the same time. These numbers are very small and we believe that more work needs to be done in order to investigate and assess the impact of social gaming on the patients' lives.

FEEDBACK

All of the reviewed games use some kind of visual and audio cues as feedback but only 5 of the games support haptic feedback. The haptic feedback is used to provide players with a sense of realism using force feedback which has reported to have increased the immersion/ involvement in the exercises [124]. The games Goalkeeper and The Blood Cell games use haptic control to improve the hand movement by inducing friction [116] or resistive forces [121] to build up muscular strength and move the haptic barrier controls to increase the ROM (range of motion) of the hands. In other games like Breakout Therapy, haptic feedback is used to provide physical assistance to the players with limited movement abilities to help them play the game [118].

FRAMEWORK FOR CATALOGUING REHABILITATION GAMES

While some of the games effectively motivate the patients to use them and hence by extension could improve the therapeutic effectiveness, not including standard descriptor for these games prevents other studies to deploy best-practice examples and to avoid repeating mistakes made by earlier studies. Although some of these games have proven to be suitable for effective therapy, their ability to sustain the interest of patients during extended exercises remains questionable and often identifying whether the achieved effectiveness is due to the game design or the interactive nature of the entire system is not addressed.

This is partly due to combining games with the interactive medium such as a robot or a hand-held device, but also due to less standardized forms for reporting and measuring engagement and motivation. Articles reporting games have no standard way of cataloguing their games' design hence it becomes hard to assess the effectiveness of the games.

In order to catalogue these games, we propose a framework based on game design techniques for documenting the design parameters of rehabilitation games. We aim to provide a way to classify the games through which the design aspects of rehabilitation games and their effectiveness can be understood by researchers working in similar fields. Using this framework, games could be compared across different sets of parameters to better understand their effectiveness.

Focusing on game design techniques, we have identified some parameters which can be used to effectively describe a rehabilitation game, given in the table below:

<table>
<tr><th colspan="3">Game Description</th><th colspan="3">Target Condition:</th><th colspan="4">Movements</th></tr>
<tr><td colspan="3"></td><td colspan="3"></td><td colspan="4"></td></tr>
<tr><th>Hardware</th><th>Genre</th><th>Movement Calibration</th><th>No. of Levels</th><th>Scoring</th><th>Rewards/ Punishments</th><th>Feedback</th><th>Haptics</th><th>Dynamic Difficulty Balancing</th><th>Multiplayer option</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

4.2.4. *CONCLUSION*

This review highlighted some of the important aspects of game design many of which are either not reported or not used within the rehabilitation games. We retain that better documentation of games used in rehabilitation can benefit from a framework presented in this paper which allows for identifying more effective approaches in game design used for rehabilitation. Different aspects of design, for example genre, visual and multimodality, dynamic difficulty balancing and feedback are highlighted as influential parameters that can increase the chance of game use and subsequently could impact on the length of time a patient spends within an interactive environment.

We pointed out that the design of games for rehabilitation of the upper limb after stroke can benefit from techniques of game design established in the gaming industry.

Although, like some of the reviewed games, commercially available games could be used for rehabilitation using an interface that makes them usable for patients, they lack some of the parameters important for rehabilitative purposes for example, lack of feedback on movements, customizability within the game or dynamic difficulty balancing. Hence, we advocate designing games for rehabilitation which can focus on the rehabilitative task and also have the appealing traits of a commercial game.

In addition to the identified parameters, we propose a framework through which rehabilitation game developers can catalogue and document their games' design allowing understanding of the effectiveness of these parameters with regards to rehabilitation therapy.

After reviewing a set of current games being used for rehabilitation, we can see that using games for rehabilitation have a proven potential for benefitting patient motivation. However, the number of tests done using these games was not enough to deem certain technique as conclusive; nevertheless they do suggest that games in general provide a good interaction medium that could be used in therapeutic context.

5. SCRIPT PROJECT

The chapter provides an introduction to the SCRIPT project and its objectives. The chapter also details the system's hardware, software interface, and the games it comprises followed by a brief overview of the clinical trials carried out testing the systems usability and compliance.

5.1. INTRODUCTION

Functional recovery after stroke requires intensive and active training. High training doses, active initiation and exertion of movements and application of functional exercises are some of the key aspects that stimulate restoration of arm function after stroke [133] . Intensive training of arm and hand are provided after stroke in clinical settings with supervision from highly skilled professionals, however, due to limited resources and high costs it is limited to only a few weeks with limited treatment.

Technological advancements and innovations have tried to address the issue by designing interventions which take these key aspects of stroke therapy into account and provide safe and effective treatment. Rehabilitation robotics, as discussed before, has become popular over the years with the potential of providing intensive training and active participation of patients to functional exercises. If such a system is set up at home, larger dosage of treatment can be delivered to patients through tele-rehabilitation. Patients can practice independently, with support from the device and remote supervision by a healthcare professional. Such a system, supported by a home-based application, can provide a distributed practice throughout the day or week, which is associated with better retention of the learned skills [133].

Due to the inherent complexity of designing grasping tools, the earlier studies on robot-assisted rehabilitation mainly focused on proximal arm and targeted training for reaching targets. However, wrist and hand play an important and a pronounced role in a person’s functional independence in activities of daily living. Proper use of wrist and hand is particularly relevant for functional use of hemiparetic arm, and hence, in order to maximize the independent use of the upper extremity in daily life, it is important to include functional practice of hand and wrist [134].

In addition to the amount and type of therapy, the adherence of a patient to the training programme affects the actual dosage of treatment delivered [135]. Interactive and engaging gaming aspects are often used with the robotic systems to motivate patients into actively participating in their training [136]. Along with motivational feedback and assessments of performance, a home-based system can provide a complete training platform for rehabilitation.

With the advancements in the technologies for assistive rehabilitation robotics discussed previously, we see potential for home-based rehabilitation which could reduce the cost of training and improve therapy outcomes. In this chapter we present a similar technology developed for home-based tele-robotic rehabilitation.

5.2. SCRIPT SYSTEM

The EU-FP7 Supervised Care and Rehabilitation Involving Personal Tele-robotics (SCRIPT) Project (http://scriptproject.eu/) is an ongoing study which is intended to provide distal arm training to chronic stroke patients at their homes. The main objective of this project is the development of user-driven technology for stroke rehabilitation at home. The system is based on a custom-design orthosis that passively supports wrists and hand function combined with a motivational user interface with gaming environment [134]. The system also provides off-line supervision by a health-care professional (HCP) through a remote database module.

The orthosis is a new design equipped with sensors that enable users to play the games using shoulder, hand, and wrist movements. The resistive sensors enable capturing the individual movements of each finger of the hand. A potentiometer measures the angle of wrist flexion and extensions, and an inertial measurement unit which provides information about the velocity and orientation of the hand. Also equipped with a camera, the system tracks the lateral movements of the arm wearing the orthosis through color tracking.

Designed through several translations, translating the user requirements to workable design and accompanying technical specifications, the system is equipped with a dedicated microcontroller which sends the analogue bending sensors for fingers and the wrist potentiometer readings to a PC. The dedicated PC guides the users through playing the interactive games and to interact with the physiotherapists and technicians through a specially designed interface [137].

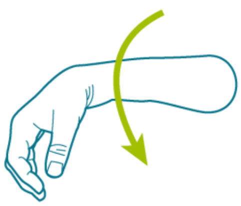
The orthosis interfaces with the forearm, hand and fingers of the users using respectively a forearm shell, a hand plate, and finger caps. Passive leaf springs and elastic chords apply adjustable external extension torques on the fingers. Elastic chords are also used to provide adjustable tension to the wrist flexion and extension through a double parallelogram between the forearm shell and hand plate. A separate forearm support provides support to the arm helping user deal with the gravity [138].

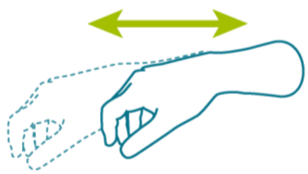
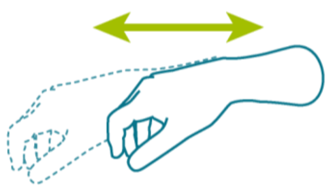
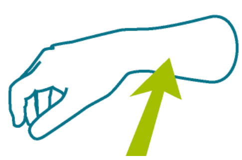
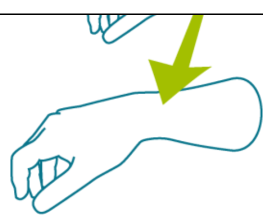
Depending on the severity of the stroke, the range of motion of rotation of joints may vary amongst patients. Some may have very limited movements while less affected patients may have a larger range of motion. To ensure appropriateness of the reactions of the games, the system learns the characteristics of each individual patient through an initial calibration process before the games [139].

A gesture recognition mechanism was developed for the system which enabled the patients to control the games using the arm, hand, and wrist movements. This allows comprehensive training and a potential for expandability for other games. Since the hand and wrist movements are essential to perform the activities of daily living such as eating, drinking, holding objects etc., the system focuses on movements similar to these. Table 5-1lists some of the gestures identified by the system.

Table 5-1 - Movement/ Specification for the SCRIPT System gestures

Movements	**Specifications**
 Hand Open	Combined information from finger sensors is in a range (90-100%)

 Hand Close	Combined information from finger sensors is in a range (0-10%)
 Grasping	Combined information from finger sensors is in a range (40-70% of maximum value)
 Wrist Flexed	Angle from wrist sensor is in a range around its upper boundary (90-100%)
 Wrist Extension	Angle from wrist sensor is in a range around its lower boundary (0-10%)
	Hand roll angle is in a range (90-100%)

Hand Pronation	
 Hand Supination	Hand roll angle is in a range (0-10%)
 Hand Forward	Hand anteroposterior velocity is around its upper boundary (80-100%)
 Hand Backward	Hand anteroposterior velocity is around its lower boundary (0-20%)
 Hand Right	Hand horizontal velocity is in a range (80-100%)
 Hand Left	Hand lateral velocity has gone in a range (80-100%)

In order to engage in tele-robotic rehabilitation, the user experience of the system is crucial. The User Interface (UI) of the system needs to be motivating, easy to use and accessible [140]. The SCRIPT follows a user-centric design to iteratively develop a platform which provides the patients with access to training, feedback, communication between patient and HCP. The HCP remotely set up the training plan for patients according to the patients' therapeutic progress and goals. According to the set plan, the UI provides the patients the access to the rehabilitation games appropriate to the patients' level of ability. The UI is based on a very simple and easy to use interface controlled by the patient through a touch-screen.

To create a motivating and engaging environment for the patients, a library of games is provided with the system allowing patients to choose and select different games according to their personal preferences and the therapists' recommendation. The games are specifically designed for stroke patients through a number of user specific design iterations, implemented, and tested before the deployment of the system in a patient's home.

The games are based on therapeutically beneficial movements of the arm and wrist. The design of the games is kept simple enough to be easy to understand but also motivating and engaging to captivate interest. Since each stroke patient has different level of impairment, the games have different levels of difficulty and may even require a different level of movements. Each game is preceded with a calibration process which records the maximum range of motion of the patient's hands and wrist movements allowing people with limited abilities to still be able to play the games effectively.

5.2.1. SCRIPT GAMES

Currently, the system comprises 5 games briefly explained in detail below:

SEA SHELL

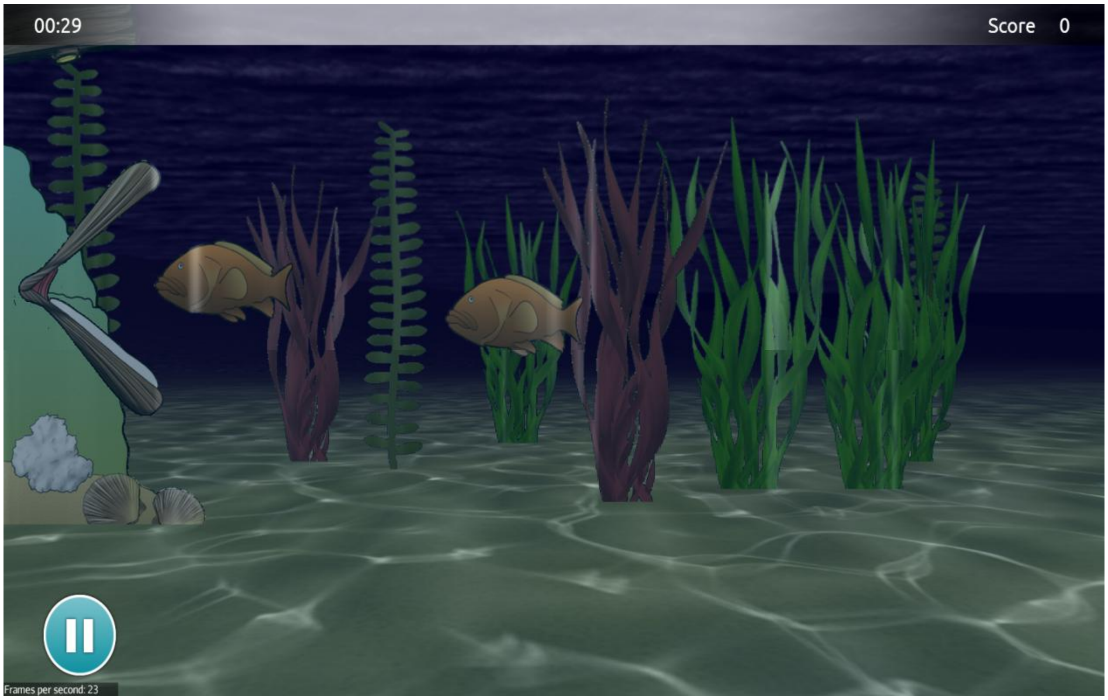


Figure 5-1 – ‘Sea Shell’ Game Screenshot

The seashell game is a simple and a basic game designed to train the wrist and hand movements. The game puts the patient under the sea in control of a seashell. Different fish move along the screen and the objective is to catch as many fish as possible with the shell as they get close. The patient has to close the hand when a fish approaches the shell in order to catch it. Score is awarded for every fish caught.

Hand opening and closing is an essential skill for ADL tasks. As a result of spasticity, a common symptom after stroke, abnormal synergies often make the wrist close automatically when the stroke patients close their hand [141]. In order to train the hand to counter this, the game was designed to be only played with extended hand. As soon as the wrist goes in to the flexed position, the shell goes to sleep making it impossible to catch the fish, unless the patients extend their wrist. Playing the game encourages exercising hand opening and closing while providing a chance to control the hand flexion when the wrist is fully extended [142].

SUPER CROCCO

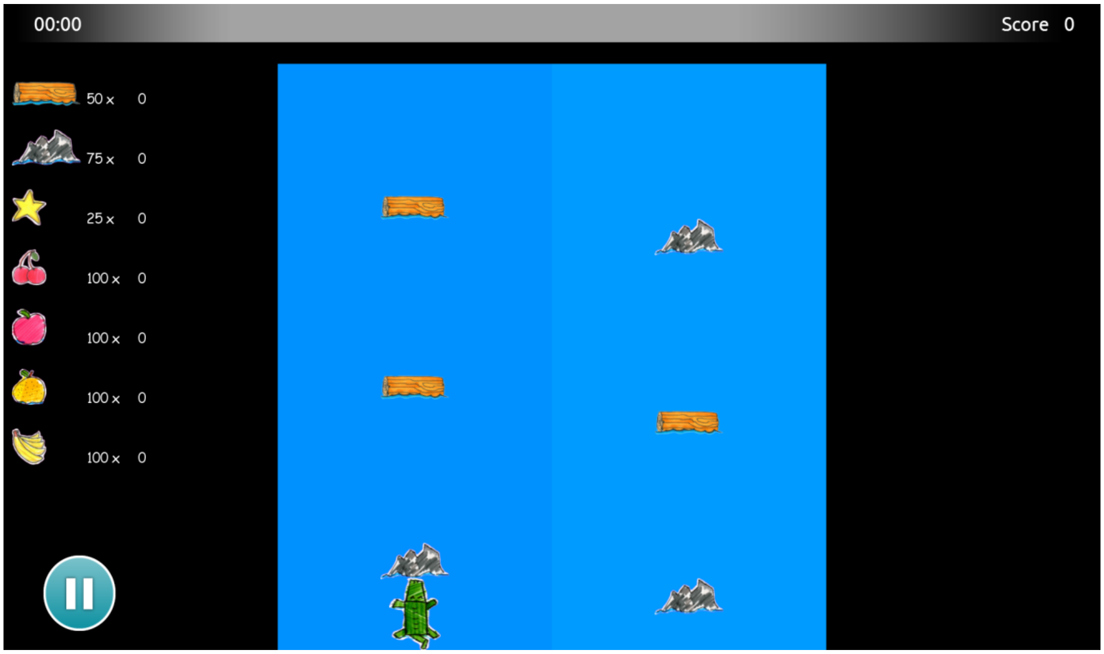


Figure 5-2 – ‘Super Crocco’ Game Screenshot

The Super Crocco is a simple platform game giving the patient control of a crocodile swimming down a river. The crocodile encounters different obstacles on its way which the patient has to avoid. Rocks on the path require the cross over by extending the wrist making the crocodile jump over. While wooden logs appearing on the path can be avoided by extending the wrist making the crocodile swim under them. In higher levels of the game, the river is divided into three lanes which the patient can switch between by lateral movement of the hand. Different fruits also appear on the path, which the patient can catch by performing a grasping gesture. Score is awarded for every obstacle avoided or fruits caught.

FRUIT PICKER

Figure 5-3 – ‘Fruit Picker’ Game Screenshot

As the affected stroke patients progress and make recovery gains, finer finger control and different grasping actions need to be practiced. Fruit picker game encourages patients to exercise different grasping techniques. The game displays a basket on the screen with different types of fruits scrolling on the side of the screen. The objective of the game is to grasp the respective fruit and drop them into the appropriate basket in a set time frame. The number and type of fruits to be picked are displayed on the basket. The camera tracks the movements of the hand which are used to control the cursor on the screen. Once the cursor is on a fruit, the appropriate grasp has to be performed in order to pick the fruit. The grasp recognition mechanism has been tested and evaluated for accuracy and robustness [143]. The type of grasp depends on the type of fruit; palmar/tripod grasp for the cherry, lateral grasp for the piece of watermelon, and cylindrical grasp for the banana.

FLIGHT GAME

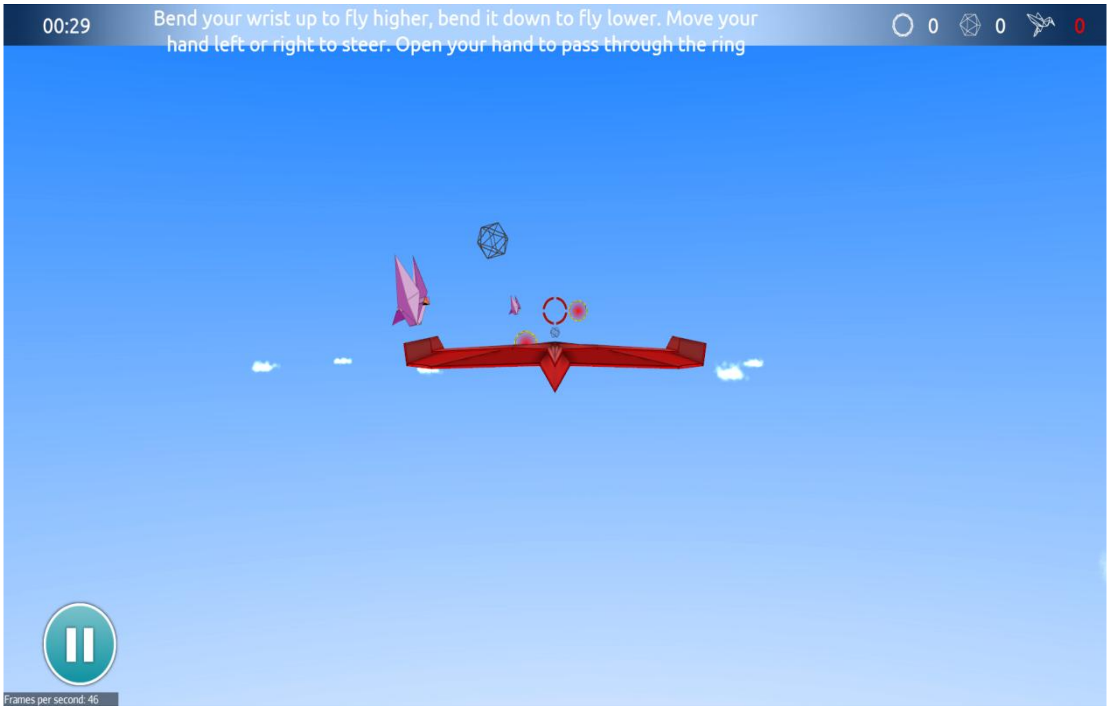


Figure 5-4 – ‘Flight Game’ Screenshot

In the flight game, the patient controls a paper plane flying in the sky. On the path, hexagonal shapes appear which the patient has to steer the plane to capture or rings which the player has to fly through. There also appear origami birds which the player has to avoid, however there is no penalization. Score is awarded for capturing the shapes and flying through the rings. Wrist extension and flexion move the plane upwards and downwards respectively while the plane is steered left and right by lateral movements of the hand.

Grandpa Lost his glasses

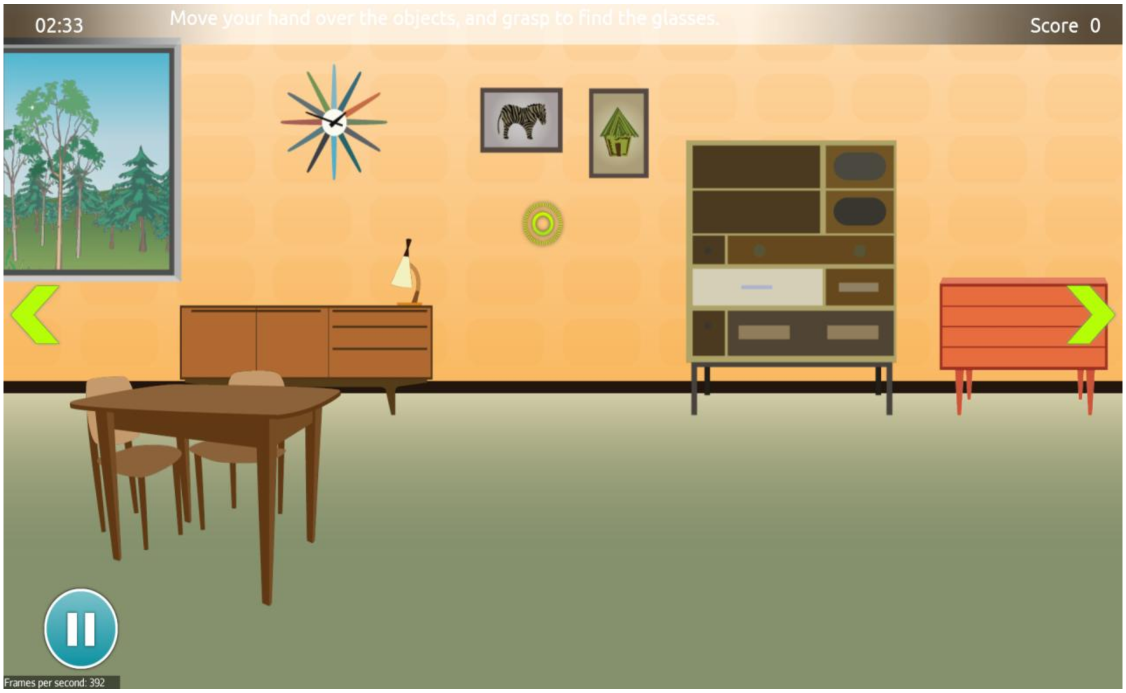


Figure 5-5 – ‘Grandpa Lost His Glasses’ Game Screenshot

The Grandpa Lost his Glasses game requires the patients to scroll through a virtual apartment. The objective is to find the lost glasses which are hidden somewhere in the apartment. The lateral movement of the hand controls the cursor which is used to scroll through the different rooms of the apartment. Grasping motion is required to check a certain location for the glasses. If the glasses are not there, a cross appears in place of the cursor along with a hint of which direction the glasses are. The player has to follow the hints to find the glasses which once found are hidden again in a different place.

Game Description	**Designed for:**	**Movements**
Sea Shell: Player has to control a seashell in order to catch fish.	Upper-limb stroke rehabilitation	Gesture based hand grasp/release.

		Continuous wrist extension.

Hardware	Genre	Movement Calibration	No. of Levels	Scoring	Rewards/ Punishments	Feedback	Haptics	Dynamic Difficulty Balancing	Multiplayer option
SCRIPT System	Arcade	Yes	Infinite	Yes	No	Audio/Visual	No	No	No

Game Description	Designed for:	Movements
Super Crocco: Player has to control a crocodile swimming in a river to eat fruits and avoid obstacles	Upper-limb stroke rehabilitation	Gesture based hand lateral movement Gesture based wrist-flexion/extension Gesture based hand grasp/release

Hardware	Genre	Movement Calibration	No. of Levels	Scoring	Rewards/ Punishments	Feedback	Haptics	Dynamic Difficulty Balancing	Multiplayer option
SCRIPT System	Platformer	Yes	Infinite	Yes	No	Audio/ Visual	No	Yes	No

Game Description	Designed for:	Movements
Fruit Picker: The player has to pick different types of fruits and drop them in the correct basket	Upper-limb stroke rehabilitation	Continuous hand lateral movement Gesture based hand lateral grasp Gesture based hand cylindrical grasp Gesture based hand palmar/tripod grasp

Hardware	Genre	Movement Calibration	No. of Levels	Scoring	Rewards/ Punishments	Feedback	Haptics	Dynamic Difficulty Balancing	Multiplayer option
SCRIPT System	Simulation	Yes	Infinite	Yes	No	Audio/ Visual	No	No	No

Game Description	Designed for:	Movements
Flight Game: The player has to control a flying paper plane in order to collect objects and avoid obstacles.	Upper-limb stroke rehabilitation	Gesture based hand lateral movement Gesture based wrist flexion/extension

Hardware	Genre	Movement Calibration	No. of Levels	Scoring	Rewards/ Punishments	Feedback	Haptics	Dynamic Difficulty Balancing	Multiplayer option
SCRIPT System	Platformer	Yes	Infinite	Yes	No	Audio/ Visual	No	No	No

Game Description	Designed for:	Movements
Grandpa Lost his Glasses: The player has to follow hints to find the hidden glasses in a virtual environment	Upper-limb stroke rehabilitation	Gesture based hand lateral movement Gesture based hand grasp/release

Hardware	Genre	Movement Calibration	No. of Levels	Scoring	Rewards/ Punishments	Feedback	Haptics	Dynamic Difficulty Balancing	Multiplayer option
SCRIPT System	Puzzle	Yes	Infinite	Yes	No	Audio/ Visual	No	No	No

5.3. Clinical Trial

The SCRIPT system has been tested in terms of usability, compliance and associated changes in arm function. The clinical trial examined the feasibility of the system by providing 6 weeks of self-administered distal arm training to stroke patients at home setting. 24 chronic patients with impaired arm/hand function were included in the study across 3 clinical sites:

- Roessingh Research and Development (Enschede, the Netherlands),
- IRCSS San Raffaele Pisana (Rome, Italy)
- and University of Sheffield (Sheffield, United Kingdom).

The SCRIPT system was installed at the patients' home and the participants were recommended to train with the system for 180 min/week (or more if desired). The HCP paid weekly visits and provided offline remote-supervision adjusting the level of support and the available games depending on the number and type of movements suitable for the patient.

The feasibility of the system was measured using the System Usability Scale (SUS) and compliance in terms of the actual usage of the system. Additionally, the arm motor function was measured using the Fugl-Meyer (FM) assessment and the dexterity was evaluated using the Action Research Arm Test (ARAT).

Out of the 24 patients, 20 completed the training period and were able to work with the SCRIPT system independently. Only 9% of the participants were not able to and/or willing to perform home-based training using the system, whereas the other 20 completed training using the system for an average of 107 minutes/week. The preliminary findings suggested positive compliance and usability experience while modest improvements in the motor function and dexterity were observed [134].

6. GAME DEVELOPMENT

Following the understanding that different game design techniques can influence compliance in game based therapy, one of the aims of this PhD was to design and develop rehabilitation games based on the techniques discussed in the previous chapter. Therefore, the following chapter presents the detail of the design and development of the rehabilitation games designed during the course of this research.

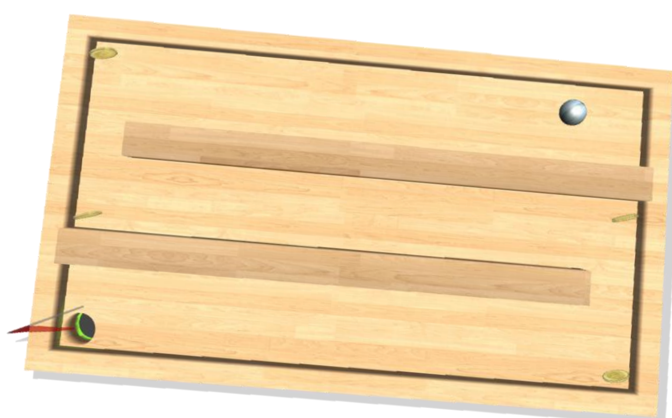
6.1. INTRODUCTION

As observed in the literature research, serious games can be used to provide stroke patients with an interactive and engaging platform for therapy. It was also noted that most of the current rehabilitation games used for stroke therapy use no or minimum game design techniques which could have potential benefits for the rehabilitative therapy.

As this research is based on testing the effects of these parameters and techniques on the motivation of patients undergoing stroke therapy, three different rehabilitation games have been developed based on these parameters during the course of this PhD. These games have been designed specifically for the upper-limb motor rehabilitation from post-stroke impairments.

6.2. MARBLE MAZE

6.2.1. OVERVIEW



The first game developed; Marble Maze is a puzzle-solving game based on physical skill consisting of a wooden board with a maze on top and a steel marble. The design of the game is based on the classic labyrinth game, where the player has to tilt the playfield to control the movement of the marble as it rolls on the board. The player plays against time guiding the marble through to the end of the maze encountering different obstacles on the way. The game is designed for rehabilitation of hand and wrist impairments amongst stroke patients.

The marble maze game is designed to engage stroke patients into exercising forearm pronation/ supination and wrist flexion/extension movements. The game is one of clever planning and fine motor control, challenging both, the players' physical as well as cognitive skills. The game is set in realistic environment with active physics applied where the marble rolls based on the gravity and friction. The velocity and the torque of the marble are set so it does not exceed a certain speed making it easy to control.

6.2.2. Gameplay

The player's main task in Marble Maze is to guide the marble through a maze by tilting the board, rolling the marble accordingly in the direction of the tilt. The goal location, where the player has to guide the marble to from its starting location, is presented by a hole lit with a green glow. The player plays against time within which the player has to guide the marble to the goal hole. If the time runs out, the marble is transported to its starting location.

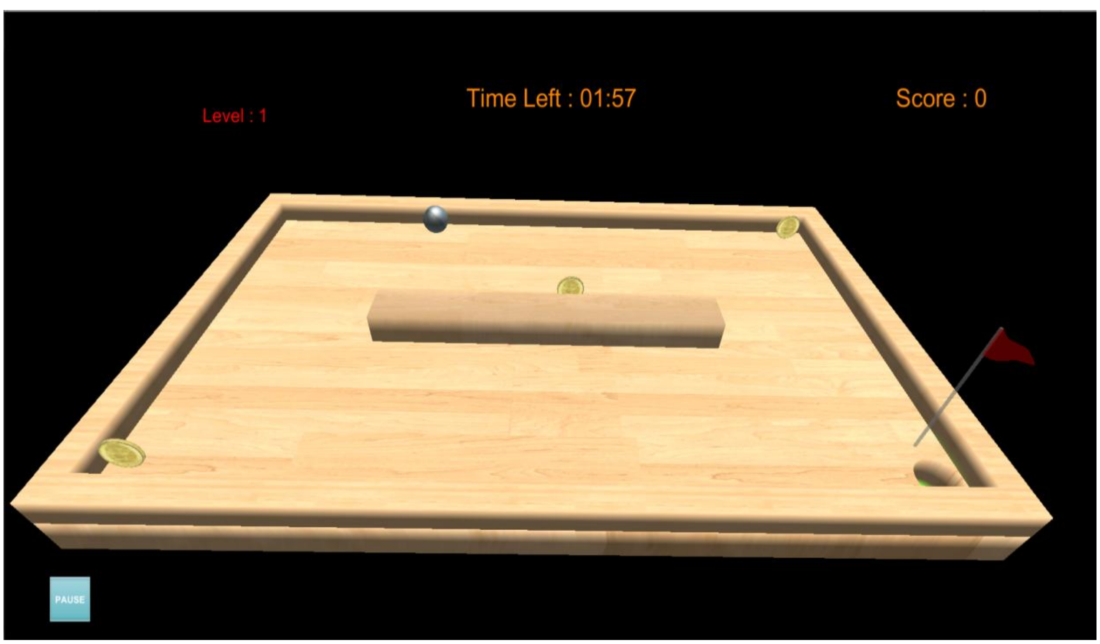


Figure 6-1 - 'Marble Maze' Game Screenshot

6.2.3. Goals/ Achievements

The game initially consisted of five different levels, each presenting the player with a different maze. As the player gained command over the controls and the game progressed, the levels of the game are unlocked, one after the other. Each level is designed to have a higher difficulty level than the previous ones for example, increased complexity of the maze, lesser time to complete, or more challenges to overcome.

6.2.4. Scoring

A scoring mechanism is also built into the game to motivate the player in performing better. The sooner the player guides the marble to the goal, higher is the score. In addition, virtual coins placed in the maze can be collected to achieve bonus scores. Some coins are placed outside the shortest path to the goal and the choice is left to the player either to collect the coins for extra score or simply to finish the level to go on to the next.

6.2.5. Operant conditioning

This technique is built on the principle of incorporating within the game a fixed ratios schedule of reinforcements and aversive stimuli for players to avoid. In addition to the bonus score for each of the coins obtained by the user, certain ‘‘power-ups’’ or rewards are built in the game. These power-ups are obtained by collecting three coins in a row in a single level. For every third coin collected, the player either gained double score for the third coin, an extra 30 or 15 seconds added to the timer to complete the level, or an ability to go through a wall of the maze. The choice of these rewards is random to build an element of surprise for the player.

Figure 6-2 - Magnet Object in Marble Maze Game

Figure 6-3 - Fan Object in Marble Maze Game

In addition to the rewards, small punishments or challenges are also built in to make the game more challenging. In addition to the goal hole, a few wrong holes are added in the maze through which the marble could fall down from. The player has to avoid these wrong holes by carefully manoeuvring the board. If the marble falls through one of these wrong holes or the time runs out, the level starts again with the marble back to its starting location. Moreover as the game progresses to more complex levels, small obstacles are also placed to deviate the path of the marble to make the player think and choose the safest route. These obstacles include magnets which would activate when the marble came close to it and would pull the marble towards itself. Another obstacle is a small fan which blows at the marble deviating it away from its path. And lastly, a door is placed that blocks the path to the goal location and can be opened only by pressing a red button placed somewhere in the maze.

6.2.6. *FEEDBACK*

At the end of each level, a screen is designed to display the performance feedback of the player. The feedback includes the score achieved in the level, the time taken to complete the level and the number of times the marble fell in the hole. The screen also shows the previous scores of the players for them to compare their recent performance with the former. The screen also gives the players the chance to replay a level in case they are not satisfied with their performance.

6.3. RUN JACK RUN

6.3.1. OVERVIEW

Unlike the marble maze game which is based on fine, continuous movements, the second game; 'Run Jack Run' is based on gestures. It is a running platform game, where the player controls a virtual character running through a park. The aim of the game is to achieve the highest score by running farthest distance. The running character encounters various obstacles which need to be avoided by performing an appropriate action. This game is designed to provide hand and wrist movement therapy at the same time providing a cognitive challenge to perform the right gesture at the right time.

6.3.2. *GAMEPLAY*

Figure 6-4 - 'Run Jack Run' Game Screenshot

The game sets the scene with a virtual character named Jack on a fenced path in a lush green park surrounded by trees and bushes. The game starts with a set speed and a fairly simple path where the character starts running on. After a certain distance, randomly generated obstacles appear on the path which the player has to act upon in order to avoid or counter. These obstacles include turns on the path, which when appear, require the player to make the character turn its direction accordingly to avoid crashing into the fence. As the game progresses, the player may face additional obstacles. The obstacles include the path being broken with a hole in the ground which the player has to make the character jump over to avoid falling into. Also, the player has to make the character jump over sleeping dogs which appear on the path in order not to disturb and wake them up. There may also appear some fallen trees on the path, which the character can slide under to avoid collision.

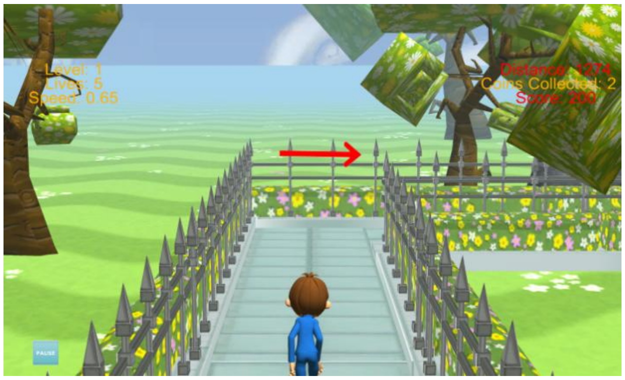


Figure 6-5 - 'Run Jack Run' Turn Task

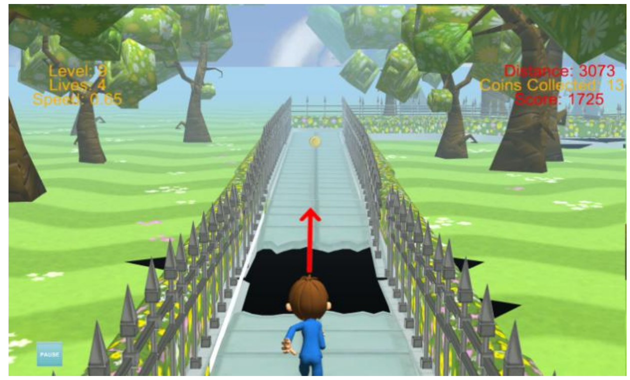


Figure 6-6 – Jump task

Figure 6-7 – Collect Coin Task

Figure 6-8 - Slide task

6.3.3. *GOALS/ ACHIEVEMENTS*

The game is based on different levels which are unlocked when the character successfully runs a certain distance. The goal of each stage is to run a distance without losing all lives. With advancement in each level, the complexity of the game increases with more challenges to overcome and/or speed of the game increasing.

6.3.4. *SCORING*

A scoring mechanism is maintained in the game awarding the player for every correct action performed. Additionally, in each level, virtual coins are placed on the path of the character which the player can collect when the character is near the coin. The player is recommended to collect as many coins as possible to achieve a high score.

6.3.5. Operant Conditioning

The game also has a few rewards and punishments built into the gameplay. For each of the obstacles that the player has to avoid, the player is given a certain set time to counter it by performing the appropriate action. This time is shown in form of bars which appear when the action is required. If the player fails to perform the correct action within the time limit, the character crashes into the obstacle and the player loses one of its initially set lives. Once a life is lost, the player is given another chance to counter the same obstacle the character crashed into. Once all the lives are lost, the game ends and the player may start from the beginning if desired. As a reward, for every ten consecutive coins collected, the player earns an extra life.

6.3.6. Challenge

In order to prevent the game from becoming frustratingly difficult or so easy that it becomes boring, the game had to be designed such that it adapts to the player's performance. Thus, dynamic difficulty balancing is implemented in the game. The game monitors the performance of each player and adjusts the speed to perform the action to avoid each obstacle. If a player fails a certain action, the next time that action is required, the game slows down but speeds up to the normal speed for other actions the player is performing successfully.

6.3.7. Feedback

To guide the player through the game, instruction screens and in-game feedback messages are displayed. Furthermore, when the player is required to do a specific gesture, hints are displayed on the screen showing the player what gesture to perform and when to perform it. The hints can be toggled on or off depending on the personal choice of the player.

6.4. BURGER HUB

6.4.1. OVERVIEW

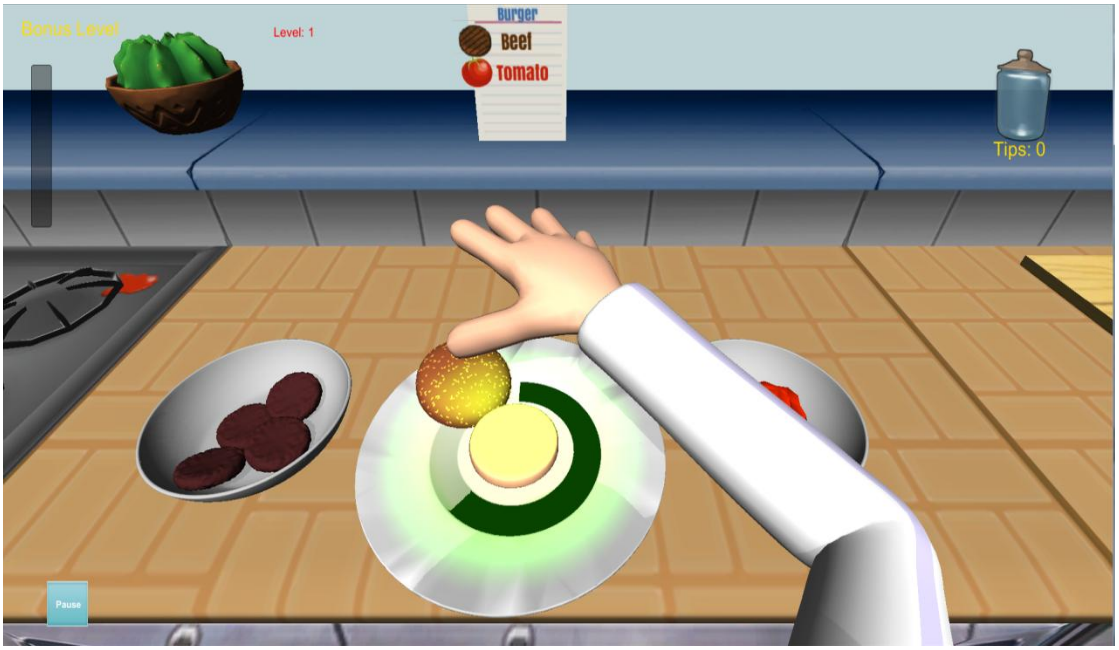


Figure 6-9 - 'Burger Hub' Game Screenshot

The third game is based on a different genre and is built upon functional tasks which the players can relate to in real life. The game puts the player in place of a chef in a restaurant's kitchen preparing burgers from a set of defined ingredients and cutting vegetables. The game is based on two different tasks between which the game alternates; one of preparing burgers and one of cutting the vegetables. This game is designed to train the wrist and hand movements required to carry out ADL tasks.

6.4.2. GAMEPLAY

The game puts the player in first person view of the chef facing a restaurant kitchen's counter. A number of bowls, each with a different randomly generated ingredient, are placed on the counter. The player reads the order from a card on the screen which shows the player the ingredients to put in the burger. The player has to then pick the appropriate ingredients and drop them on top of the plate in middle of the counter in order to make a burger, all in a set time limit. Once the number of ingredients put on the burger is equal to the number of ingredients in the order, the order is completed. If the ingredients placed match the order, the order is counted as a success. If the wrong ingredients are placed in the burger, or the time to prepare an order runs out, the order is counted as a fail.

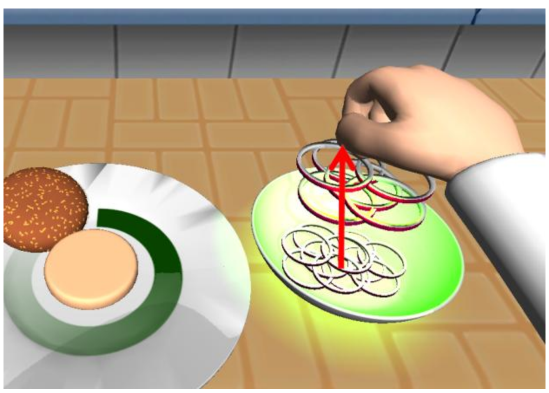


Figure 6-10 - Burger preparing task

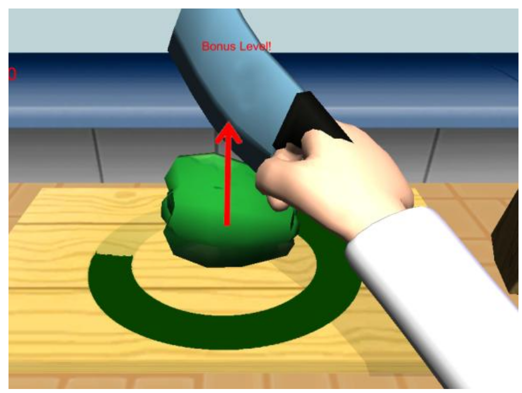


Figure 6-11 - Cutting task

For the cutting task, the players are required to grab a knife and cut as many vegetables as they can in a set time limit. When the level starts, the timer starts ticking and the vegetables appear on the screen one by one. Each vegetable requires a certain number of cuts to be done to it which is displayed on the screen. Once a vegetable is cut, it disappears and the next one appears. When the time finishes, the game progresses to the next burger making task.

6.4.3. Goals/ Achievements

The game is based on different levels, which are unlocked as the player progresses through the game. The game starts with the burger level where the player is required to make a certain number of successful burgers. When a successful burger is made, a 'bonus' counter is incremented which when this counter reaches a set value, progresses to the next level.

Between these levels, the player is given a chance to earn extra score in the bonus level. The bonus level is based on the cutting task which requires players to cut as many vegetables as they can in a set amount of time. When the time runs out, the game takes the player back to the burger making task.

6.4.4. Scoring

A scoring mechanism is maintained in the game awarding the player for every successful burger made. Additionally, in the bonus levels, score is awarded for every cut done. At the end of the game, the scores of all the levels are accumulated and a final score is presented to the player.

6.4.5. Operant Conditioning

The game also has a few rewards and punishments built into the gameplay. The bonus level is awarded for every level successfully completed, allowing players to earn extra score. Whereas, when a burger is failed due to the time limit or a wrong ingredient, the bonus counter is decreased requiring the player to make an additional burger to complete that level.

6.4.6. Challenge

As the levels increase, the complexity of the burger's recipes increase and more ingredients are required to make each burger. Consequently, the number of bowls on the counter holding these ingredients increases requiring players to race against the time to complete an order with the right ingredients. Also, the time to complete each burger decreases as the levels advance. Furthermore, the number of successful burgers required to complete the level also increases as the player levels up.

6.4.7. Feedback

To guide the player through the game, instruction screens and in-game feedback messages are displayed. Furthermore, audio and visual effects are played throughout the game to make the game easier and engaging to play. Hints are also displayed showing the player what action to perform and when to perform it.

6.5. Software Development

Each game has been carefully designed for the purpose of hand and wrist rehabilitation movements. The games' designs were initially sketched on paper and presented to stroke patients and HCPs in focus groups and meetings. In order to design the game, the 3D models of the game were designed using an open-source 3D graphics and animation software, 'Blender 3D' (http://www.blender.org/). The game character models have been designed using the Daz3D Studio (http://www.daz3d.com/) tool. Following the common practice in game development, polygonal modelling was used to create all the models. Since the models were designed for a game, polygonal meshes have an advantage of being quicker to render than other representations. The polygon count of the models was adjusted to be kept to a minimal value for the game to be able to render them quickly to achieve an interactive frame rate of at least 60 frames per second (FPS) at the same time not compromising the quality of the models.

The maze models for the Marble Maze game were textured with royalty free stock images giving them different wooden look and the marble a metallic look presenting the game in a photorealistic manner. Whereas the model textures for the Run Jack Run and Burger Hub game were digitally hand-painted on to the models using Adobe Photoshop CS5 following the artistic, stylized non-photorealistic rendering style.

All the games were developed in Unity3D 4 game engine (http://unity3d.com/) in C# language. The Unity is a game development ecosystem including game engine and integrated development environment. JMonkeyEngine and Microsoft XNA Game Studio were also considered, but Unity was chosen due to its ease of use and extensive support available. Also, Unity allows importing of models directly from Blender 3D without conversion. Furthermore, Unity engine supports various downloadable plugin contents which add to the functionality of the engine.

Furthermore, stereo sound effects and music tracks were added to the games. Relevant royalty free game sound effects from www.soundbible.com, www.freesfx.co.uk, and www.freesound.orgwere used for the games in order to further enhance the sense of immersion of the games. In all the games, an option to mute these sound effects and the music tracks is built in allowing them to set the game environment according to their preferences.

7. GAME DESIGN PARAMETERS

The purpose of this research was to investigate how different game design techniques (discussed in Chapter 3) can affect the motivation of the players and the game-play in order to state whether it might be beneficial for rehabilitation games.

7.1. Introduction

Multimodal video games can be designed to provide the patients with an immersive, engaging and an appealing environment, not only to make the therapy more interesting, but also to encourage and motivate patients into putting most of their efforts into the exercises. Proficiently designed rehabilitation games, benefitting from psychology and behaviour modification knowledge, can keep the patients engaged and help to increase the duration of active participation in therapeutic interactions [57].

7.2. Game Design Parameters

To date, the games used for rehabilitation are either commercial games that require movements too difficult for people with motor disabilities to perform, or simple games that use minimum or no game design techniques. In order to design games for rehabilitation which are suitable for patients undergoing therapy and also effectively motivate them, some of the game design techniques used by commercial game developers need to be incorporated into such games.

The primary goal of this study is to incorporate and observe the effects of some of these game design parameters in rehabilitation games on player motivation and game-play time. Since we have discussed a number of possible parameters, we chose to implement a few of these in a game we designed and developed. Moreover, the parameters which could be toggled were implemented so that they could be turned on or off in order to analyse their individual importance.

7.3. Experimental Setup

As this research is primarily concerned with upper limb stroke rehabilitation, the study involved developing a prototype game which aims to exercise patient’s affected wrist using flexion/extension, pronation/supination movements and hand grasping motions. This aims at acquiring fine motor skills of the wrist.

7.4. Software

The experiment was based on the first of the three games developed; The Marble Maze Game (explained in 6.2 -Marble Maze)

In order to observe the effects of these parameters we developed four versions of the game:

- Basic Version: The basic version consisted of neither the Operant Conditioning nor the Scoring parameters. No score was recorded and the player simply had to complete the stages before the set time for each stage to move on to the next stage.
- Operant Conditioning Version (OC Version): The 'OC' version had the rewards and challenges of the Operant Conditioning parameter built in. However no score was recorded.
- Scoring Version (SC Version): This version had the scoring mechanisms turned on without the Operant Conditioning.
- Operant Conditioning + Scoring Version (OC-SC Version): Lastly, the OC-SC version had both, the Operant Conditioning and the Scoring parameters built in.

7.5. Hardware

Since the research is focussing on hand/wrist motor abilities, in order to map the hand movements to the game we used the Geomagic Touch haptic device (formerly known as Sensable Phantom Omni; Geomagic, Morissville, NC, http://geomagic.com/en/). The orientation of the maze is directly mapped to a Styrofoam board attached to a Phantom

Omni and is held by the player giving a feel of actually holding the virtual maze on the screen.

Figure 7-1 - Geomagic Touch with styrofoam board attachment

7.6. Pilot Trial 1 – Usability Evaluation of Marble Maze

This section details the pilot trial carried out using the Marble Maze game. The goal of the experiment was to carry out a formative evaluation of the game identifying any playability issues with the design and the control before moving on to an evaluation with a higher number of participants.

7.6.1. Experimental Procedure

Ten healthy volunteers from the University of Hertfordshire participated in the study approved by the University of Hertfordshire's ethics board under approval – Protocol number: 1213/21. Each participant took part in a 10 minute session. Prior to each session, they were each asked to fill in a consent form. The participants were then briefed about the structure of the session and how to play the game. Once the game started, they could pause the game any time or stop the session if they felt any discomfort or did not prefer to continue.

For the pilot trial, the OC-SC version of the game was chosen to be played by all the participants through whom we can test both the parameters (OC & SC). After playing the game, the participants were asked to fill in a survey answering a questionnaire based on the experience of the game play and report any issues with the playability and control of the game.

7.6.2. Outcome Measures

As an outcome measure, survey questionnaires (see Table 7-1) were adapted from Intrinsic Motivation Inventory (IMI) to measure the players' perception of intrinsic motivation on the game. IMI is a multidimensional measurement instrument that contains several subscales. Several hypotheses [144], [145] have been tested using specific subscales of IMI and have established its reliability and validity, although these had some variance in the context and languages compared to this study. The instrument assesses the participants' enjoyment/interest, perceived competence, effort/importance, pressure and tension, and perceived choice while performing a certain task yielding six subscale scores. The interest/enjoyment subscale is considered the self-report measure of the IMI, thus, although the overall questionnaire is called the Intrinsic Motivation Inventory, it is only the one subscale that assesses intrinsic motivation, per se. The perceived choice and perceived competence concepts are theorized to be positive predictors of intrinsic motivation while pressure tension to be the negative predictor. Effort/Importance subscale is considered in relation to motivation [146]. Each question category consisted of 5 questions with answers ranging from 1 to 7, with results from each category summed up for analysis. Thus a total score of 35 was the maximum achievable total for each category.

Table 7-1– Survey Questionnaire

No.	Category	Question
1	Enjoyment/Interest	When I was playing the game, I was thinking about how much I enjoyed it.
2		I would describe the game as very enjoyable.
3		I thought the game was very boring.
4		I had fun playing the game.
5		The game did not hold my attention.
6	Perceived Choice	I felt like I was doing what I wanted while playing the game.
7		I felt in control of how to play the game.
8		I did not have a lot of choice about how to do the in-game tasks.
9		I did things because they interested me.
10		I felt controlled and pressured in a certain way.
11	Pressure/Tension	I felt very capable and effective.
12		The game was too difficult for me.
13		The game kept me on my toes but did not overwhelm me.
14		I was frustrated while playing the game.
15		I felt relaxed while playing the game.
16	Perceived Competence	I was satisfied by my performance.
17		I feel pretty skilled at the game.
18		After playing the game for a while, I felt very competent.
19		I would like to play the game again.
20		I want to perform better than others in the game.
21	Effort/Importance	I put in a lot of effort to play this game.
22		I tried hard to do well in the game.
23		It was not important for me to do well in the game.
24		It was important for me to do well in the game.
25		I did not try to do well in the game.

7.6.3. RESULTS AND CHANGES TO THE SOFTWARE

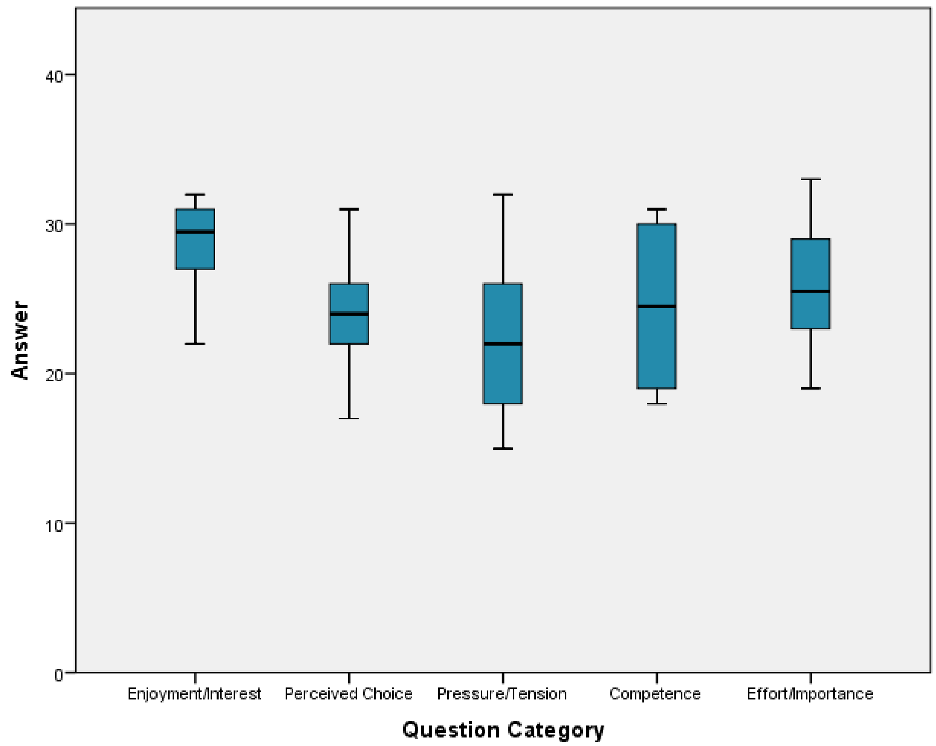


Figure 7-2 – Boxplot of Survey Answers

Figure 7-2 shows the average scores for each category of the questionnaires. Overall, these results were positive and subject to minor changes, the game was playable using wrist and hand movements.

Some issues with the game control and the physics engine of the game were reported which were sorted by tweaking some parameters of the game. Also, some lighting and textures of the game's 3D models were changed in order to make the visuals of the game better as suggested by a participant. The background music was also changed and an option to mute the music was also added to the game.

7.7. STUDY 1 – FORMATIVE EVALUATION OF MARBLE MAZE WITH HEALTHY SUBJECTS

Following the necessary changes in the game design, we carried out a formative evaluation in order to test the game design parameters on player motivation.

We hypothesized that the addition of Feedback/ Operant Conditioning parameter would facilitate creating an experience of increased enjoyment/interest and perceive choice effort in game play. We also incorporated scoring mechanisms which we expected to be associated with game competence and importance. We further suggested that the combination of these parameters facilitate players' motivation, high user engagement and longer play time, as assessed by the rated enjoyment and competence through which we would assess changes from before to after game play.

7.7.1. EXPERIMENTAL PROCEDURE

For the experiment, the participants were recruited among people who called at an installation in a public venue of the University of Hertfordshire (Hatfield, Herts, UK). Preliminary explanation of the research and its aims was given to people as they came along, eventually in groups. Those who showed interest in taking part filled in a consent form. The participants were then briefed about the structure of the session and how to play the game, and then participated in a 10-15 minute session which was administered by the first author. After playing each session, they were asked to fill in a questionnaire. They would then play the alternate version and were asked to fill in the survey once again.

Participants were assigned to one of the three groups: OC, SC or OC-SC. Each participant played two versions of the game; the Basic and another depending on the randomised group they were assigned to. The version played first amongst the two was also randomly decided for each participant as counter-balancing. As the switching between experimental versions of the game took time (order of minutes), if participants were recruited jointly they had been assigned to the same experimental group thus allowing to keep the waiting time to a minimum. However, care was taken so that the experiment would have then been conducted separately, with each subject not being exposed to the previous participant's briefing-gameplay. This allocation resulted in slight imbalance in number of participants per group as highlighted below.

This study has been approved by the University of Hertfordshire's ethics board – Protocol number: COM/PG/UH/00001. Once the game started, they could pause the game any time or stop the session if they felt any discomfort or did not prefer to continue.

Thirty-seven participants took part in the study (26 males and 11 females; mean age, 21.6 years; SD, ±2.3). Since the participation was voluntary, randomised assignment to the groups and as no incentive was offered, equal number of participants could not be achieved (OC, n= 13; SC, n = 11; OC-SC, n= 13).

Outcome Measures

Similar to the pilot-trial, as primary outcome measure, survey questionnaires adapted from the Intrinsic Motivation Inventory (IMI) to measure players' perceptions of intrinsic motivation on the game were used.

Additionally, the secondary outcome measurements include the gameplay duration and the number of failures (i.e. marble fell into the wrong hole). These quantities were compared for the OC, SC and OC-SC versions of the game with respect to the basic version.

Data Analysis

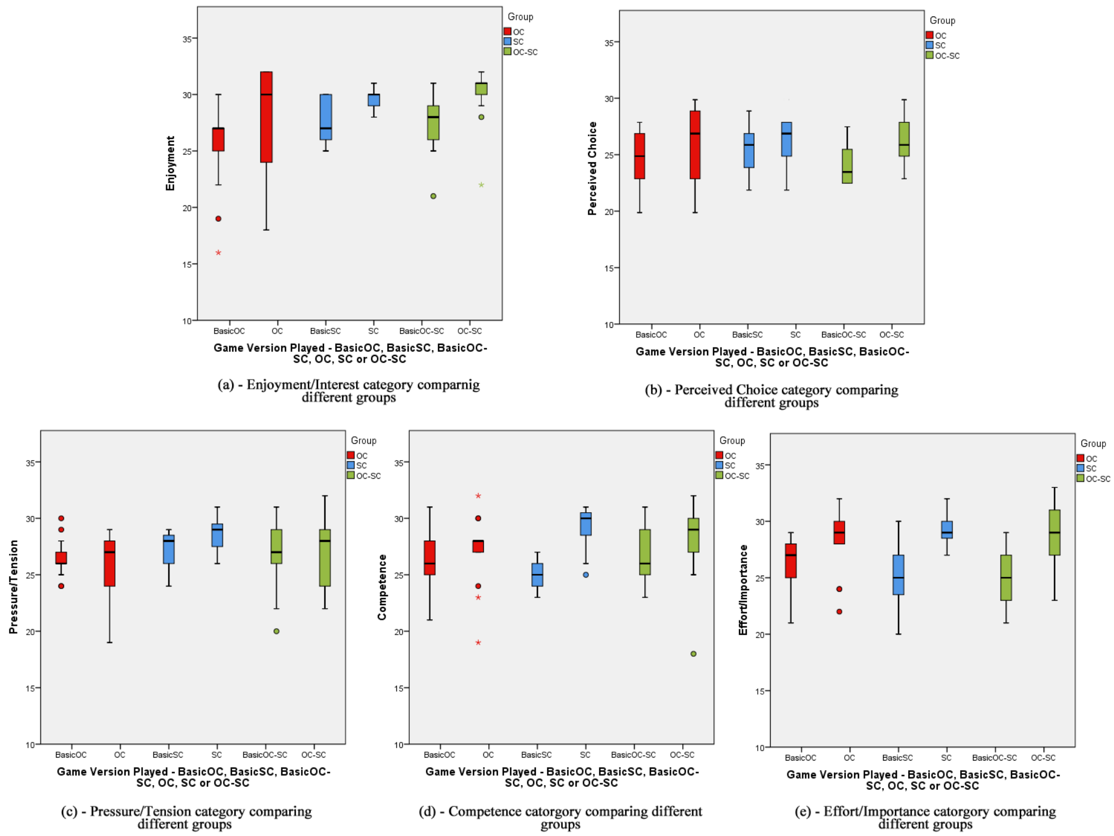
The differences in each category between basic and experimental (OC, SC, OCSC) versions of the game were determined by using repeated measures ANOVA (analysis of variance). A paired-samples t-test was conducted to compare the means of the time taken to complete the different versions of the game between the basic and the experimental versions. In order to compare the medians of the number of fails amongst the basic and the experimental versions, a Wilcoxon Signed-Test was used as a nonparametric analytical method. These analyses were performed using Microsoft Excel 2010 and SPSS Statistics version 21.0 (IBM, Armonk NY, USA).

7.7.2. Results

Results obtained during the experiment are divided into observations based on different outcome measures used in this study.

IMI Scores for each group

Significant changes were observed for the categories of Enjoyment/Interest ($p < 0.0005$), Competence ($p = 0.002$) and Effort/Importance ($p < 0.0005$), compared to the versions without these parameters whereas, this addition of these parameters did not affect Perceived Choice ($p = 0.066$) nor Pressure/Tension ($p = 0.379$).



<u>Figure 7-3 - IMI questionnaire results</u>

<u>Figure 7-3</u> shows the IMI scores for the different group medians in the boxes with outlier values as circles and stars; (a) for Enjoyment/Interest, (b) for Perceived Choice, (c) for Pressure/Tension, (d) for Competence, and (e) for Effort/Importance category.

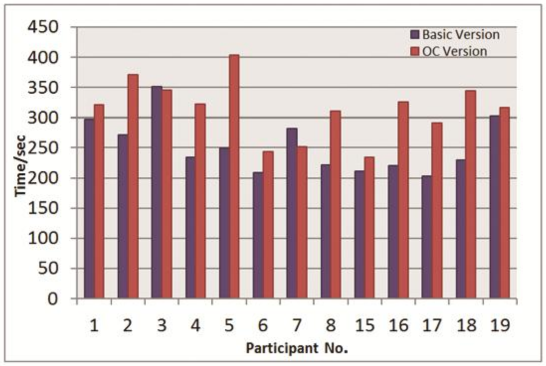


Figure 7-4 - Time taken to complete the game by participants (OC Group)

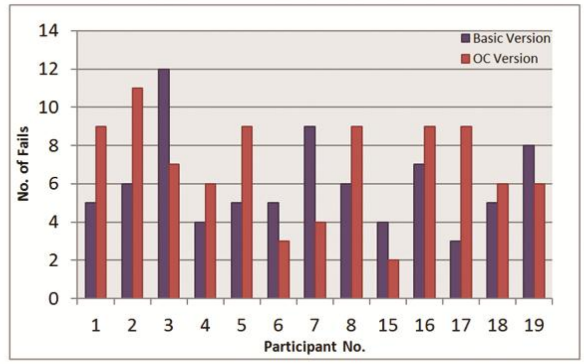


Figure 7-5 - No. of fails by participants (OC Group)

Figure 7-4 shows the game-play duration for the basic version and the OC version, and Figure 7-5 shows the number of fails in the two versions of the game for the participants in the OC group.

There was a statistically significant difference in duration between the basic and the OC version as determined by paired t-sample test ($p = 0.002$; Basic: $M = 252.38$, $SD = 45.110$; OC: $M = 314.00$, $SD = 49.195$). However, there was no statistically significant difference in the number of fails amongst the Basic and the OC version as determined by Wilcoxon Signed-Rank test ($p = 0.418$; Basic: Mdn = 5, OC: Mdn = 7).

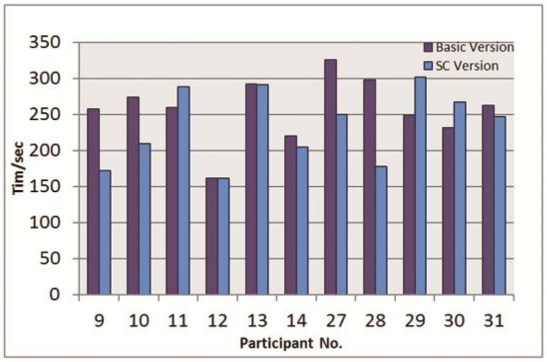


Figure 7-6 - Time taken to complete the game by participants (SC Group)

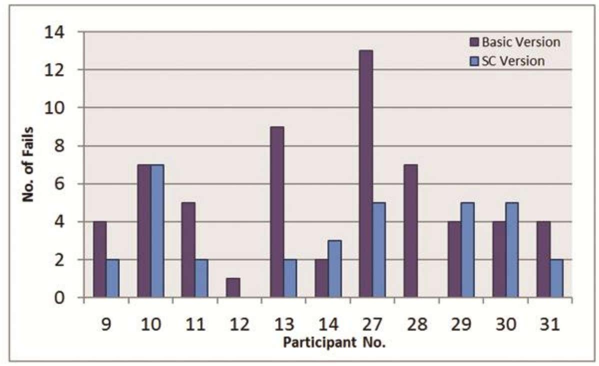


Figure 7-7 - No. of fails by participants (SC Group)

Figure 7-6 shows the durations for the gameplay in basic and scoring versions (SC) for each participant in the SC Group and Figure 7-7 shows the number of fails by each participant for each version of the game in the same group.

A paired sample t-test showed no difference in the duration of play for the Basic version and the time of the SC version (p = 0.189; Basic: M = 257.18, SD = 43.943; SC: M = 233.55, SD = 51.122). However the number of fails in this group differs significantly between the Basic version and the SC Version as determined by Wilcoxon Signed-Rank test (p = 0.04; Basic: Mdn = 4; SC: Mdn = 2).

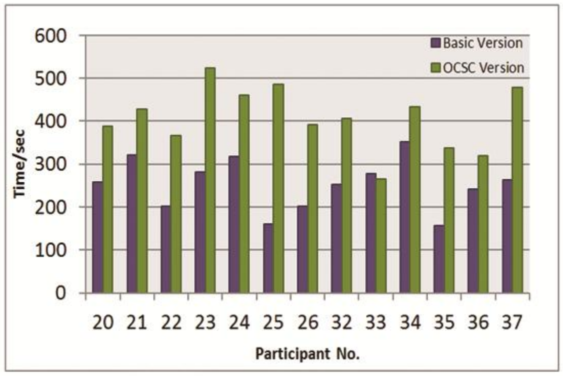


Figure 7-8– Time taken to complete the game by participants (OC-SC Group)

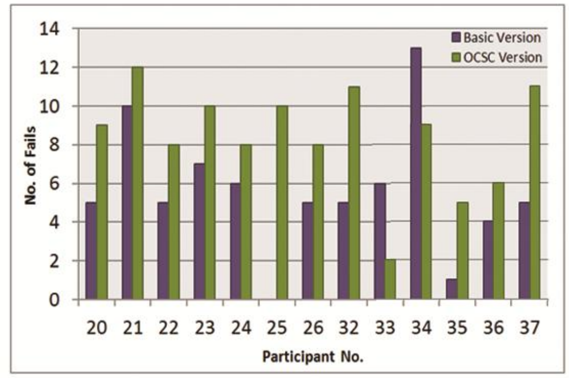


Figure 7-9 - No. of fails by participants (OC-SC Group)

Figure 7-8 and Figure 7-9 show difference in time for which the basic and the OC-SC versions were played by each participant in the OC-SC group and the number of fails by each participant in the OC-SC group respectively.

A paired-samples t-test shows increase in the time taken to complete the OCSC version with respect to the basic version ($p < 0.005$; Basic: $M = 252.23$, $SD = 60.13$; OC-SC: $M = 406.31$, $SD = 72.907$). Also, there is a statistically significant difference in the number of fails amongst the Basic version and the OC-SC version as determined by Wilcoxon Signed-Rank test ($p = 0.045$; Basic: $Mdn = 5$; OC-SC: $Mdn = 9$).

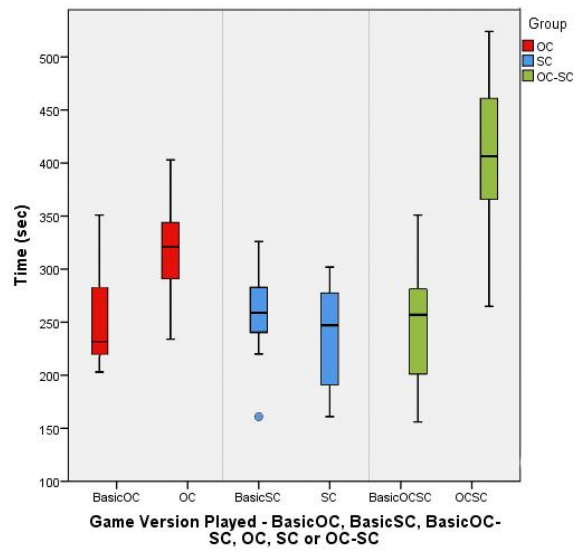


Figure 7-10 – Duration of game-play comparing different groups

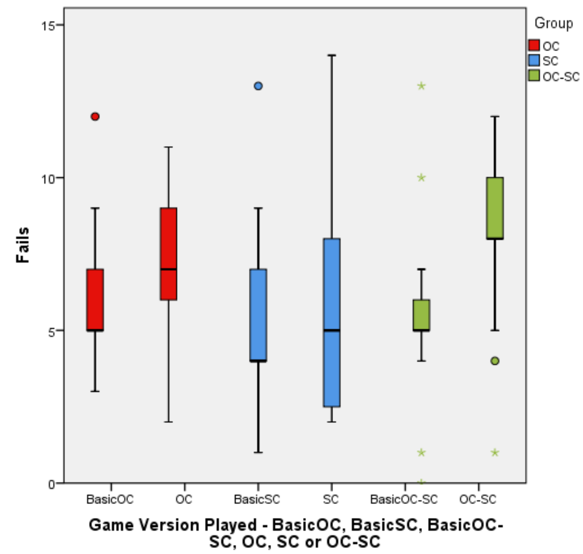


Figure 7-11 – Number of fails during game-play comparing different groups

Figure 7-10 presents the duration of play for the different experimental conditions. Figure 7-11 provides instead the number of fails for each group. The figure allows for comparison between basic conditions and those of OC, SC and OC-SC conditions with the appropriate pairing.

7.7.3. *Discussions*

The objective of this study was to test some key game design parameters and investigate their effects on player motivation, enjoyment and game play times. These parameters, once identified, can be incorporated in rehabilitation games in order to motivate and engage patients undergoing therapy into participating in their exercise regimes more actively.

The results obtained from this study suggested that addition of both the parameters, operant conditioning as well as scoring, results in higher motivational scores.

The results also suggested that although operant conditioning parameter had no effect on the number of fails, the time taken to complete the game was significantly increased because of it. This was perhaps because of the time taken to solve or overcome the challenges introduced by the operant conditioning parameter. Also, the fact that the player had to deviate from the primary goal to acquire minor rewards (e.g. coins and power ups) makes them keen on deviating from the shortest possible path, taking longer to complete the game. Since there was no score, the players were not under any pressure to complete the game quickly, giving them plenty of time to manoeuvre carefully, hence the lower number of fails. This could however be different with stroke patients where fine motor control might be lacking.

Whereas when the scoring parameter was introduced, the participants tended to finish the game quickly in order to achieve higher scores within shorter playtime. However, the lack of additional challenges (as there were in the operant conditioning version) resulted in lower number of fails.

Interestingly, we observed that the operant conditioning parameter increases the playtime but it affected the number of fails only when there is a scoring mechanism. Similarly, the scoring parameter on its own decreased the number of failures. The incorporation of both differed from their individual effects. We observed that the number of failures and the play times had both increased significantly without compromising the player's enjoyment (Figure 7-3). This might be because the additional challenges added by the operant conditioning parameter may be easier to overcome when there is no pressure to complete the game quickly, unlike when put together with a score. This lead to an important conclusion that it is not only the parameters that are important but also the combination of the different parameters together which results in player motivation and longer game plays.

Since this study was an initial test of the design parameters, it was carried out only with healthy participants and it is thus not possible to conclude if these parameters are beneficial in rehabilitation games. However, the results suggested that the key parameters tested could be used to influence patient motivations and increase game playtime amongst rehabilitative games, especially if aligned with rehabilitation objectives. Also, the game is only suitable for patients' with some wrist movement and a certain level of cognitive skills that are required to comprehend the flow of the game.

8. GAME DESIGN PROCEDURE

The objective of this chapter is to provide some clarity on player-centric design and how involving patients in the design process of rehabilitation games can give us a notion of what patients want in a game environment. This involves designing rehabilitation games with the involvement of designers, patients, and health care professionals while documenting each stage allowing us to identify and analyse the key areas of gameplay and interface.

8.1. Introduction

Game design process cannot be purely based on theoretical approaches. Iterative, qualitative, and quantitative analysis supports the designer by analysing the end result to refine the implementation and analyse the implementation to refine the results [147]. In order to design a game that is challenging, yet entertaining, it is important for the designers to know the target audience. Player-centric game design requires the designers to envision a representative player of the game and design a game that must meet the player's desires and preferences.

For years, game designers have designed games for, in effect, game designers themselves and rely primarily on personal experience and intuitive sense of player demands [148]. Designer-driven games, where the designers retain all creative control and make all the decisions themselves, often ignore the benefits of play-testing or other people's collective wisdom usually resulting in a botched game [148]. In recent years, as the market for games has expanded beyond the traditional gamer and games are being used for more than just entertainment; game designers have started adopting player-centric design philosophy.

Furthermore, games used for rehabilitative purposes are designed with player as the central element focusing on improving the user's therapeutic experience. However beneficial the design of the game, it is useless if the player is not comfortable or willing to play it. In the context of games for health, this makes it essential for designers to involve the target patients, and health care professionals early on in the design stages enabling them to create a game which is not only appealing and engaging but also accommodates the necessary elements beneficial for the therapy.

8.2. Player Centric Design

Player-centric design process is based on empathizing with the intended players and learning to design for what they like. Salen and Zimmerman [82] and Fullerton et al. [85] recommend one such method referred to as iterative design approach and argue in favour of inviting feedback from players early on in the design stages. Iterative design is play-based design process in which the emphasis is given to play testing and prototyping. A rough prototype version of the game is proposed and rapidly developed defining the fundamental rules, gameplay, and the core mechanics of the game which is then played, re-evaluated and adjusted repeatedly prior to a working product release. The process involves the target audience in the development as early as the design stage transforming the consumers into producers, and hence consumption itself becomes an act of production resulting in a completely user-centred system, ensuring game-element functionality, and expands game concepts for increased user enjoyment.

Iterative design is important as it not only anticipates and predicts the player experience in advance, but also gives the designer an insight into the audiences' point of view of what they expect of a game. Academic studies focusing on this subject matter are rare and the industrial research is mostly kept confidential [147].

As part of this research, it was aimed to test the approach by developing a number of rehabilitation games by undertaking them through a number of cycles of iterative design. The three games; Marble Maze, Run Jack Run, and Burger Hub games were put through a number of focus groups and usability tests with healthy subjects, stroke patients, and health care professionals and this chapter details the process.

8.3. Study 2 – Formative Evaluation of Games Using SCRIPT

The study was designed to test the effectiveness of the iterative design approach through usability testing of the games by gathering qualitative and quantitative feedback from the healthy players, stroke patients, and HCPs. This study was part of a formative evaluation of the games which is then followed by long-term summative evaluation (Chapter 9) with a larger group of stroke patients in their homes.

The study was based on the developed games; Marble Maze, Run Jack Run, and Burger Hub (detailed description of which can be found in Chapter 6.2 - 6.4). The hardware used was the SCRIPT System (explained in Chapter 5.2).

8.3.1. Iterative design of the games:

The iterative design process of the games involved healthy subjects, stroke patients, formal carers, and health care professionals. The games, following the evaluation with healthy subjects, were presented to the therapists, formal carers, healthy subjects, and stroke patients and their family members at focus groups and demonstration sessions where feedback was gathered.

The Figure 8-1 shows the phases of the iterative design process followed in order to make the games playable for stroke patients. Following each phase of the iterative design process, each game was modified according to the feedback received. As the Marble Maze game was developed first and the feedback results from that game were also adapted while developing the second game; Run Jack Run, and similarly feedback from both these games was adapted in the Burger Hub game.

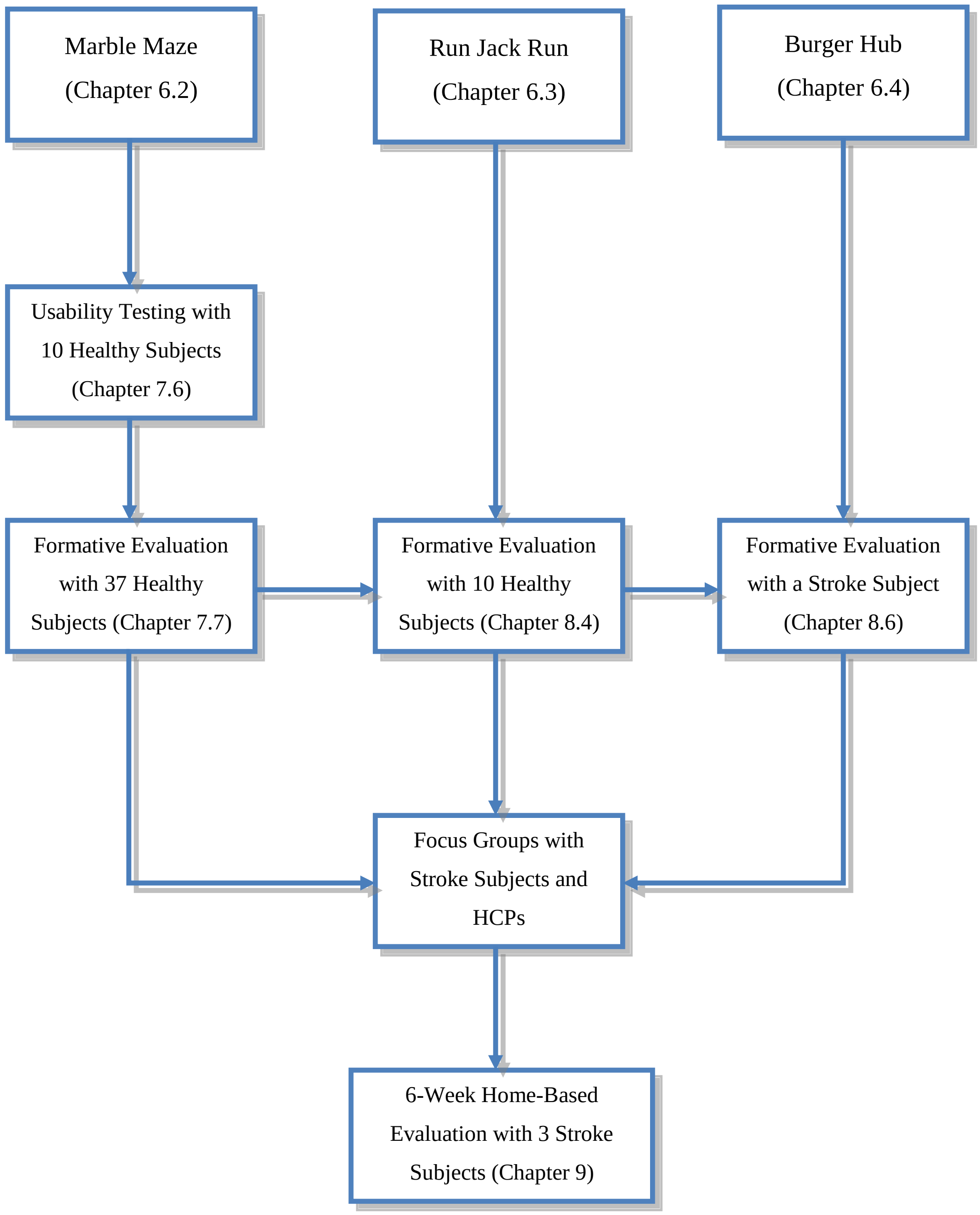


Figure 8-1 - Iterative Design Process

Following each session the games' design was modified to address the issues raised in the feedback from the formative evaluations and focus groups. The changes made to each game's design are detailed in the following sections followed by the results of the formative evaluations with healthy and stroke subjects. Summaries of the feedback collected and the modifications made to the games resulting from the feedback are detailed in Appendix I.

8.3.1.1. Marble Maze

- Game Engine

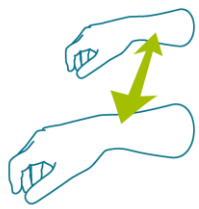
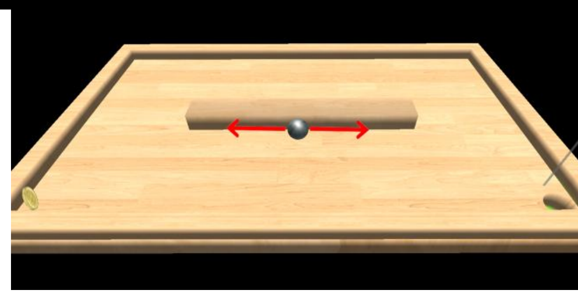
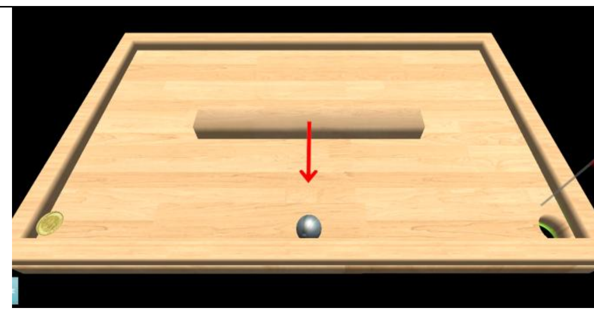
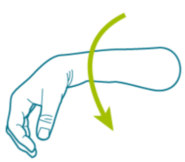
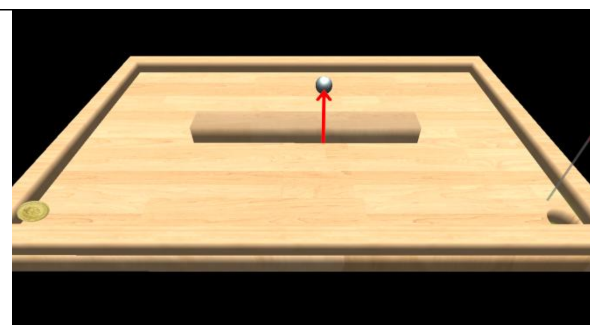
The Marble Maze game was initially designed using the JMonkey game engine. Due to the customizability limitations of the game engine in respect to physics engine and graphics, the game was redeveloped in Unity3D. The Unity3D platform allows graphic models to be imported from different graphic modelling suits while also supporting different shaders, allowing better graphics to be rendered. Unity3D also has an Asset Store which allows various game-specific plugins to be used, delivering substantial visual and audio quality improvements and physics functionalities.

- Control

To make the game playable using the SCRIPT system, changes were made to the game. The tilt of the board was mapped directly to the flexion/extension of the wrist and the pronation/supination of the hand. After the first trial with the stroke patient, it was observed that hand pronation/supination was difficult to execute due to the arm support of the system limiting the movement of the arm. Thus, with recommendation from health care professionals, the controls were changed to wrist flexion/extension and lateral movement of the hand on the horizontal plane.

Table 8-1 represents the movements and their corresponding game actions.

Table 8-1 - Movements required for game actions (Marble Maze)

Movements		**Action**	
Hand lateral movements		Move Marble Left/Right	
Wrist Extension		Move Marble towards screen	
Wrist Extension		Move Marble away from screen	

- Physics

After the usability testing, the torque and the friction of the marble were adjusted to make the movement of the marble more responsive and robust. Limits were applied to the acceleration and the maximum speed of the marble in order to make it easier to control the movement. Limits were also applied to the tilt of the board making it to only tilt to a certain angle in order to prevent the board from flipping over. Also, gravity was increased to counter the marble from bouncing off the board or over the walls of the maze, which was a problem encountered during the usability testing. Lastly, filters were applied to the signals from the potentiometer and camera in order to counter the noise causing flickering in the tilt of the board.

- Gameplay

Initially the Marble Maze game was based on 5 levels, each with a different maze. Although, each of the levels were playable and completed by most of the healthy participants in the Study I, considering the limited movement ability of stroke subjects, easier levels were considered as it was observed that stroke patients found it difficult to perform coordinated movements of the wrist and hand. Thus, 10 easier levels were added with simpler maze which could be completed without coordinated movements early on or had fewer obstacles to counter, making it consisting in total 15 levels. The time to complete each level was also increased for the stroke patients.

- User Interface

Changes were also made to the game's user interface. The font, text size, and button size were increased for easier readability and easy navigation through the menus. Menu screens were designed to be consistent with the SCRIPT System's interface.

The slow background-music was changed to a higher tempo as a result of the feedback from the focus groups.

Additional option to change the camera view from side to top view of the board was also added for patients with depth perception problems but feedback preferred side view.

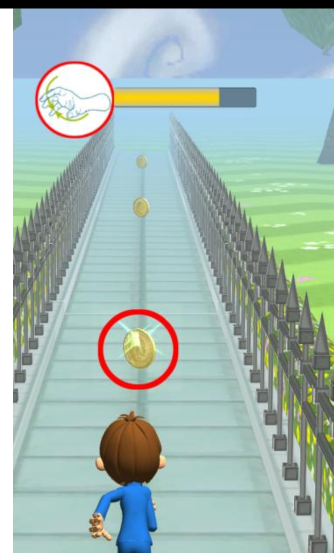
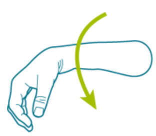
8.3.1.2. RUN JACK RUN

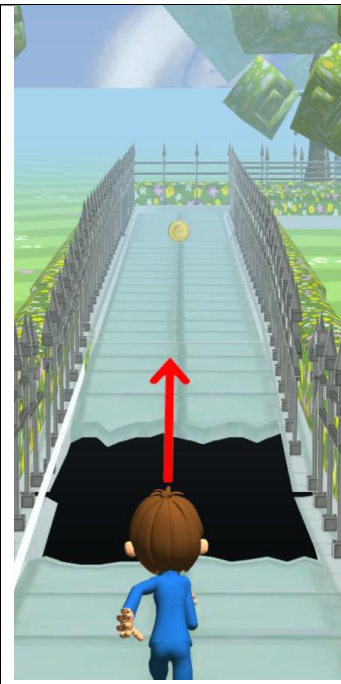
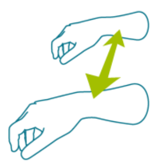
- Control

Since the Run Jack Run game is a gesture based game, the game actions were mapped to the relevant gestures recognized by the SCRIPT system. The game is played by wrist and hand movements. On screen hints were also added showing graphical images of the gestures to be performed when a certain game action is required. The

Table 8-1 shows the list of gestures and their corresponding actions in the game.

Table 8-2 - Gestures required for game actions (Run Jack Run)

Gesture		**Action**	
Hand grasp		Grab Coin	
Wrist Flexion		Duck	

Wrist Extension		Jump	
Hand Lateral		Turn	

▪ <u>Gameplay</u>

Following interaction with focus groups of stroke patients, carers and HCPs, few gamplay changes were made. Easier tutorial based levels were added to the start of the game guiding new players how to play the game along with the option to skip these levels for players familiar with the gameplay.

Furthermore, dynamic difficulty balancing was implemented in the game to make it easier for stroke patients. The start speed of the game was reduced which would adjust according to the player performance based on each gesture, allowing patients more reaction time to perform those gestures at which they are failing. Also, changes were made to accommodate delayed gestures made to be considered as successful for patients with slower reflexes.

- User Interface

Similar to Marble Maze game, changes were made to the game's user interface. The font, text size, and button size were increased for easier readability and easy navigation through the menus. Menu screens were designed to be consistent with the SCRIPT System's interface.

Also, performance feedback messages were added to the game guiding players with hints when they failed to perform required gestures, following the feedback from HCPs to make the game more motivational.

8.3.1.3. BURGER HUB

- Control

The Burger Hub uses both the vision and the tracking recognition system of the SCRIPT System. The virtual hand of the game character is mapped directly to the patients' hand wearing the orthosis. Using the colour tracking with the webcam of the system, the virtual hand on screen follows the movements of the patients' hand on the horizontal plane[149]. Due to the noise present in camera images, the signals from the camera were filtered to counter the flickering of hand reported in the feedback.

Also, performing grasping and releasing gestures wearing the orthosis causes the virtual hand to do the same. This is used to pick in-game objects, transport them, and dropping them. Furthermore, the wrist extension and flexion is mapped to hand up and down movements.

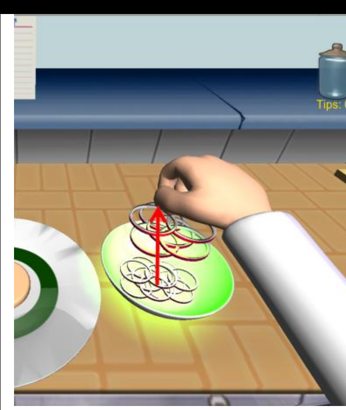
Also, performing grasping and releasing gestures wearing the orthosis causes the virtual hand to do the same. This is used to pick in-game objects, transport them and drop them. Furthermore, the wrist extension and flexion is mapped to hand up and down movements.

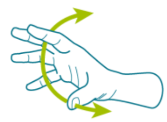
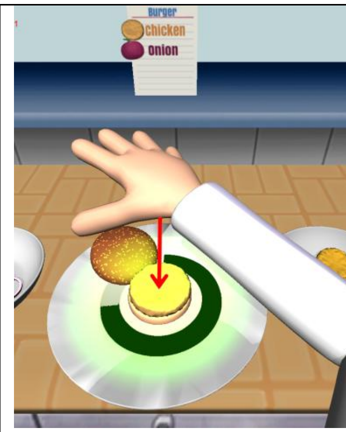
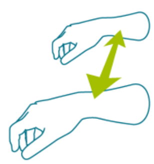
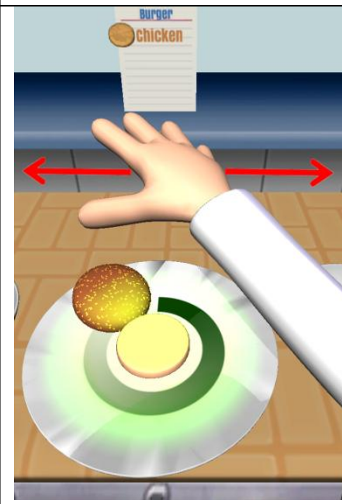
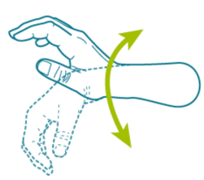
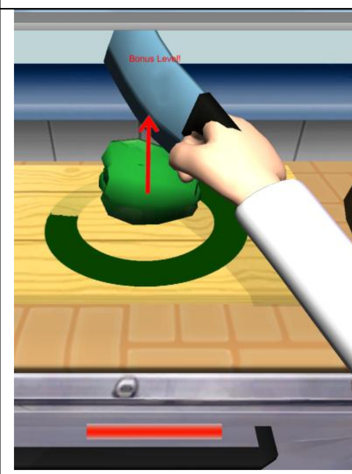
Performing grasping and wrist extension/flexion simultaneously were observed to be difficult for stroke patients; hence modifications were made to the game to require only one of the two movements at the same instance.

The wrist flexion was reported to be often registered as hand lateral movements, as the coloured tracker moves when wrist is extended or flexed. This was fixed by disregarding hand lateral movements while a wrist flexion/extension was being performed.

Table 8-3 shows the required movements and their corresponding game actions.

Table 8-3 - Movements required for game actions (Burger Hub)

Gesture		Action	
Hand grasp		Grab Ingredient	

Hand open		Drop Ingredient	
Hand Lateral		Move Hand	
Wrist Flexion/Extension		Move Knife	

8.4. Formative Evaluation with Healthy Subjects

As part of the iterative design process, following the design of Marble Maze and Run Jack Run, the two games were presented ten healthy subjects as part of a formative evaluation of the games in order to test the usability of the system and the readiness of the games for future evaluation with stroke patients. Feedback from the subjects on both these games was then adapted in the Burger Hub game.

For the experiment, the participants were recruited at the University of Hertfordshire (Ethics Protocol number: aCOM PG UH 00021). Each participant was invited to our lab to take part in a 15 minute session, where they were first briefed about the structure of the session and how to play the games and then asked to sign a consent form. Each participant then played each game administered by the author. The participants could pause or stop the game any time the wanted to. After each game, the participants were asked to fill in a questionnaire based on the experience of the game-play.

The survey questionnaires were adapted from the Intrinsic Motivation Inventory (IMI) in order to measure players' perceptions of intrinsic motivation on the game. IMI is a multi-dimensional measurement instrument which contains several subscales. In this study, a total of five items derived from the subscales, scaled from 1 to 7, were included in a questionnaire: interest/enjoyment, perceived competence, effort/importance, pressure/tension (reversed), and perceived choice. In order to cater to the sessions' limited times, the questionnaire were shortened to have one question per sub-scale.

Ten healthy participants took part in the study (8 males and 2 females; mean age, 21.6 years; SD, ±2.9).

8.5. Results & Discussions

The Table 8-4 shows the results of the game performance of the participants in Marble Maze. Each of the participants managed to complete each of the ten levels. It was observed that on average, the participants collected the coins 72% of the times most of which were outside the shortest path to the target hole. In addition to this, despite failing in some of the levels, participants continued to play the game until the end. These actions prolonged the duration of the game, supporting our previous findings that incorporating operant-conditioning and scoring parameters influence prolonged activity.

Table 8-4 - Performance Data for Marble Maze

Player	Duration	Score	Total coins collected (out of 45)	Total no. of fails
1	11.39	186040	41	8
2	8.22	159040	33	4
3	9.95	129050	42	1
4	9.88	140030	29	12
5	5.42	203030	32	0
6	5.41	123030	24	0
7	7.97	68030	23	3
8	8.32	131050	41	1
9	5.68	211040	30	1
10	8.04	131000	29	9

Furthermore, the survey questionnaire results, presented in the figure, show consistently high ratings in all the categories depicting high motivations amongst all the participants.

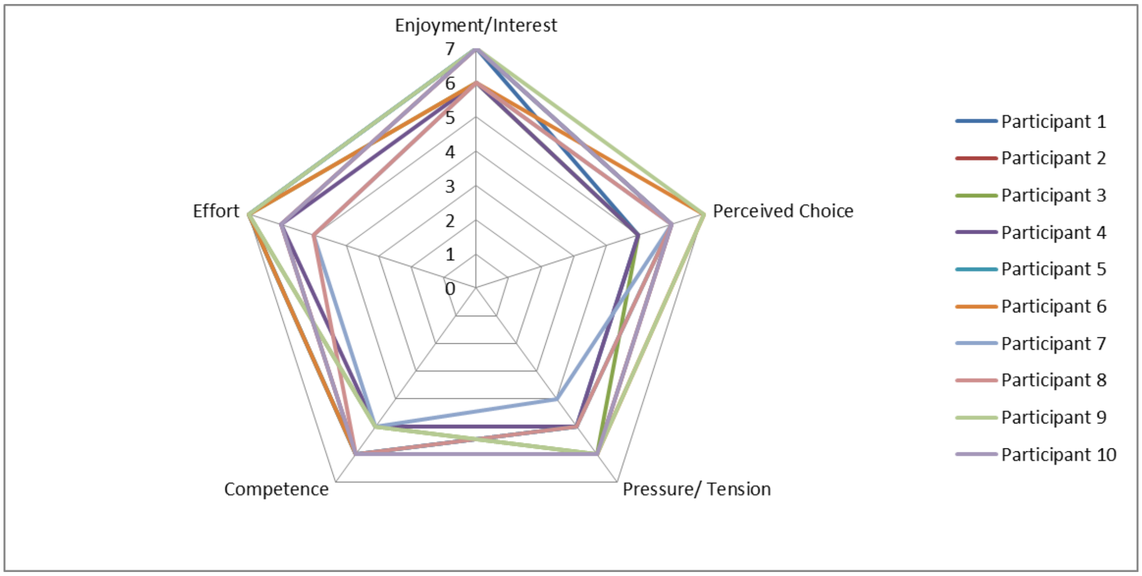


Figure 8-2 - IMI survey results for Marble Maze

The

Table 8-5 shows the results for Run Jack Run game. It was observed that each player collected almost all the coins which increased the player activity and the in-game punishments increased the game duration.

Table 8-5 - Performance Data for Run Jack Run

Player	Duration	Score	Levels Played	Coins Collected/Total Coins	Successful Jumps	Successful Slides	Successful Turns
1	5.78	51896	6	95/97	14	11	9
2	6.17	53048	9	106/106	4	8	3
3	6.48	61658	9	116/138	38	15	11
4	5.83	53000	8	106/126	33	18	5
5	6.68	71512	11	134/134	13	18	17
6	5.91	56500	5	113/117	25	18	3
7	6.24	59000	6	118/120	31	12	8
8	5.88	50000	9	100/131	20	13	25
9	5.86	59000	10	118/118	33	15	11
10	4.94	52630	5	103/103	28	13	2

This is done without compromising the enjoyment/interest of the game as shown by the figure.

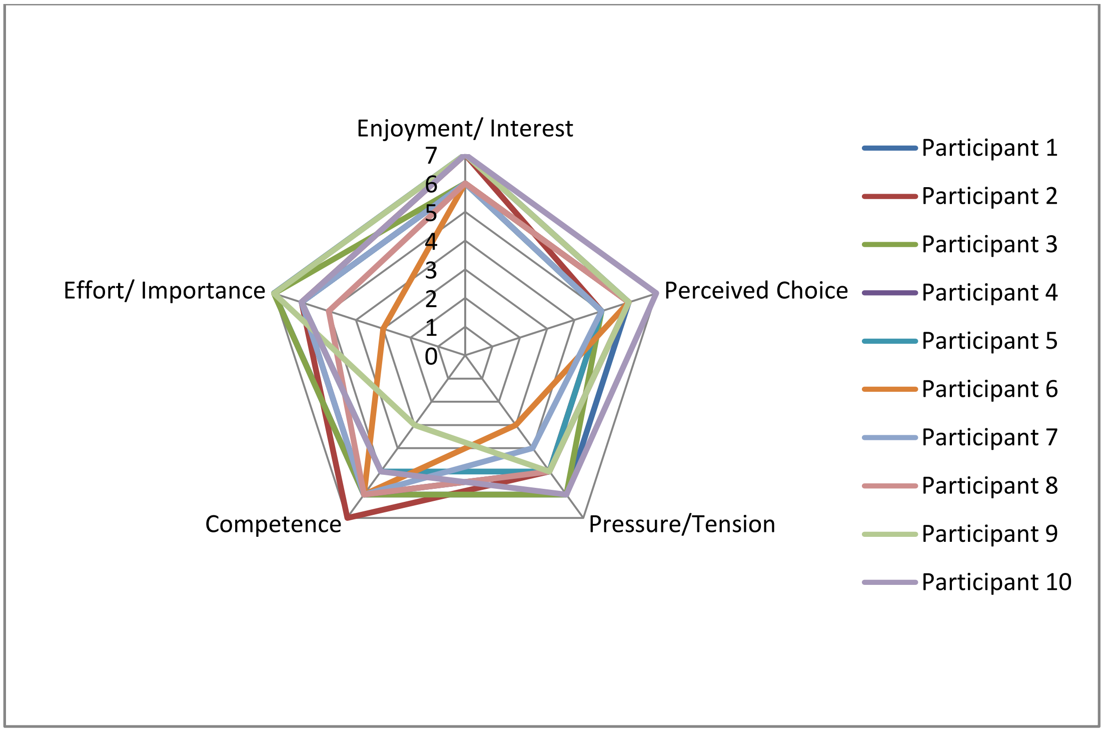


Figure 8-3 - IMI survey answers for Run Jack Run

8.6. Formative Evaluation with a Stroke Patient

Following the evaluation with healthy subjects, the games and the setup was modified to be suitable for stroke subjects. One right-handed female participant who had a first-occurrence stroke with residual movement impairment on the left-side mainly affecting shoulder, hand and wrist and attention deficits on the left side of the vision attended the experiment. After series of formative evaluation steps, the goal was to test the experiment readiness of the game and have a stroke patient playtest the game as part of the iterative design process prior to deployment in a larger formative testing.

The participant took part in a 40 minutes session at our lab in University of Hertfordshire (Ethics Protocol number: COM/PG/UH/00012). The subject was briefed about the experiment setup and the games. The subject was asked to play each game (in order of Run Jack Run, Marble Maze, and Burger Hub) for 7-8 minutes. After each game, the subject filled a questionnaire based on the experience of the game-play and reported any issues with the playability and control of the game.

The survey questionnaires adapted from the Intrinsic Motivation Inventory (IMI) in order to measure players' perceptions of intrinsic motivation on the game used with the healthy subjects were used with the stroke subject.

8.7. RESULTS & DISCUSSIONS

The survey results show that the Marble Maze game was the most favoured amongst the others with the highest score in all five sub-scales.

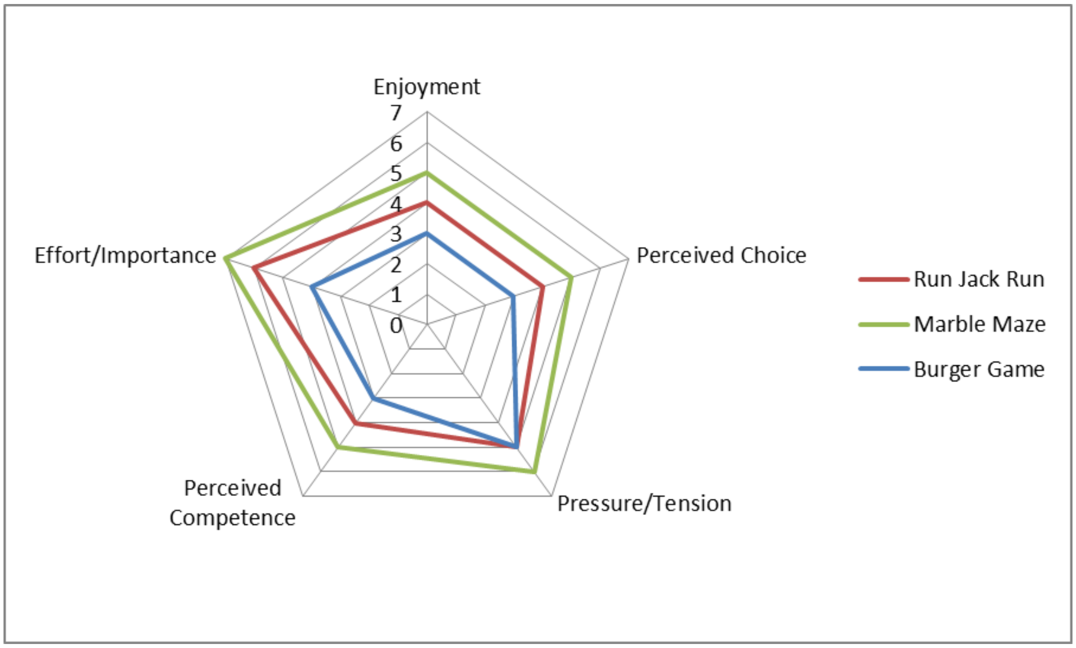


Figure 8-4 - IMI Results for the games

The game unlocks unseen stages with new mazes to be solved which adheres player attention and interest. This result supports our previous findings that different game design parameters can be used to engage players resulting in sustained interest and increased game-play time [150]. The game consists of 15 stages each of which is unlocked when the previous one is successfully completed. The first 5 stages require hand pronation/supination and flexion/extension movements but not both at the same. It is only after the 5th stage that both movements are required in conjunction. The subject could only complete the first 5 stages in this initial trial due to problems coordinating both movements at the same time but despite this, the game was rated highest in all the IMI sub-scales compared to the other games.

The ‘Run Jack Run’ game was the second favoured game according to the survey answers. The subject managed to play the game apart from occasional confusion between wrist flexion and extension:

Table 8-6 - Number of gestures performed in Run Jack Run

Gesture performed	Total Number	On time
Grasping	64	52
Wrist Extension	18	6
Wrist Flexion	4	3
Lateral Movements	4	3

Despite the failures, the subject did not feel frustrated as observed by the Pressure/Tension subscale score (which has been reversed in alignment with other scores).

The player also performed fairly well in the Burger Hub game. Since the game is based on functional tasks and the movements are instinctive, the game was easy to learn. However, the player was confused keeping the track of the virtual hand. Since the tracking of the player’s arm is done through a camera, the virtual hand goes off-screen when the hand moves out of the camera’s vision. This affected the player’s performance and probably is the reason for the low score in the survey. Despite the low scores, the player noted that she preferred games based on functional tasks because she could relate to the movements in real life.

The primary goal of the experiment was to test the playability of the games and the usability of the system for stroke patients, prior to a home-based study with stroke patients. The results show that the games were playable and suitable for stroke patients due to the modifications resulting from the iterative cycles. Thus, helping to examine if games designed with player centric process are able to create motivating and engaging interactive games which are suitable for player with limited abilities.

8.8. CONCLUSIONS

The results presented in this study provide an insight on how player-centric design process can result in games which are motivating and suitable for players. We presented multiple design steps of the iterative design process that were taken towards achieving this goal. As many formative design steps have been completed, our goal here was to design and playtest the readiness of our designed games for deployment in a larger study where patients recovering from stroke are able to practice using these games in their home and at their convenience.

Using game logs and survey questionnaires, we aimed to find out the effects of rehabilitation games on the motivation of patients and observe what key characteristics of games attract and engage patients in to playing for longer periods of time.

Our planned study incorporates a larger set of games (n=9) allowing us to also monitor choice of games and their desirability, thus helping to examine if player centric design along with design parameters incorporated into different games are able to influence length of practice at home and whether added practice would result in a better functional outcome.

9. MOTIVATIONAL STROKE REHABILITATION GAMES

The objective of this chapter is to present the research carried out following the previous studies. This involves a comprehensive evaluation of the designed rehabilitation games in a home-based robot-mediated stroke rehabilitation programme. The chapter presents the quantitative and qualitative results of the 6-week long study involving stroke patients.

9.1. Introduction

This chapter presents the results of a comprehensive evaluation of the SCRIPT system incorporating a set of designed rehabilitation games in a home-based setting. It presents the qualitative and quantitative data representing the choice of games and their desirability, in-game performance of the patients, and compliance of the system.

9.2. Game Desirability

As discussed in the previous chapters, one of the major problems with conventional stroke rehabilitation therapy is to motivate and encourage patients to perform therapeutic exercises as part of their outpatient treatment. Observing little or no improvements for long periods of time results in lack of motivation, often observed in stroke patients [57], which leads to lack of compliance. Therefore, finding motivating and appealing ways to engage patients with their therapy is crucial for recovery of the lost motor control. In combination with home-based rehabilitative technologies video games can add the potential benefit of engaging and exciting patients into practicing more, sustaining their interest and improving performance.

One of the main objectives of this study was to observe the effects of video games on motivation, compliance and prolonged exercise. We hypothesize that video games can affect compliance, engage player into therapy and sustain prolonged activity in a home-based rehabilitation exercise. Incorporating appropriate game design techniques can result in higher appeal of the game eventually increasing active participation in the therapy.

9.3. Study 3

This study was designed to evaluate the developed games using the SCRIPT system in a home-based setting. The developed system was intended to be used independently at home by chronic stroke patients for distal arm training. The objective of the study was to examine effects of games in 6 weeks of technology-supported arm/hand training. The study focused on testing the usefulness of games based on different game design parameters in sustaining long-term engagement during therapeutic interaction.

9.3.1. *Experiment Protocol*

Three chronic stroke patients were recruited by Roessingh Research and Development (Enschede, the Netherlands) to undergo 6-weeks of home-based therapy and receive arm and hand training using the SCRIPT system. The system was installed in the patients' homes by a trained healthcare professional (HCP) in the first week of training and each patient was independently trained to operate the system. The HCP was also remotely supervising, off-line, the patient's activity.

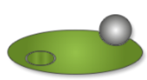
Patients hence trained independently by choosing among a range of games made available to them by the HCP. These provided the context for their therapeutic interaction. The games made available were adjusted remotely, based on the individual requirements and progression, possibly involving different wrist and hand movements in each week. The HCP visited each patient on a weekly basis to aid in solving any occurred problems. During these visits, the HCP could adjust the amount of support provided by the orthosis to the wrist and fingers of the patients to support hand opening by changing the tension of the elastic cords.

The patients were recommended to train using the system for a minimum of 180 minutes per week, but they were free to use it more, if so desired. Amongst the available games, the HCP recommended some games according to the patient's needs but the choice to choose their own preferred game amongst the available games was left to the patient.

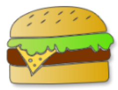
The game library consisted of 5 of SCRIPT games (Seashell, Super Crocco, Fruit Picker, Flight Game, Grandpa lost his glasses) and, the 3 games designed as part of this thesis (Marble Maze, Run Jack Run, and Burger Hub), which incorporated game design techniques and parameters.

In order to comply with the SCRIPT system, the last three games were also split into different categories, each of a different difficulty level in terms of the complexity of the movements required to play them. Table 9-1 lists the type of movements required for each category of the different games. Each category of the game presented a different level of challenge to the patient.

Table 9-1 - Different categories of the available games with respect to the movements required to play the games

Games	Categories	Movements required to play
 Seashell	-	Hand Grasp
 Marble Maze	-	Wrist Flexion/Extension Hand Lateral Movements
 Super Crocco	Crocco1	Hand Grasp Hand Lateral
	Crocco2	Hand Grasp Wrist Extension/Flexion
	Crocco3	Hand Grasp Hand Lateral

		Wrist Extension/Flexion
 Fruit Picker	Fruit1	Hand Grasp Hand Lateral
	Fruit 2	Hand Grasp Hand Lateral
	Fruit 3	Hand Grasp Hand Lateral
 Flight	Flight	Wrist Extension/Flexion
	Flight 2	Hand Lateral Movements Wrist Extension/Flexion
	Flight 3	Hand Grasp Hand Lateral Movements Wrist Extension/Flexion
 Run Jack Run	Run 1	Hand Grasp Hand Lateral Movements
	Run 2	Hand Grasp Wrist Flexion/ Extension
	Run 3	Hand Grasp Hand Lateral Movements Wrist Flexion/ Extension

 Burger Hub	Burger1	Hand Grasp Wrist Flexion/ Extension
	Burger2	Hand Grasp Hand Lateral Movements
	Burger3	Hand Grasp Hand Lateral Movements Wrist Flexion/ Extension

Clinical partners within the SCRIPT project developed this difficulty schedule by considering the difficulty of each category of the games based on the required movements to perform in-game interactions. Depending on the patients' level of impairment, motor abilities, therapeutic needs and level of motivation, the appropriate category was assigned in each week of the training period. As the patient progressed through the training, more games and categories with higher difficulty were provided to the patient to stimulate them.

Table 9-2 presents the different difficulty schedules designed for the patients. The difficulty schedules are designed based on the Gentile Taxonomy which classifies motor skills and movements based on the environmental context and action function [86].The complexity of the movements required to play the games increased from Category A to E.

Table 9-2 - Game Difficulty Schedule

Game difficulty schedule		
Category	**Recommended games**	**Optional games**
A	Crocco 1, Labyrinth 1, Flight 1	
B	Crocco 2, Flight 2, Fruit 1, Run 1, Marble	
C	Seashell, Crocco 3, Labyrinth 2, Lost glasses, Run 2, Burger 2	Flight 2, Fruit 1, Marble
D	Crocco 4, Flight 3, Fruit 2, Run 3, Burger 1	Seashell, Labyrinth 2, Lost glasses, Marble
E	Labyrinth 3, Labyrinth 4, Fruit 3, Fruit 4, Burger3	Seashell, Crocco 4, Flight 3, Lost glasses, Run 3, Marble

9.3.2. *Materials and Methods*

A structured interview questionnaire was designed to measure the patients' perception of the game, and their responses represent the primary outcome measures. The patients were asked to rate each game - depending on how amusing and how difficult they found the game - after each week of training. Such responses were also used for choosing the following week's game difficulty schedule.

In addition to the structured interview, patients were also advised to maintain a log book recording the feedback for the week's training which was discussed with the visiting HCP at the end of the week. The feedback reported usability and technical issues with the games and the overall system.

Furthermore, a survey questionnaire was adapted from the Intrinsic Motivation Inventory (IMI) [61] to measure the patients' perception of intrinsic motivation on the system at the end of the training period. The IMI is a multidimensional measurement instrument containing several subscales. Six question categories were included in the questionnaire, regarding interest/enjoyment, perceived competence, effort/importance, pressure/tension, perceived choice, and value/usefulness.

In addition the quantitative data, game logs were recorded for each game played in order to measure the patients' in-game and exercise performance and the game's desirability. These parameters included the duration for which each game was played, the score achieved and the gestures/movements performed during the game. In order to assess the effects of certain game design parameters built in a particular game, additional parameters for those games were also recorded and analysed as further detailed below.

Following the previous findings that incorporating operant conditioning and scoring mechanism leads to a prolonged activity while sustaining interest, the related parameters were incorporated in the Marble Maze game in order to see their effect on the play duration and patient motivation. In order to do so, the path on which the patients manoeuvred the marble in each of the levels was mapped, depicting the patient activity during game play. The paths were analysed to see how the added parameters affect the duration of the game. Furthermore, the length of the path taken within a level along with the score achieved (based on the number of coins collected) in the level were analysed to measure the performance of the player in the game.

Additionally, in order to deliver an optimum level of challenge, making the game neither too easy (possibly boring) nor too challenging (possibly frustrating), dynamic difficulty balancing was built in the Run Jack Run game. The game monitors the performance of the patient performing a certain gesture and changes the speed of the game accordingly when that gesture is required to be performed again. In order to see the effects of this parameter, we observed the change in the speed of the game based on the rate of change of the score in a game's session and observed its effects on the perceived difficulty of the game.

Table 9-3 presents a summary of the qualitative and quantitative data recorded for analysis of the results.

Table 9-3 - Summary of the outcome measures used for the analysis

Outcome Measure	Analysis
Quantitative	
Structured Interview	Game amusement and difficulty
Patient Feedback	Usability feedback of games and the system
IMI Questionnaire	Intrinsic motivation on the use of home-based rehabilitation system
Qualitative	
Game Play Duration	Game desirability and sustained interest
Player Performance	Player performance in game
Movements/Gestures performed	Intensity of training
Movement of the marble in Marble Maze game	Effects of in-game rewards/punishments on player game play duration
Dynamic difficulty balancing in Run Jack Run game	Effects of adaptive difficulty on game performance and game play duration

9.4. RESULTS & DISCUSSIONS

Results obtained during this experiment are based on observations for each of the patients, while a discussion session summarizes the overall findings. As there are only three patients involved in this study, results are offered as a case by case presentation of the observations.

9.4.1. *PATIENT 1*

9.4.1.1. PATIENT PROFILE

- **Age:** 59
- **Gender:** Male
- **Time since stroke:** 25 months, 3 weeks.
- **Stroke type:** Ischemic/Infarction
- **Affected side:** Left
- **Dominant side:** Right

9.4.1.2. MARBLE MAZE

Marble Maze game was the most played game during the 6 week training period with a total play time of 73 minutes (out of total 177.50 minutes), It was played the most in the first and the least in the fifth week (28.36 and 2.14 minutes, respectively).

As the Marble Maze game is based on continuous movements in contrast to gesture based games, the scoring mechanism is based on the time to complete the level and the coins collected. In order to measure the patient's activity, we calculated the length of the path followed by the marble in each level. This path length was then summed up to calculate path length for each week of the exercise.

Figure 9-1 presents the duration for which the game was played and the sum of the lengths of paths taken during each week. It can be seen that as the length of the path increases, the duration of the played time increases.

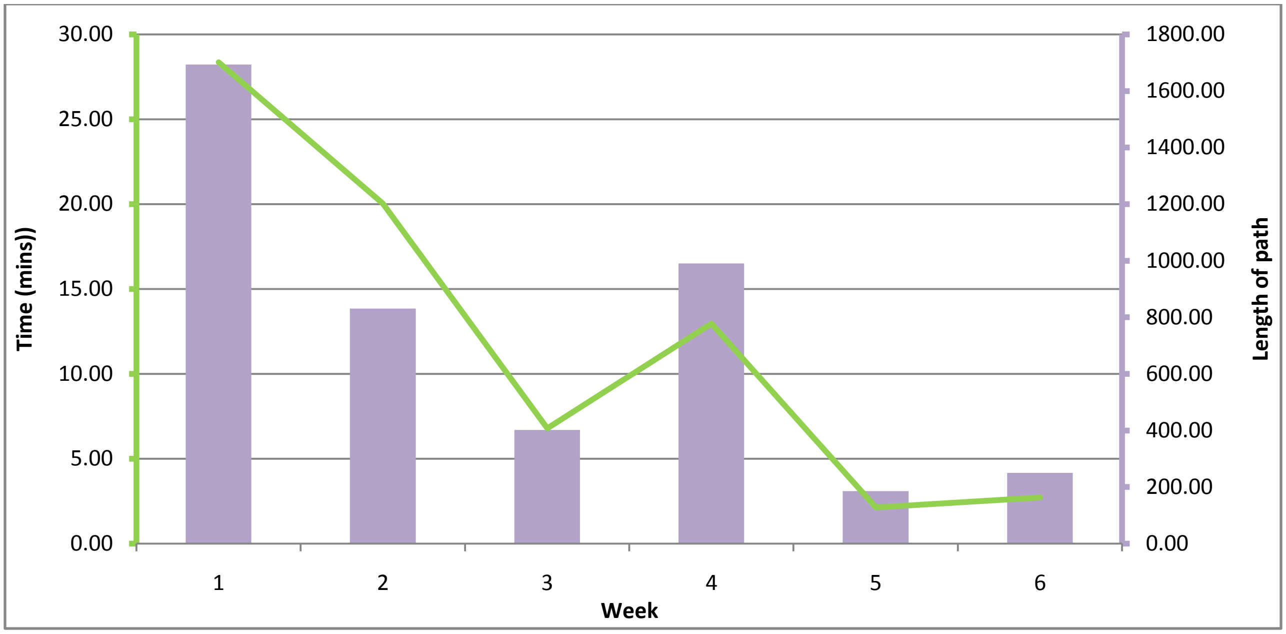


Figure 9-1 - The game play durations of Marble Maze and the sum of lengths of paths followed by the marble per week

The paths followed by the marble depend on the patient's choice of completing the level by adopting the shortest possible path to the goal or adopting a longer route in order to collect all the coins to achieve a higher score. The coins are usually placed outside the shortest possible path from the starting location of the marble to the goal location. Thus, the patient has to deviate from the shortest path in order to collect the coins, increasing the length of the path, in turn increasing the patient activity and game duration. Figure 9-2 represents the paths taken by the patient in the first level of the game amongst all different sessions. It can be seen that the patient, in almost all the sessions, deviates from the shortest path to collect the coins. Figures showing the paths and their lengths for all the levels played in each session are included in Appendix II (Section 13.1).

Figure 9-3 presents the length of path covered per minute of the game's duration depicting the patient's performance efficiency. We can see that as the training progresses, the speed at which the level is solved is also increased, depicting improvement in the performance.

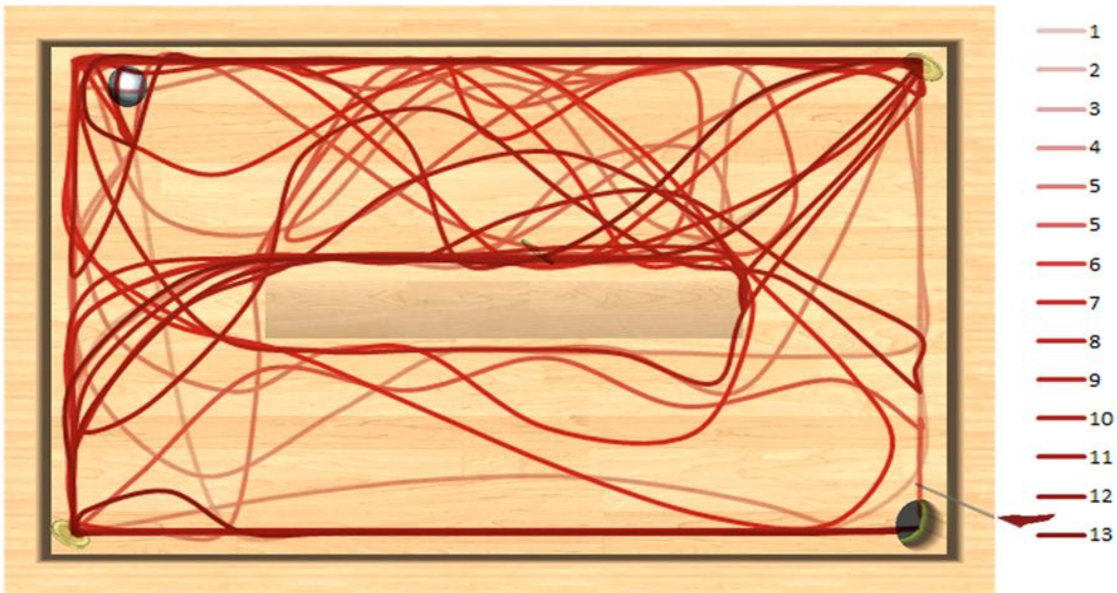


Figure 9-2 - Paths followed by the marble in Level 1 of Marble Maze amongst all the sessions of the game

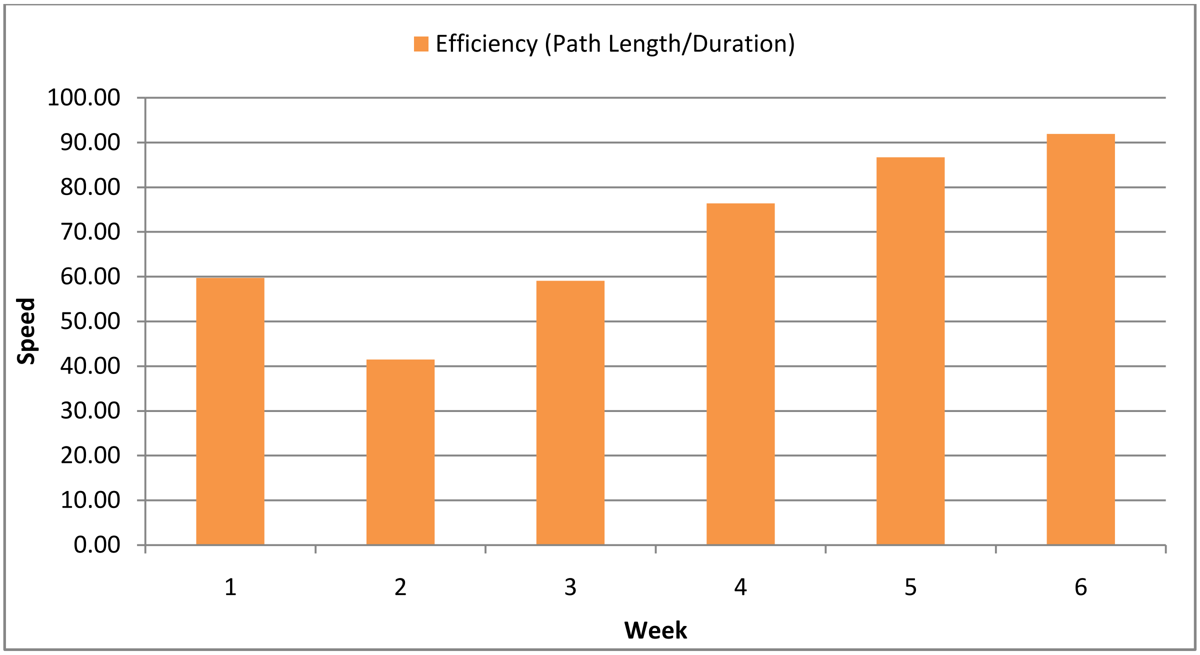


Figure 9-3 - Efficiency of patient's performance

Figure 9-4 presents the patient’s rating for the Marble Maze game’s amusement and difficulty. We see that this game was found to be very amusing by the patient and easy to play, with the amusement scale rated with a median 5.00 during all six weeks and the difficulty scale rated with score median of 4.00.

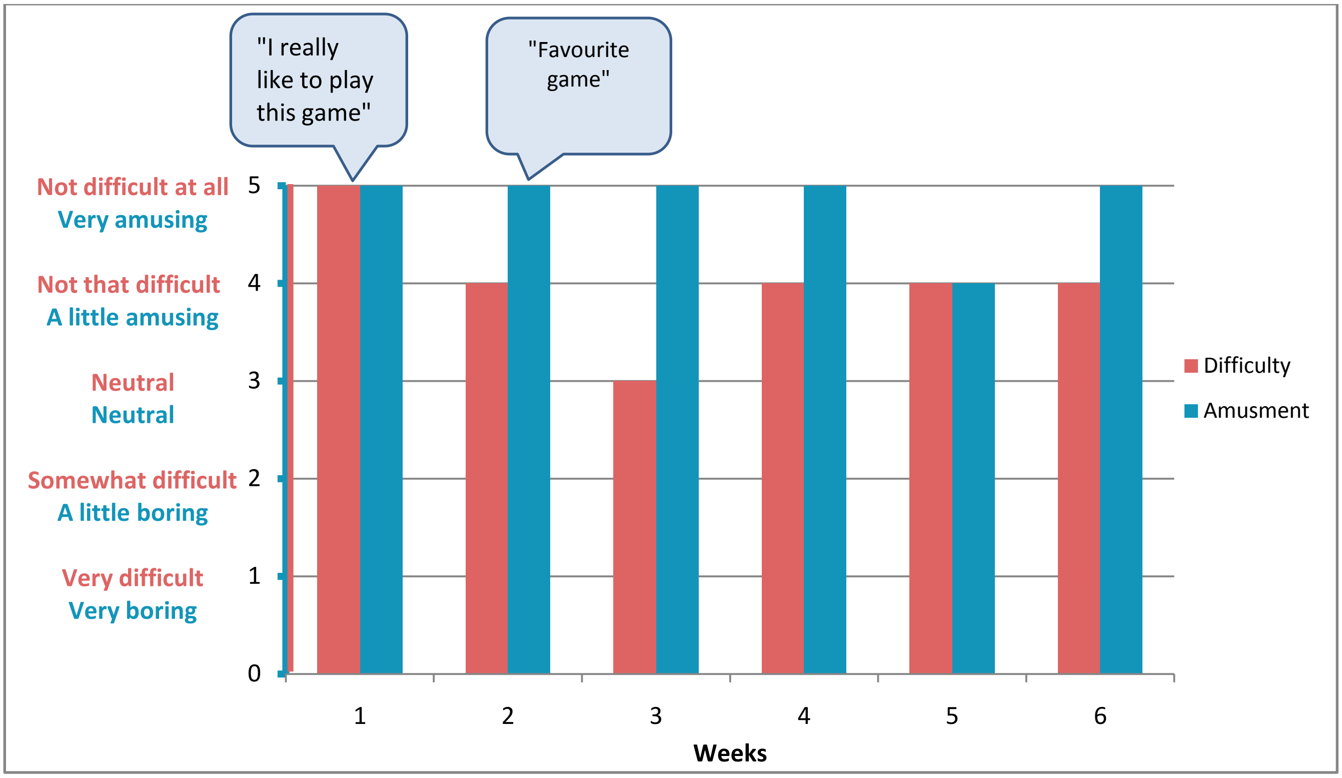


Figure 9-4 - Amusement and difficulty rating of the Marble Maze game per week

The game's ratings may also be affected by external factors such as the systems' usability and reliability, personal preferences, and the patient's impairment. In addition to the structured interviews, feedback about the games and the system was also collected at the end of each week by the visiting HCP. The feedback specific to games presented in Appendix III – Feedback from patients identified the concerns and problems faced by the patient during that week's training. The patient mentioned that he really liked to play the Marble Maze game and that it was his favourite amongst all the games.

9.4.1.3. RUN JACK RUN

Figure 9-5 shows the duration for which the game was played (total 17.30 minutes) and the score achieved per week. The game was played the most in the fifth week and least in the sixth week (6.01 minutes and 1.45 minutes, respectively), but during the 4th week, the game was not played.

The Run Jack Run is played by performing differing hand and wrist gestures so the score is awarded for each successful gesture performed. Thus the score is a direct representation of the patient performance in producing the required gestures. It can be seen that the duration of the game decreased as the training progressed however with the introduction of the new category of the game, the duration increased slightly again.

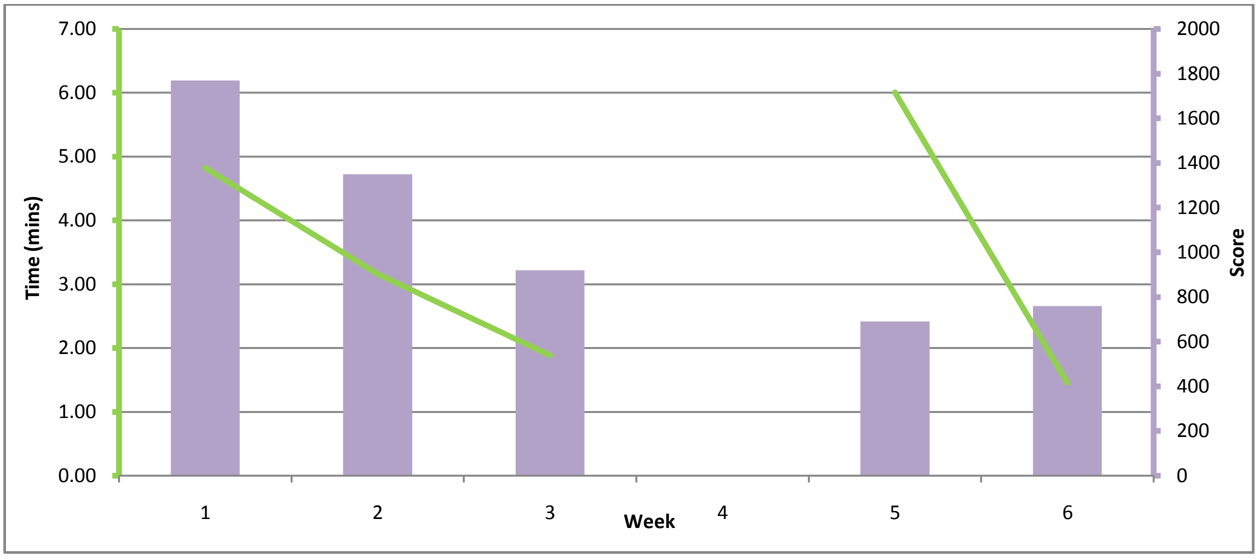


Figure 9-5 – The Run Jack Run game play durations and the score achieved

The Run Jack Run has dynamic difficulty balancing built into it, which adjusts the difficulty (speed) of the game according to the patient's performance. The game monitors the patient's performance for each gesture and adjusts the speed of the game when that specific gesture is required according to the performance. The Figure 9-6 shows the maximum speed reached for the different gestures achieved per week. It can be seen that as the week progresses, even though the played duration decreases, the performance of the patient increases per category of the game. In week 5, when a new category is introduced, the patient's performance decreases but is improved the following week.

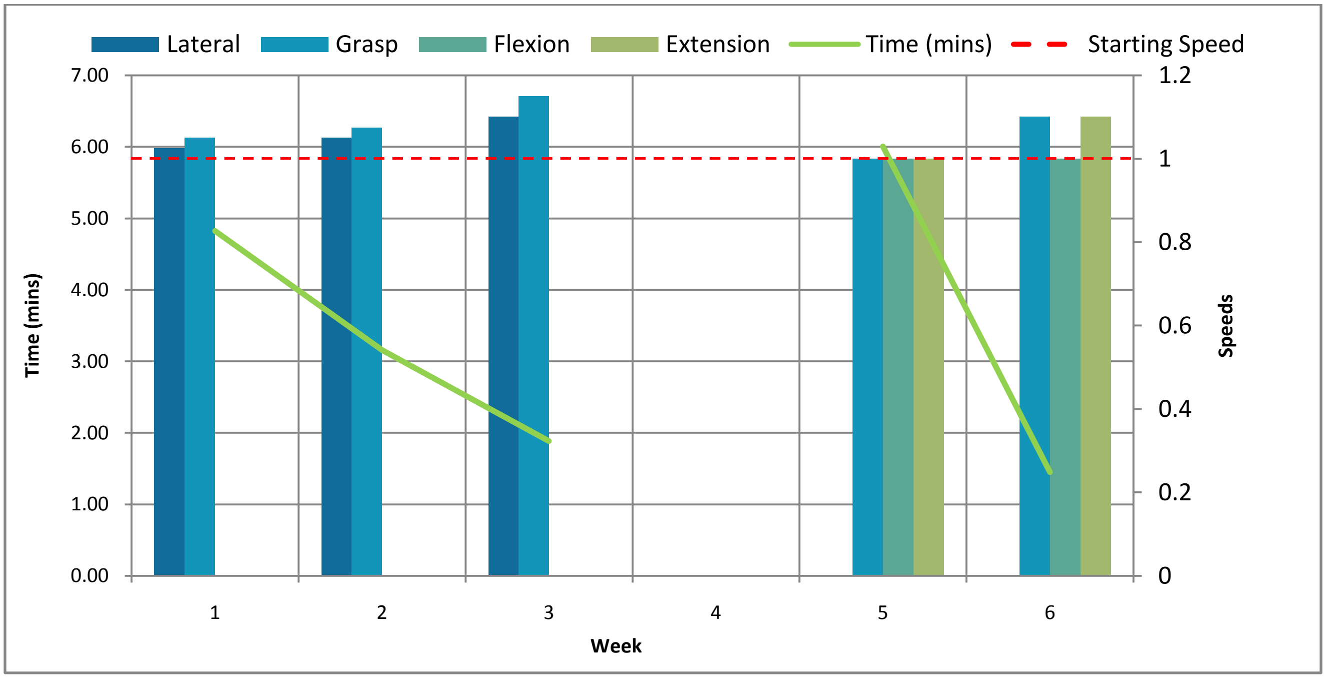


Figure 9-6 – Maximum speeds for different gestures in Run Jack Run and played duration per week

Looking at the qualitative data, it is seen, in Figure 9-7, that on the amusement scale the game was rated with a score with median 3.00 during the training period and the game was rated as somewhat difficult with a score of median 2.00 on the difficulty scale.

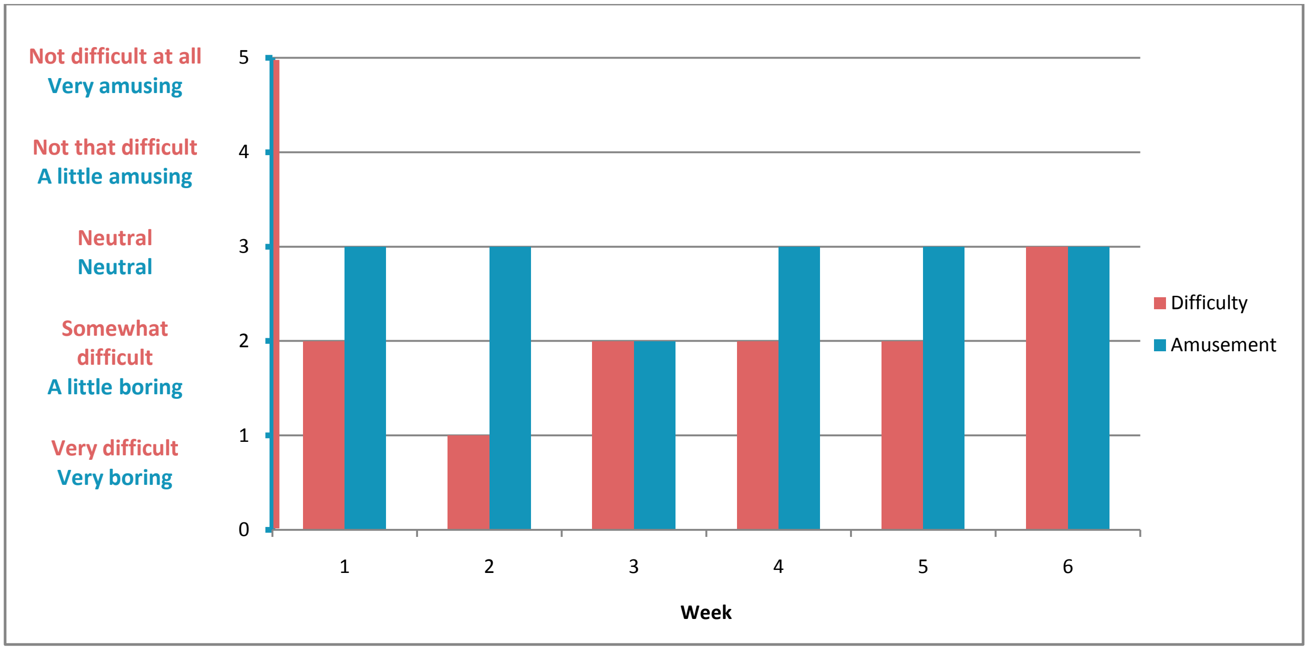


Figure 9-7 - Amusement and difficulty rating of the Run Jack Run game and the game play duration per week

The difficulty and amusement of the Run Jack Run may have also been affected by problems with the arm tracking and gesture recognition of the system as reported in the logs.

The patient reported some problems during calibration of the marker which may have affected the performance during the Run Jack Run game.

The patient reported that the tracking did not seem to work well which resulted in poor detection of the lateral arm movements. The patient mentioned that the turning of the character did not work very well in the Run Jack Run game, and hence liked the Runner 2 category a lot more and found it more amusing where wrist movements are required to play the game instead of lateral movements of the arm.

Furthermore, the patient also reported problems with grasping resulting in him not being able to collect coins in the Run Jack Run game. Due to muscle spasticity, the patient's wrist automatically flexes while performing the grasping gesture, resulting in an incorrect detection of the gestures.

9.4.1.4. BURGER HUB

The Burger Hub was added to the portal by the HCP in the fourth week of the training. The Burger 2 category required lateral movements of arm and hand grasping and opening gestures to play the game, which was played in the fourth week. In week 5 and week 6, Burger 1 category was played which required lateral movements of the arm, and wrist flexion and extension.

The Burger Hub was played for 8.3 minutes in total; most in the fifth week least in the sixth week of the training period. The Figure 9-8 shows the duration for which the Burger Hub game was played and the score achieved per week. The patient could not achieve any score in the Burger 2 category of the game, however performed well in the Burger 1 category.

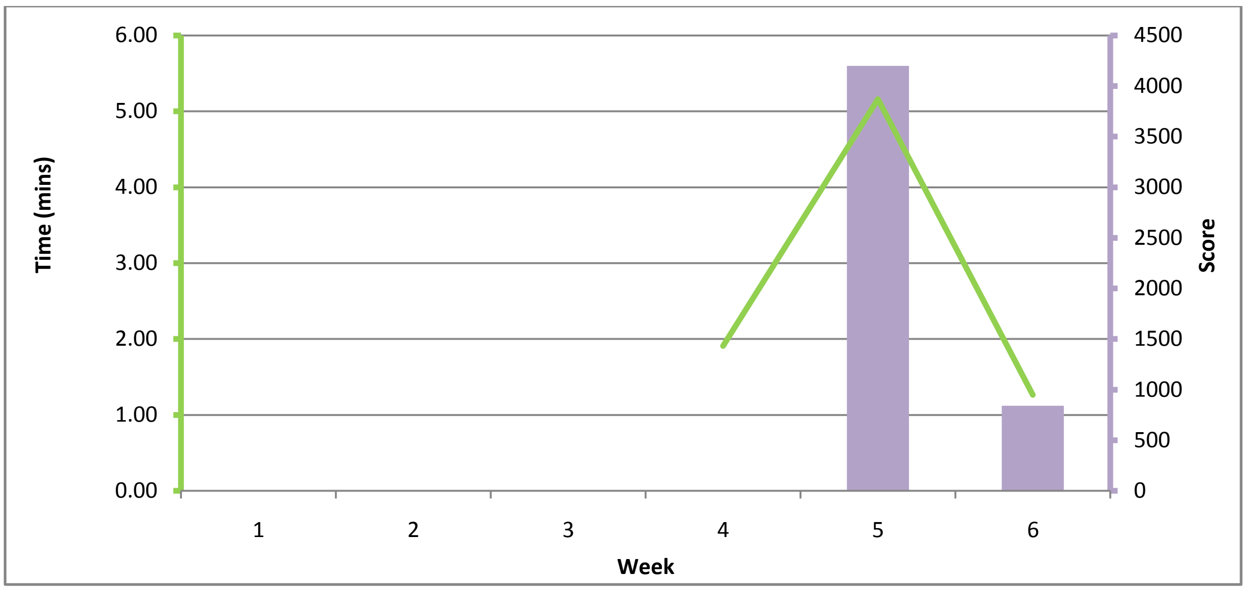


Figure 9-8 - Duration of Burger Hub game played and score achieved per week

Figure 9-9 presents the rating of the Burger Hub game on the amusement and difficulty scale. The game received a score with a median of 3.00 on the amusement scale and 2.00 on the difficulty scale. Similar to the previous games, it can be seen that the patient found the category of the game requiring wrist movements more amusing than the category requiring hand movements.

Similar to Jack Run Jack, the Burger Hub's performance was affected by the problems in the tracking of the system and the patient's impairment and difficulty in performing the grasping gesture which may have caused the poor performance in the category of the game requiring lateral arm movements and hand grasping gesture.

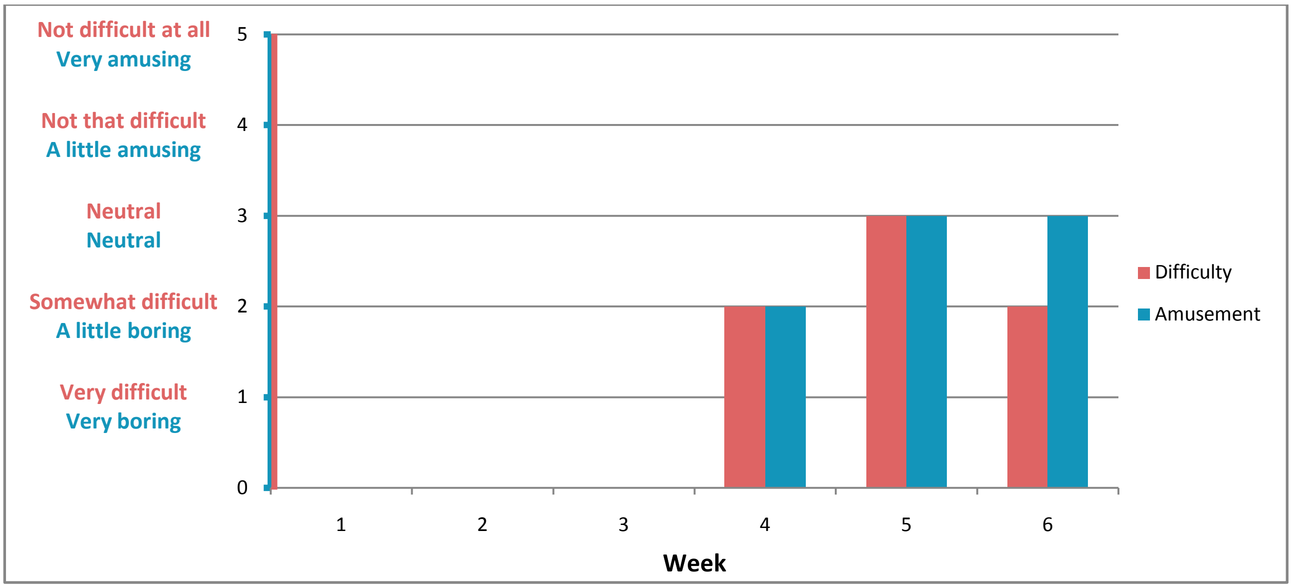


Figure 9-9 - Amusement and difficulty rating of the Burger Hub game and the game play duration per week

9.4.1.5. GAME DURATION IN COMPARISON TO OTHER GAMES

Figure 9-10 shows the total duration of the games played during the training period. The results show that overall the patient trained using the system for 177.50 minutes during the six-week period with an average of 29.58 minutes of training per week. It can be seen that the Marble Maze was played the most amongst all the games.

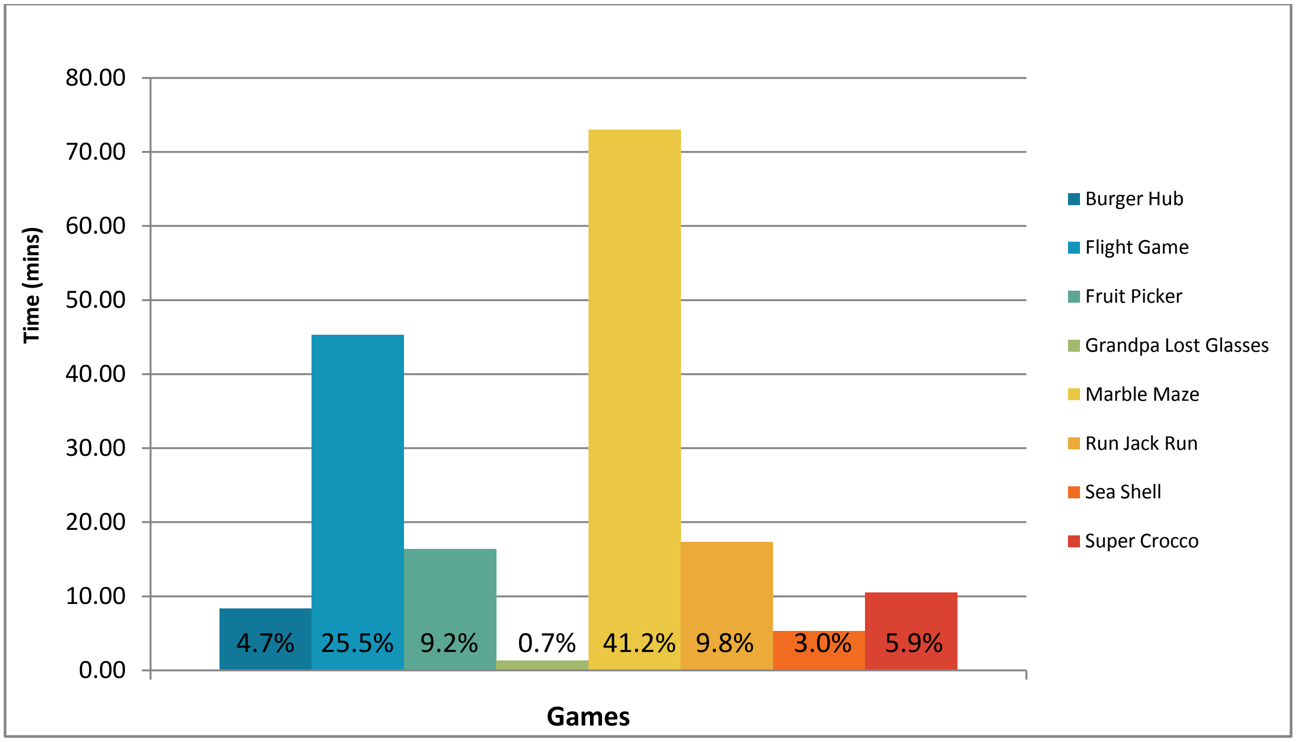


Figure 9-10 - Total duration of the games played during the 6 weeks training period

Figure 9-11 shows the total duration of each game played per week of the training period. It can be seen that the total duration of training decreases as the patient progresses through the training.

As the patient progresses through the training and more games are made available in the portal, a larger variety of games is played during the week, with the maximum of 7 games played during the fifth week.

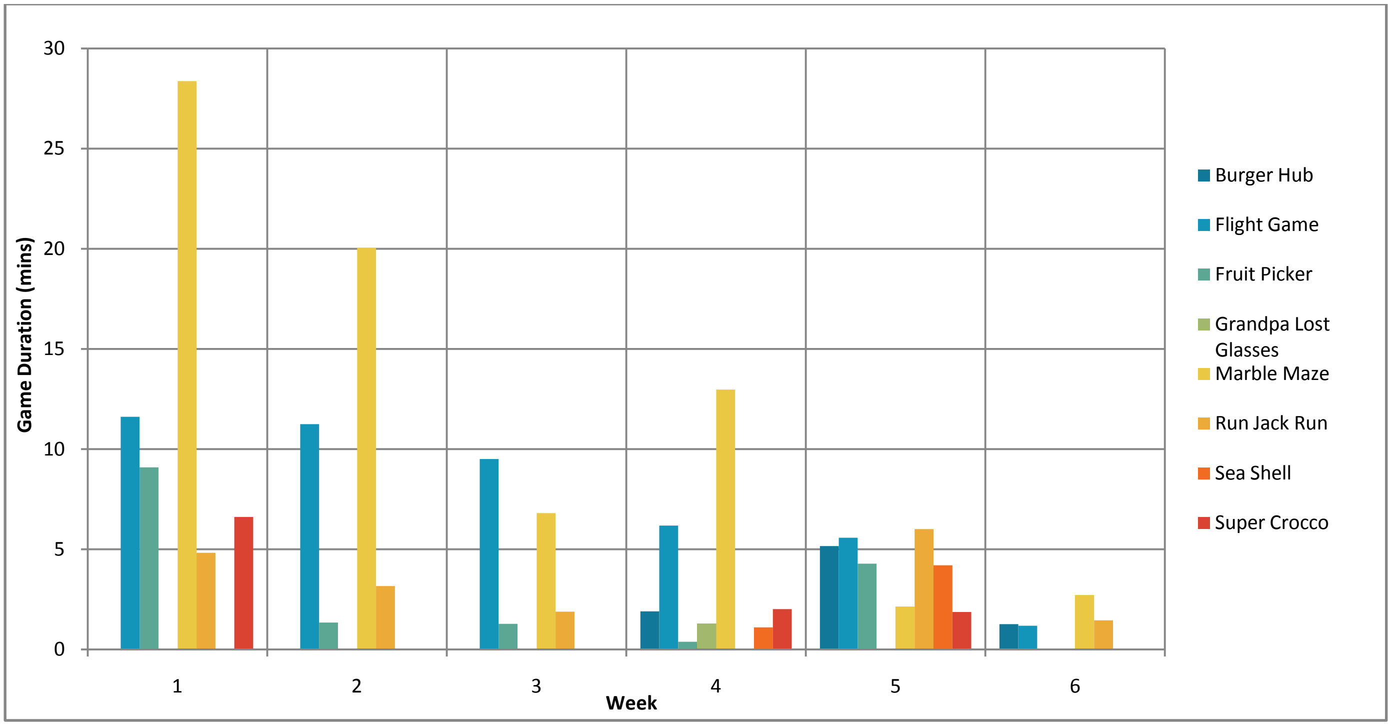


Figure 9-11 - Total duration of the games played per week of the training period

9.4.1.6. GAME PERFORMANCE IN COMPARISON TO OTHER GAMES

In order to compare performance, we look at the score achieved in a game per minute. As the score is awarded based on the gestures made, the scoring mechanism is consistent amongst the gesture based games. Marble Maze game however, is based on continuous movements, and has scored on how quickly the patient achieves the goal. Figure 9-12 presents the performance statistics of each game showing the score/min achieved per week of the training period.

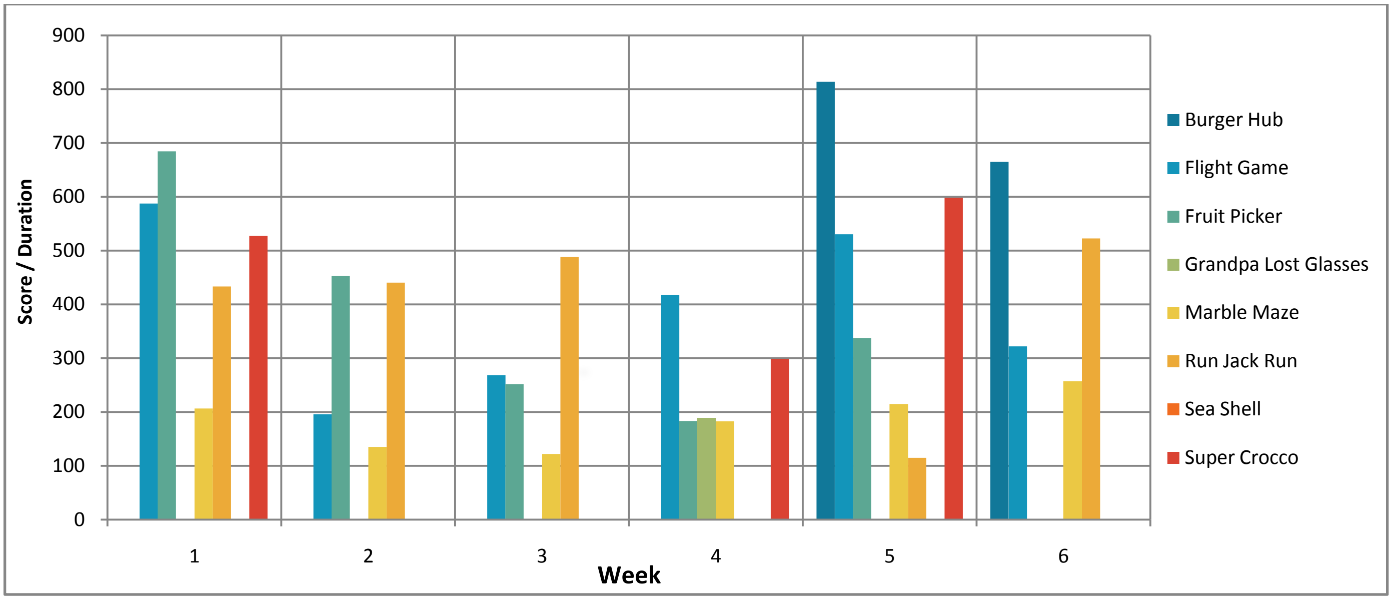


Figure 9-12 - Score/min achieved in games per week

The results show that the patient performed the best in the Burger Hub game achieving an average score of 493/minute per week, achieving a maximum of 814 score/min in Burger1 category during the fifth week of training. The second best performance was recorded in the Super Crocco game with an average score of 475/minute per week with a maximum score of 598/min in Crocco3 category during the fifth week. In the Run Jack Run, the patient achieved an average score of 400/minute per week, achieving a maximum of 523 score/minute in the sixth week. The patient achieved an average score of 387/minute in the Flight Game reaching a maximum of 587.5 score/minute in the first week. In the Fruit Picker, the patient achieved an average score of 382/minute per week, reaching a maximum of 684score/minute in the first week becoming the second best recorded performance during the entire training duration. Grandpa Lost Game was only played once during the fourth week and the patient achieved a score of 189/minute. The patient played the Sea Shell game only twice and failed to achieve any score in one of the sessions, while no score was recorded due to technical fault in the system for the second session.

The patient scored an average of 186 score/minute in the Marble Maze game. However, since the game is not gesture based, the scoring mechanism is different from other games.

9.4.1.7. INTERVIEW QUESTIONNAIRES

In order to further understand the patient desire towards the games and their motivation, we looked at the qualitative data collected. In form of a structured interview, the patients were asked to rate each of the played games on how amusing the game was to them and how difficult it was to them. Figure 9-13 and Figure 9-14 presents the results of the patient's rating of each of the played games recorded at the end of each week of training. Figure 9-13 presents the rating given to each game by the patient based on amusement representing the game's desirability and ability to sustain patient's interest in therapy whereas the Figure 9-14 presents the ratings based on the perceived difficulty of each game, depicting the level of difficulty provided by them.

On the amusement scale, the Marble Maze game was rated the highest for all six weeks given a median score of 5.00. Sea Shell and Super Crocco were given the second highest rating with a score of 4.00 median. Flight Game received a rating of 3.50. Run Jack Run and Burger Hub, both, were rated with a median score of 3.00 while Fruit Picker and Grandpa Lost Glasses received the lowest ratings with a median score of 2.00.

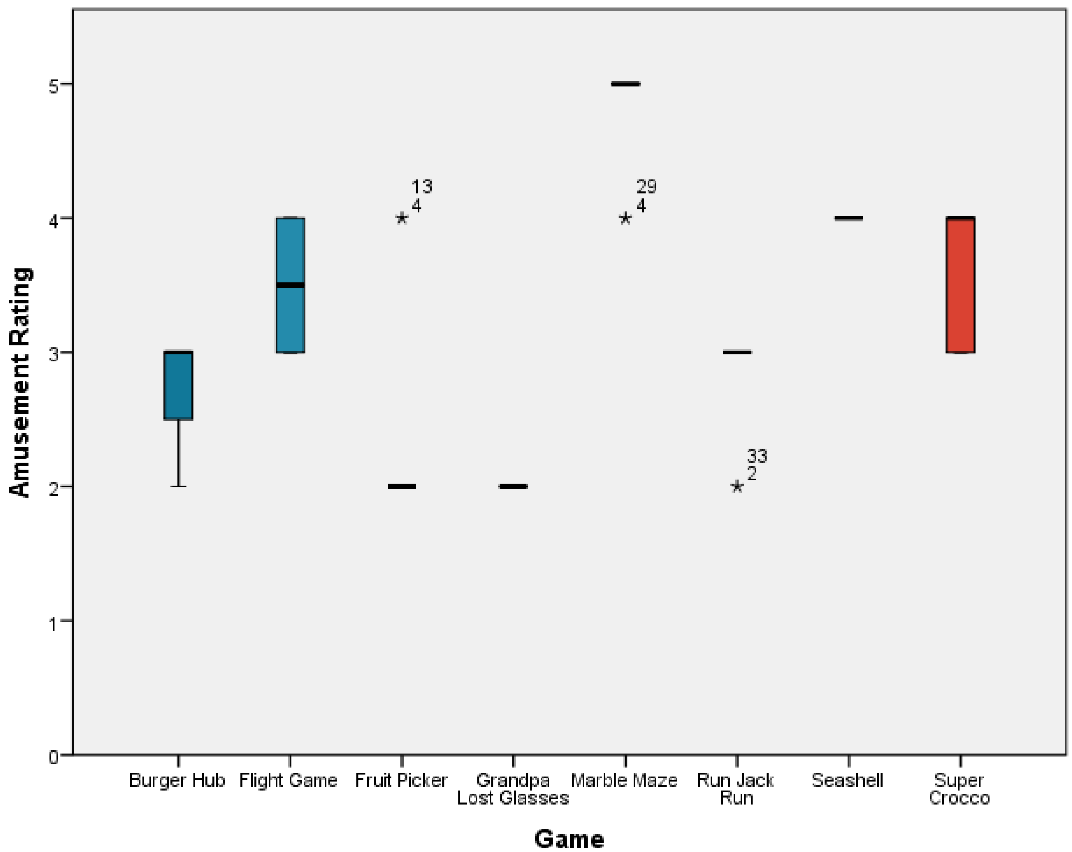


Figure 9-13 - Patient's weekly rating of the played games based on amusement

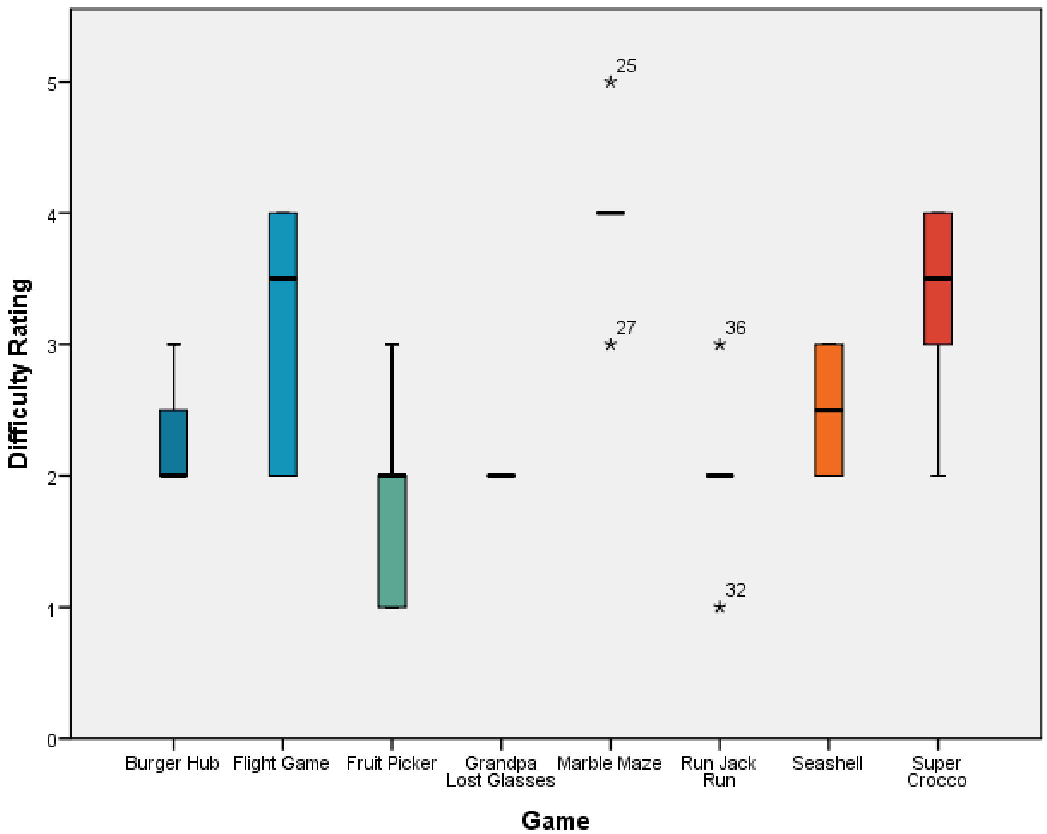


Figure 9-14 - Patient's weekly rating of played games based on difficulty

The difficulty scale ranged from 1 to 5, with 1 meaning "very difficult" and 5 "not difficult at all". This patient rated Marble Maze and the Flight Game as the easiest games, with a median score of 4.00. Then, he found more difficult Super Crocco (3.00), Sea Shell (2.50) while Fruit Picker, Grandpa Lost his Glasses, Run Jack Run, and Burger Hub were all given a rating of 2.00.

In addition to the structured interviews, feedback about the games and the system was also collected at the end of each week by the visiting HCP. The feedback specific to games presented in Appendix III identified the concerns and problems faced by the patient during that week's training.

- The feedback from the patient states that Marble Maze game was the favourite amongst all the games - *"I liked the marble game most"*, whereas Fruit Picker was the least favourite – "*The fruit picker was least fun. Many times the banana felt just next to the basket, which was frustrating"*.

- The patient also reported some problems during calibration of the marker which may have affected the performance during the Run Jack Run game.
- Also, the tracking did not seem to work well which resulted in poor detection of the lateral arm movements. The patient mentioned that the turning of the character did not work very well in the Run Jack Run game, and hence liked the Runner 2 category a lot more and found it more amusing where wrist movements are required to play the game instead of lateral movements of the arm. Similar problems were faced in the Fruit Picker game which caused the cursor to be very jerky.
- The patient also reported problems with grasping resulted in him not being able to collect coins in the Run Jack Run game, grasp ingredients/knife in Burger Hub, and play the Fruit Picker game properly. This is probably because the patient had difficulty in grasping. While performing a grasping gesture, the patient flexes his wrist a lot which prevents the system from detecting a grasping gesture.
- In Fruit Picker, issues were reported with recognition of hand open gesture which prevented fruits from being dropped in the basket.
- A technical issue was repeatedly reported preventing Run Jack Run from being played again once all lives were lost in the game.

Overall, the patient liked the ideas of using games for therapy as they were more fun and distracted him from the idea of actually training the hand. He reported to have found using games for exercises as less monotonous compared to traditional exercises.

Furthermore, in order to measure the patient's level of motivation an IMI questionnaire was presented to be filled by the patient at the end of the training period. Figure 9-15 presents the mean scores for the different IMI survey sub-scales depicting the intrinsic motivation of the patient. The results are based on the overall usability of the SCRIPT system, not the games only.

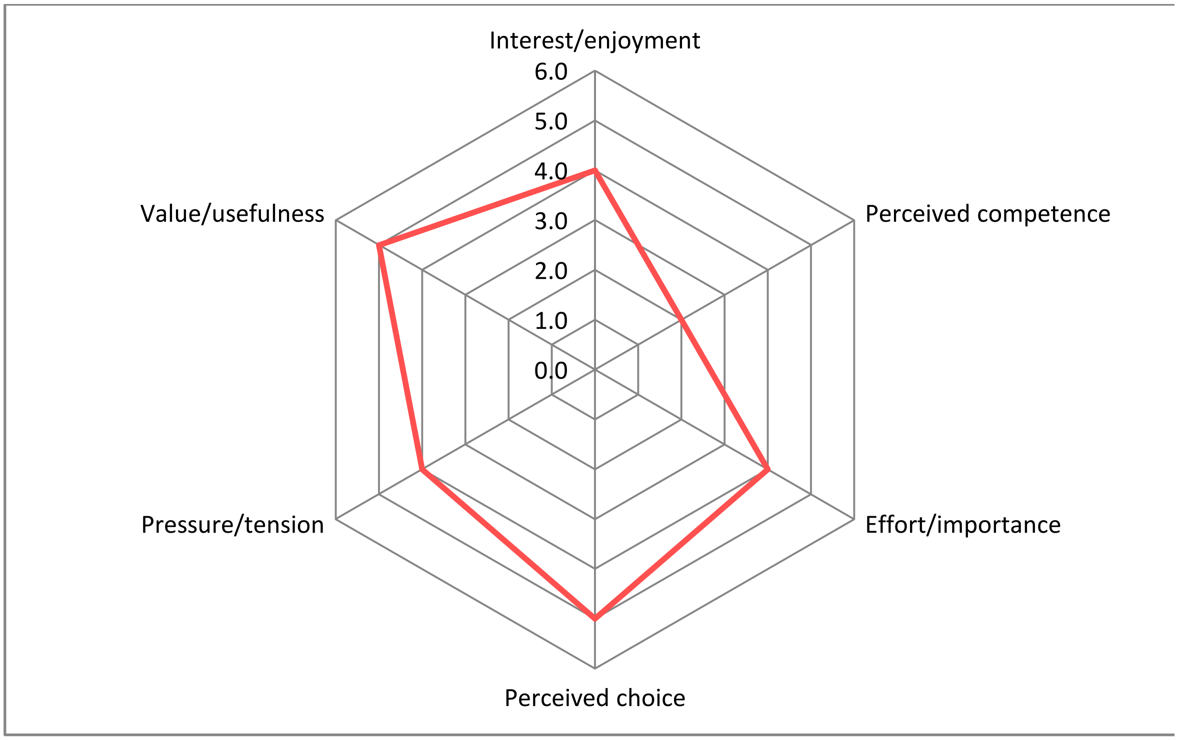


Figure 9-15 - IMI Survey results (median)

9.4.1.8. DISCUSSION

The objective of this study was to observe the effects of video games on motivation, compliance and prolonged activity. The results presented show various aspects of how games can affect home-based therapy. One of the primary goals of using games for stroke rehabilitation is to motivate the patients in actively participating in their exercises in order to regain their lost motor skills.

It is evident from the results provided that a game's desirability can affect the patient's participation in therapy and prolong activity. Providing the patient with a variety of games allows us to compare the effects of different game design parameters that influence the game's desirability subsequently affecting the patient motivation and performance.

Amongst the different games provided to this patient, Marble Maze was the favorite. This can be seen from the interview feedback results, the amusement/difficulty ratings of the game and the total duration of the played games. Marble Maze game amongst all, was the most played game and received the highest rating in terms of amusement as well as being the least difficult game. However, the question remaining is whether this patient tends to prefer easier games due to his/her perceived low competence in performing them.

Looking into the Marble Maze data, by observing the paths followed by the marble in each level, we observe that the operant conditioning and scoring parameters installed in game further enhance the player's engagement in the therapy as we see that the patient actively worked towards obtaining a high score by collecting as many coins and rewards as possible in almost all the levels. The patient reported in the feedback that he did not care much about the score as he was not playing against someone. This supports our previous findings that the scoring mechanism alone may not have the same influence on motivation than with the operant conditioning parameter [150] .

Furthermore the results suggest that the acquisition of in-game rewards and avoidance of built in punishments, not only engage the player to participate in the therapy more actively, but also prolongs the duration of the exercise, all while sustaining the interest. Also, since the game is based on continuous movements, it requires the player to be constantly active.

The effects of operant conditioning are more evident in comparison with the second most played game - The Flight Game. Although the game was also played relatively longer than other games, the lack of in-game rewards and punishments is observed, when analyzing the player activity during the game. It was observed by the HCP during one of the home-visits that the patient did not move his hand and waited until the objects automatically came towards him. The flight game was also rated lower in the amusement and difficulty scale, even though the game is based on the same movements as the Marble Maze.

Moving on, we look at the results from the Run Jack Run game. As the training period progressed, the duration of the game played decreased. However, since the game adjusts the difficulty according the patient's performance, we observe that the patient's performance improved over the weeks as we see him achieving higher game-speeds over the weeks. In week 5, as a new category of the game was introduced featuring different gestures, the duration increased but there was a drop in the performance (score/duration). This followed the same pattern as the previous category, as we see the duration decreasing and the performance improving the following week.

In order to acquire the rewards in the Run Jack Run, the patient had to perform a hand grasping gesture to collect the virtual coins. Due to the patient's impairment and difficulty in performing a hand grasping gesture, as reported in the interview logs, we see a lower performance ratio in this game. The performance may have also been affected by technical issues with the tracking of the hand, making it difficult to perform lateral movements, as reported in the patient feedback. Hence the game received lower rating on the difficulty scale. The patient also reported to have found the category requiring wrist movements more amusing than the category requiring lateral movements and hence, the former received higher amusement rating.

The Burger Hub game was not added to the portal by the HCP until the fourth week. In the category of the game requiring continuous lateral arm movements and hand grasping/opening gestures, the patient could not achieve any scores. As also seen in the Run Jack Run game, this may have been due to the tracking issues of the system and the patient's difficulty in performing the hand grasping gesture. In the category requiring wrist movements, the patient performed fairly well, and achieved the highest score/duration ratio amongst all the games. The Burger Hub being based on the ADL tasks allows the patient to relate to the task on hand and hence influences high activity resulting in better performance.

Furthermore, analysing the results in correlation to each other, we look into the weekly game durations and observed that there is a novelty period of two weeks after which the total training duration decreases until additional games are made available. As more games are made available, the total training duration increases once more. This suggests that a wide variety of games from different genres provided to the patients can potentially influence more activity.

Also, we observe that since the patient had problems with grasping, the patient focused more on games played with wrist movements; e.g. Marble Maze, Flight Game, Burger Hub (Burger 1 category). This suggests that the game desirability and play duration is not only dependent on the game but also the movements required to play the game.

In addition to the game design parameters and movement impairments, the training is also affected by the system's usability as the patient reported some technical problems with the system making the games less effective. As reported in the feedback for Run Jack Run game, hand tracking did not seem to work very well for other games as well, which made them harder to play, hence causing frustration and negatively influencing the game's desirability. This affected the patient's experience of playing Run Jack Run, Burger Hub, and the Fruit Picker, hence the low rating in the interview questions. The patient also had problems restarting the Run Jack Run game even when he wanted to play more, due to a technical problem in the system which affected the total duration of the game. In addition external factors, such as changes in schedule and daily activities, concentration difficulties also seemed to have an effect on the patient's motivation causing him to skip the training. However, despite these, the patient seemed to like the idea of using games for exercise as they are comparatively less monotonous and more fun.

9.4.2. Patient 2

9.4.2.1. Patient Profile

- **Age:** 44
- **Gender:** Female
- **Time since stroke:** 33 months.
- **Stroke type:** Ischemic/Infarction
- **Affected side:** Right
- **Dominant side:** Right

9.4.2.2. Marble Maze

Unlike the previous patient, Marble Maze was one of the least played games by this patient with a total playtime of 39.40 minutes (out of total 418.88 minutes); played most in the first and least in the sixth week (17.03 minutes and 1.63 minutes, respectively).

Patient activity is measured by calculating the sum of the lengths of the paths followed by the marble during the game play time. Figure 9-16 presents the duration for which the game is played for and the sum of the lengths of the paths taken during each week. It can be seen that as the length of the path increases, the duration of the played time increases.

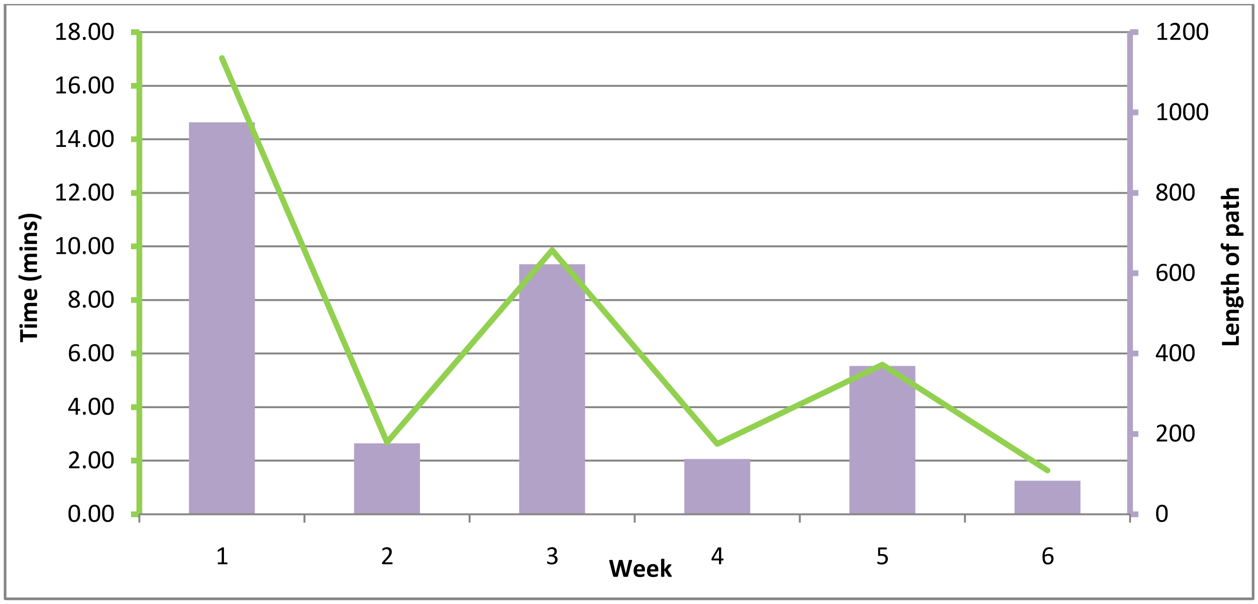


Figure 9-16 - The game play durations of Marble Maze and the sum of lengths of paths followed by the marble per week

As previously discussed earlier in Section 9.4.1.2, the coins placed in the levels of the Marble Maze deviate the patient from the shortest possible path to the goal location increasing game duration and patient activity. Figure 9-17 shows the paths taken by the patient in the first level of the game amongst all different sessions. In almost all the sessions, the patient is seen deviating from the shortest path to collect the coins. The figures showing the paths and their lengths for all the levels played in each session are included in Appendix II.

Figure 9-18 presents the length of path covered per minute of the game's duration depicting the patient's performance efficiency. There were no significant improvements in the efficiency as the training progresses.

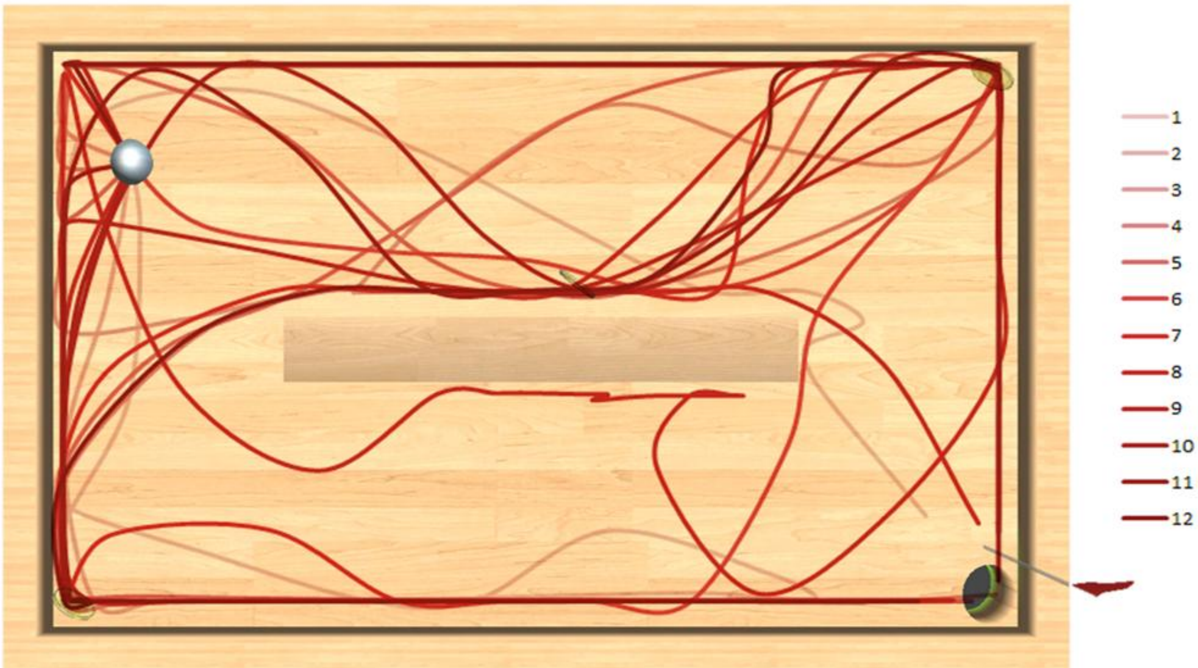


Figure 9-17 - Paths followed by the marble in Level 1 of Marble Maze amongst all the sessions of the game

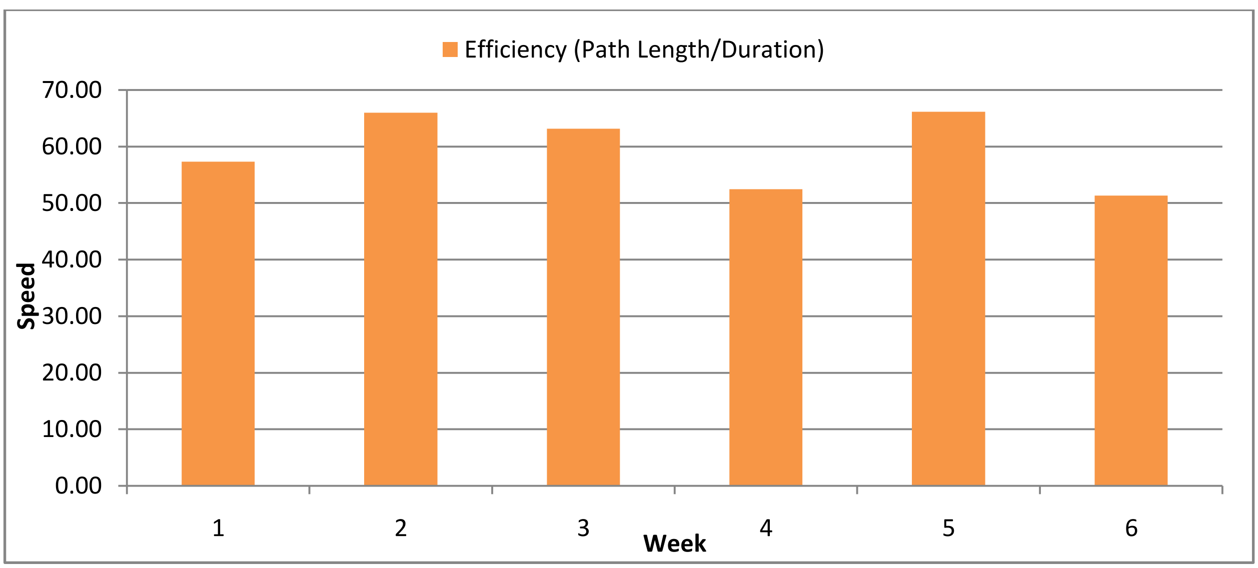


Figure 9-18 - Efficiency of the player's performance in Marble Maze

Looking into the qualitative data, we see that the patient found the game a little boring and somewhat difficult, rating the game 2.00 (median) on both, the amusement and the difficulty scale. Figure 9-19 presents the patient's rating for the Marble Maze game's amusement and difficulty at the end of each week of the training period.

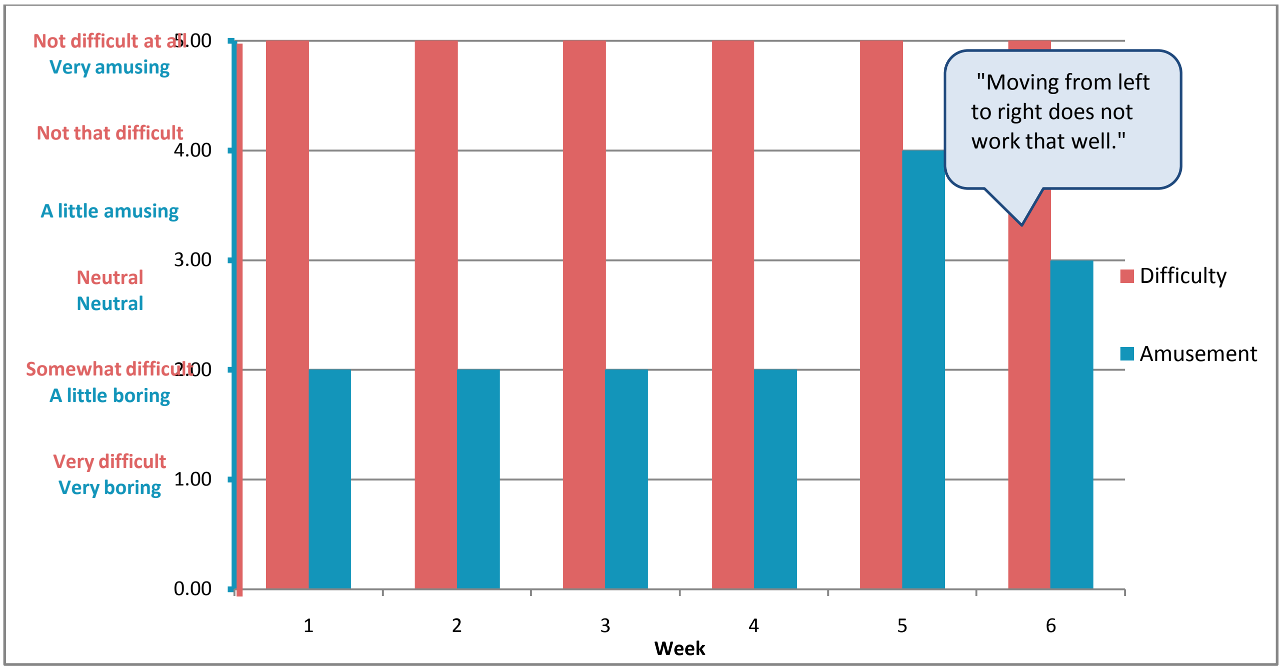


Figure 9-19 - Amusement and difficulty rating of the Marble Maze game per week

The feedback presented in Appendix III about the game was also collected at the end of each week by the visiting HCP. With regards to the Marble Maze, the patient reported problems with the tracking which prevented her from playing moving the marble left and right. This may have been due to the limited availability of the light in the room limiting the accuracy of the tracking mechanism.

9.4.2.3. RUN JACK RUN

Figure 9-20 presents the played duration of the Run Jack Run and the score in the game per week. The figure shows that the game was played for 69.45 minutes in total (out of total 418.88 minutes); played the most in the first week and the least in the sixth week (26.33 minutes and 2.83 minutes, respectively). In the first week, the Runner 1 category of the game was played with lateral movements of the arm and hand grasping gestures. Runner 2 category, with hang grasping and wrist flexion and extension gestures, was played in the second and third week. In the fourth week, the Runner 3 category was added to the patient portal which was played in the last three weeks using all available gestures; hand grasping, wrist flexion and extension, and lateral movements of the arm.

It can be seen that the duration of the game decreased as the training progresses however as more gestures are added in the later weeks of the training, more variety of movements are practiced.

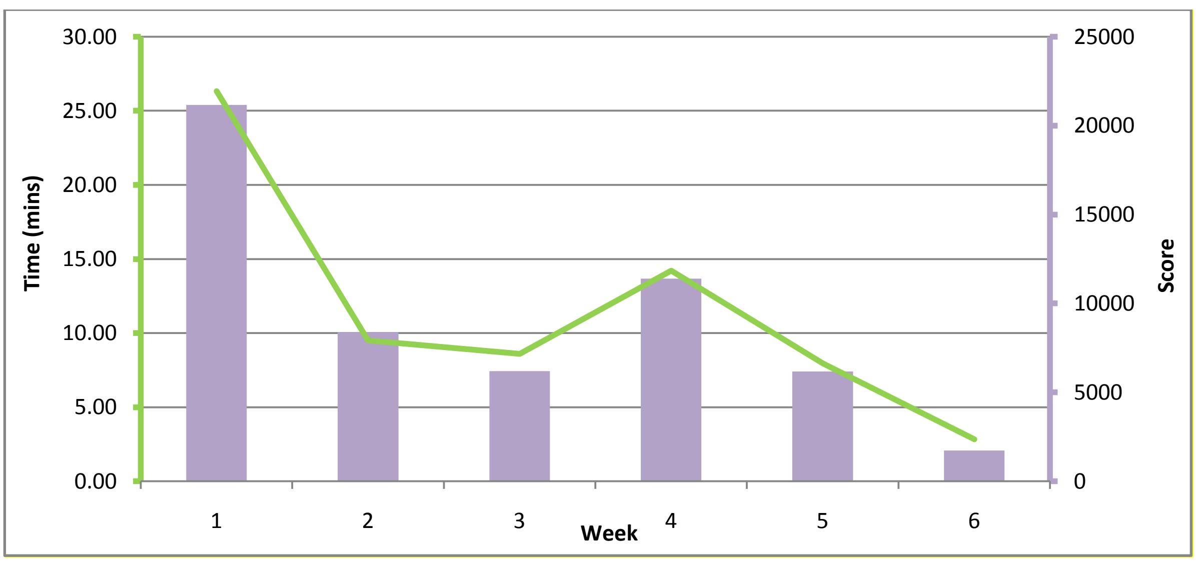


Figure 9-20 – The Run Jack Run game play durations and the score achieved

The dynamic difficulty balancing parameter built in the Run Jack Run game adjusts the difficulty of the game (the speed of the game) according to the patient's performance. The game monitors the patient's performance for each gesture and adjusts the speed of the game when that specific gesture is required according to the performance. Figure 9-21 shows the maximum speed reached for different gestures achieved per week. It can be seen that the patient performed well in performing all the gestures.

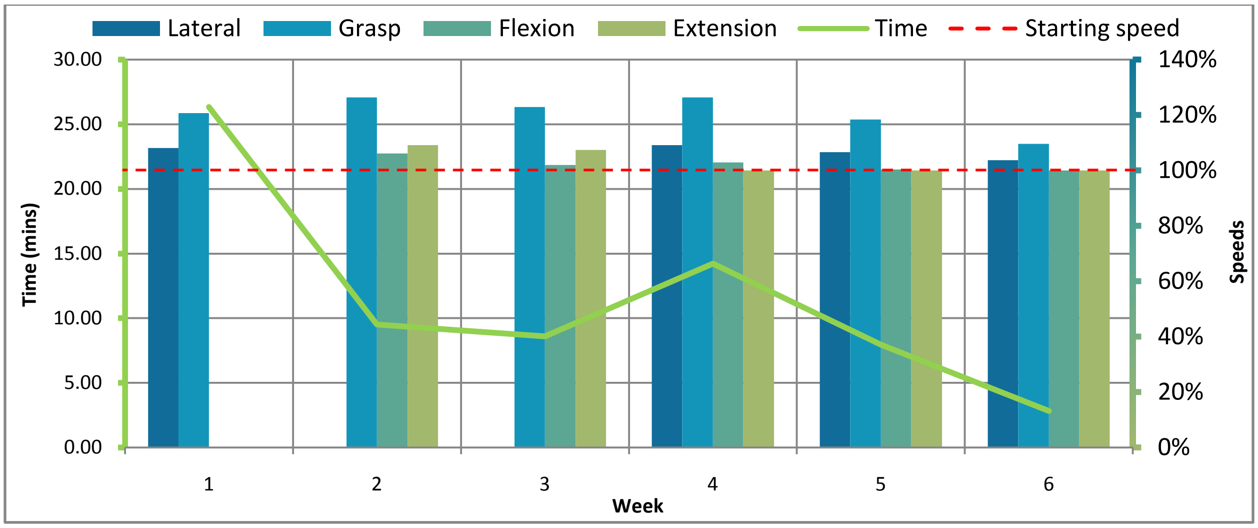


Figure 9-21 – Maximum speeds for different gestures in Run Jack Run and played duration per week

Furthermore, Figure 9-22 presents the qualitative data presenting the ratings of the game on the amusement and the difficulty scale. The Run Jack Run game received a median score of 2.50 on the amusement scale and 3.50 on the difficulty scale.

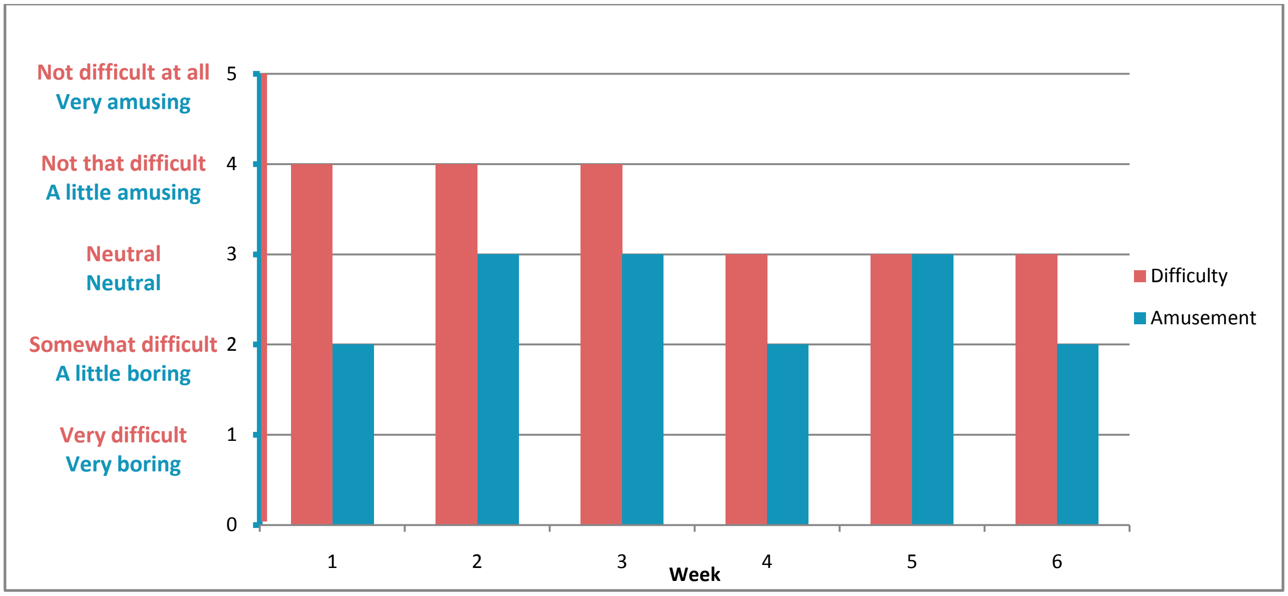


Figure 9-22 - Amusement and difficulty rating of the Run Jack Run game and the game play duration per week

The difficulty and amusement of the Run Jack Run may have also been affected by problems with the arm tracking and gesture recognition of the system as reported in the logs.

In the feedback specific to games presented in Appendix III the patient reported tracking issues making it hard to play in most of the games including the Run Jack Run game requiring lateral movement of the arm. The gesture was reported to be difficult to perform since the game would not recognize the movements. This may have been due to limited lighting in the room. The patient also reported the gesture recognition system to be too sensitive in the Run Jack Run game. Also, the player found the turning animation of the character in the game too fast.

9.4.2.4. BURGER HUB

The Burger Hub was added to the portal by the HCP in the second week of the training. The Burger 2 category was played during the second, third and fifth week requiring lateral movements of arm, and hand grasping and opening gestures to play the game. In the fourth and the fifth week, Burger 1 category was played which required hand grasping, and wrist flexion and extension movements. In the sixth week, Burger 3 category was played which required all; hand grasping and opening, lateral movements of the arm, and wrist flexion and extension movements.

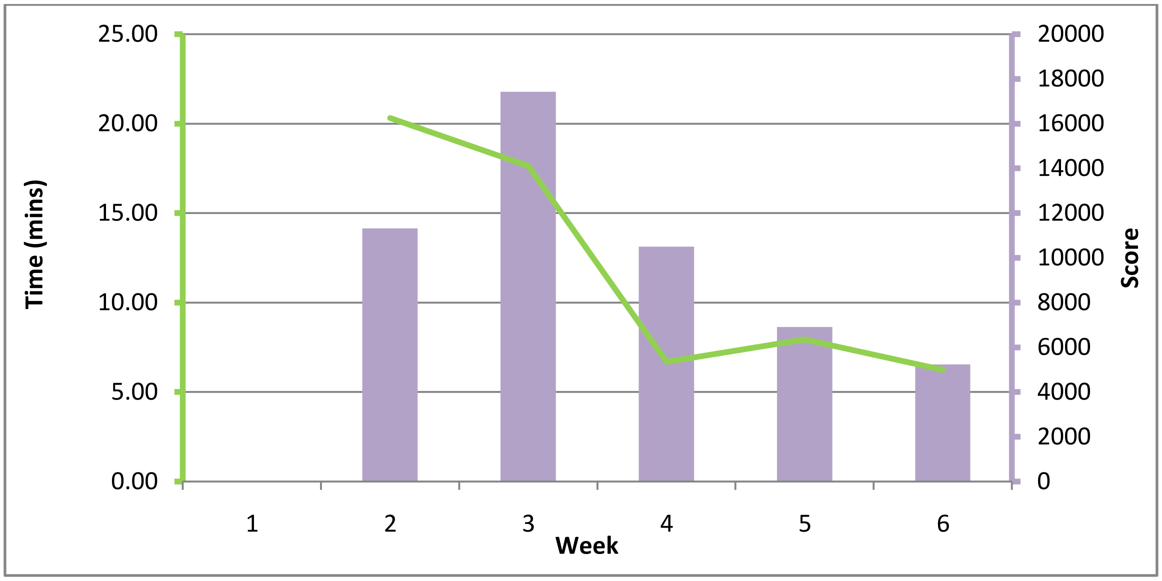


Figure 9-23 - Duration of Burger Hub game played and score achieved per week

Figure 9-23 shows the duration of the game played and the score achieved per week. In total, the Burger Hub was played for 58.79 minutes; most in the third week and least in the sixth week.

Figure 9-24 presents the rating of Burger Hub on the amusement and difficulty scale. The game received a score with a median of 3.00 on both the amusement and the difficulty scale.

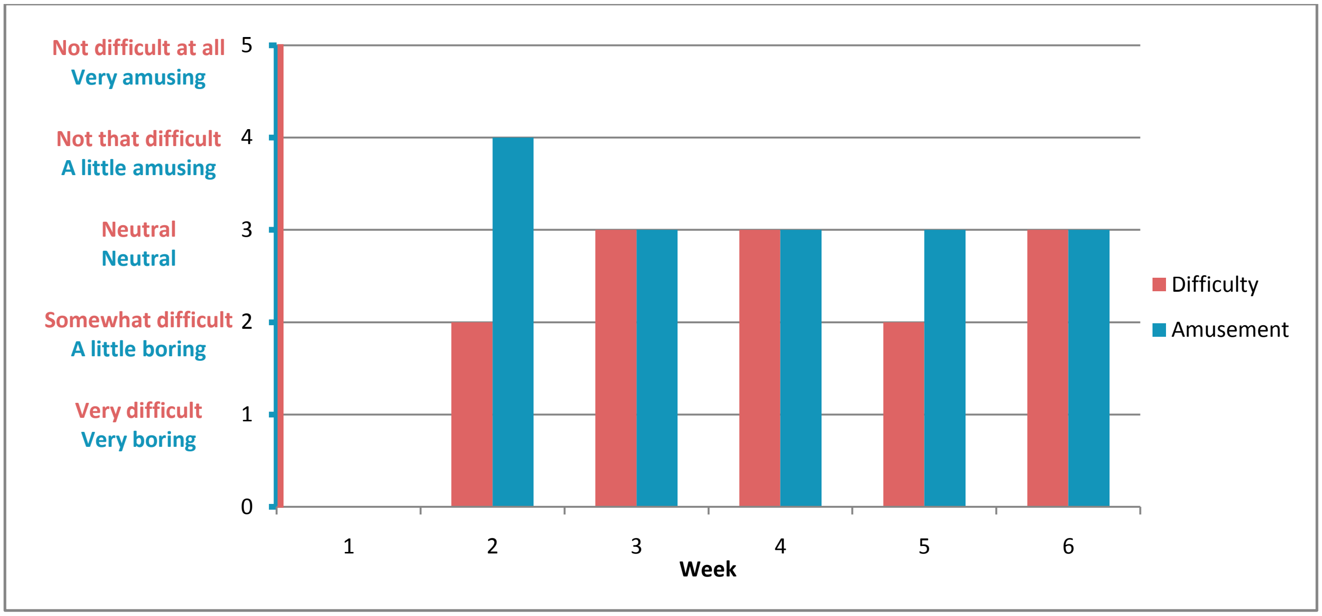


Figure 9-24 - Amusement and difficulty rating of the Burger Hub game and the game play duration per week

Similar to Jack Run Jack, the Burger Hub's performance was affected by the problems in the tracking of the system and the patient's impairment. The patient also reported having problems grasping ingredients requiring forward and backward movements of the arm. The complete feedback specific to games is presented in Appendix III.

9.4.2.5. GAME DURATION IN COMPARISON TO OTHER GAMES

The results show that overall the patient trained using the system for 421.84 minutes during the six-week period with an average of 52.73 minutes of training per week. Figure 9-25 shows the total duration of the games played during the training period. Run Jack Run was played the most amongst all the games.

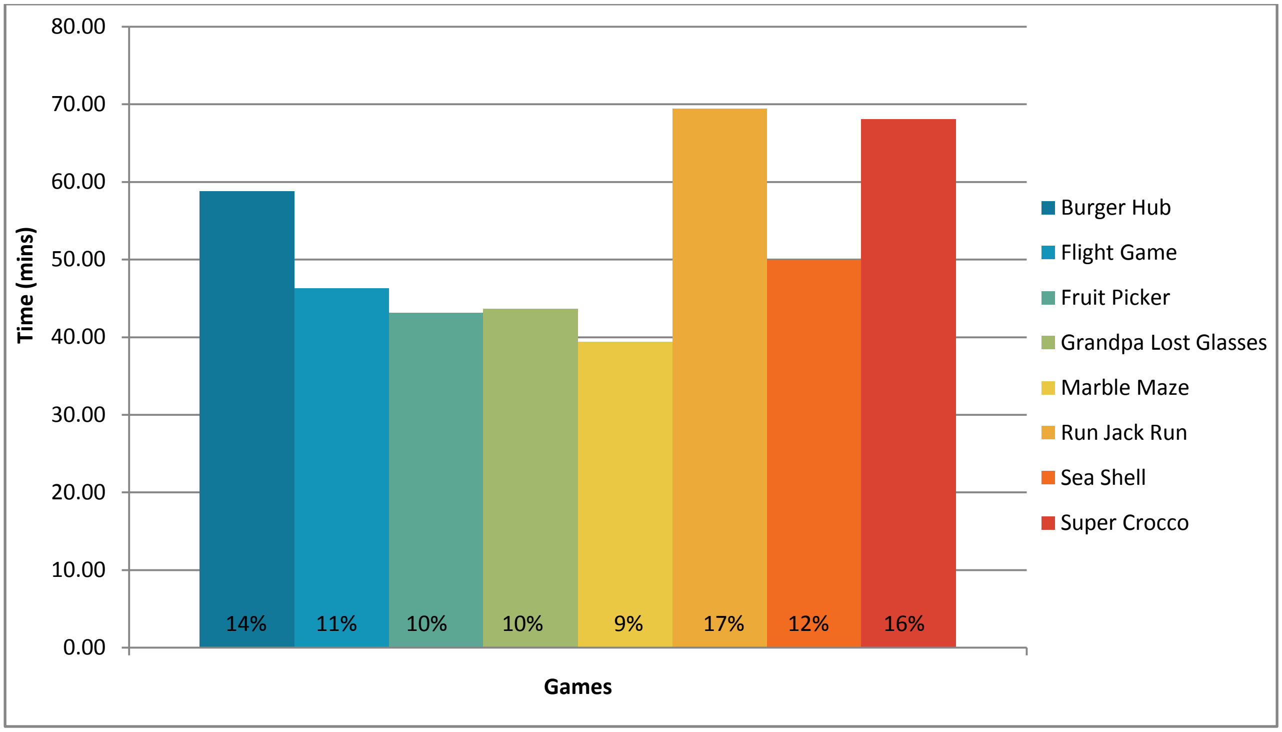


Figure 9-25 - Total duration of the games played during the 6 weeks training period

Figure 9-26 shows the total duration of each game played per week of the training period. It is seen that the total duration of training decreases as the patient progresses through the training.

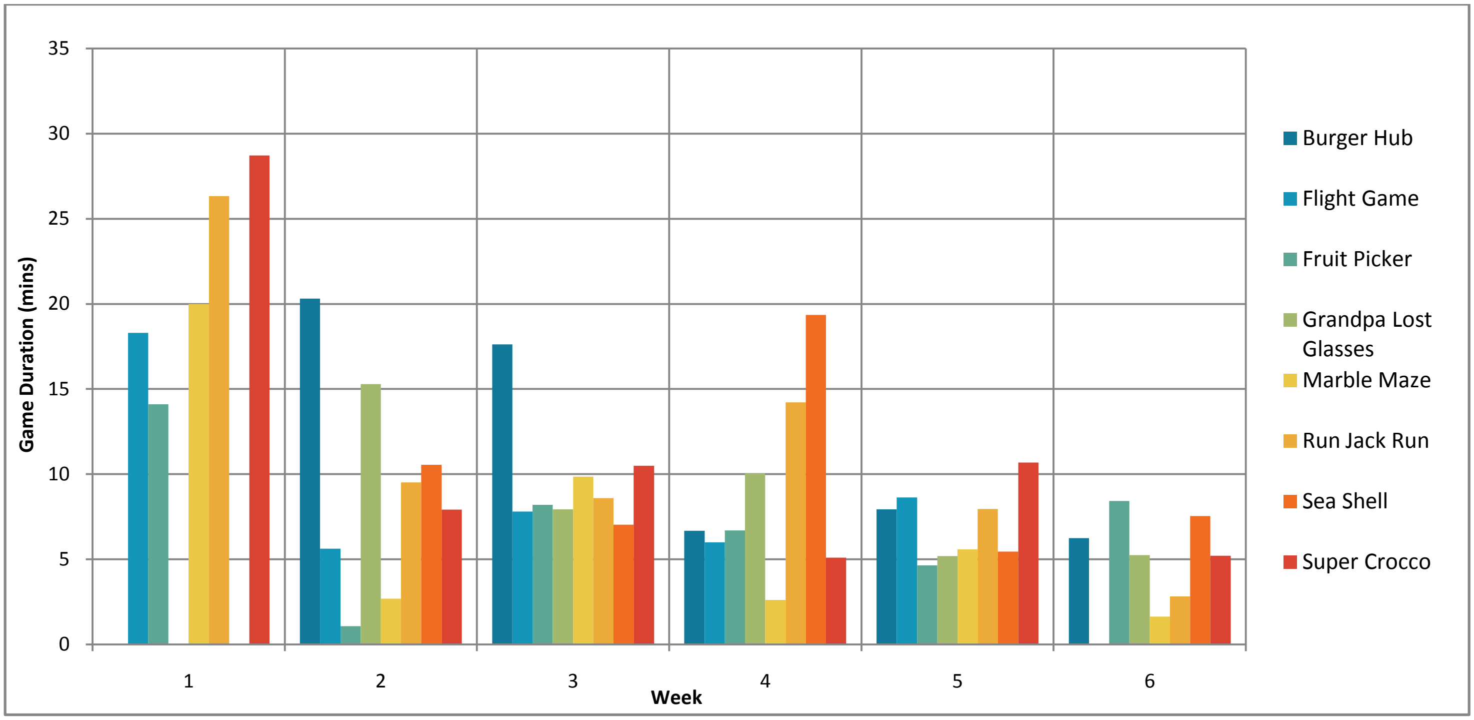


Figure 9-26 - Total duration of the games played per week of the training period

9.4.2.6. GAME PERFORMANCE IN COMPARISON TO OTHER GAMES

To measure the performance of the patient within each game, the game logs were also recorded. Figure 9-27 presents the performance statistics of each game showing the score/min achieved per week of the training period.

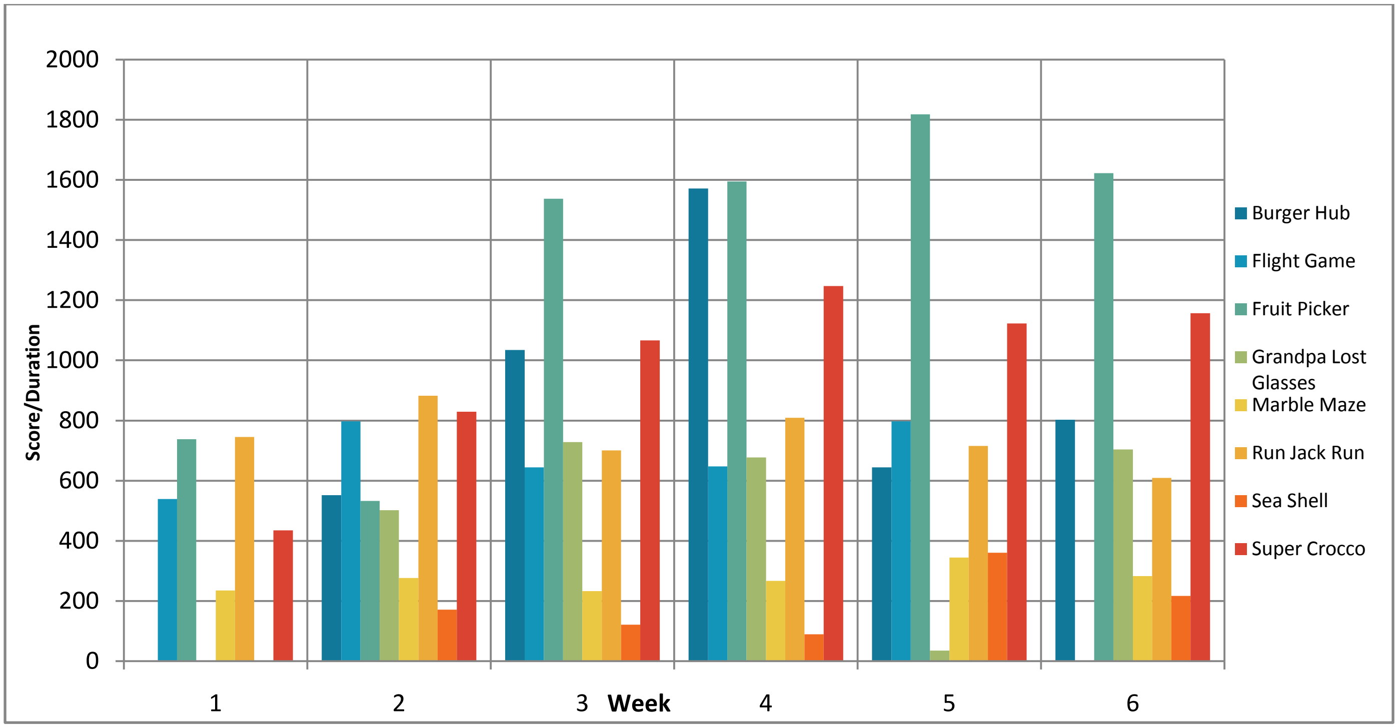


Figure 9-27 - Score/min achieved in games per week

The results show that the patient's best performance was achieved in the Fruit Picker game achieving an average of 1115/min per week with the best performance in the fifth week scoring 1818/min. The second best performance was recorded in the Burger Hub game with an average score of 880/min per week, with a maximum of 1572/min in the fourth week. In Super Crocco, the patient scored an average of 761/min per week with the maximum score in the fourth week of 1247.5/min. This was followed by the performance in Run Jack Run with an average of 744score/min during the training session with a maximum of 882 score/min in the second week. In the Flight Game, the patient scored 661/min per week on average with the best performance in the second week scoring 798/min. In Grandpa Lost Glasses, the patient achieved 576 score/min with a maximum of 728 score/min in the second week, followed by an average score of 264/min in the Marble Maze game with best performance in 344 score/min. Lastly, the patient performed the least well in the Seashell game with an average of 199 score/min, achieving the highest score/min in Week 5 of the training with 360 score/min.

9.4.2.7. INTERVIEW QUESTIONNAIRES

Figure 9-28 and Figure 9-29 presents the results of the patients' rating of each of the played games recorded at the end of each week of training. Figure 9-28 presents the rating given to each game by the patient based on amusement representing the game's desirability and ability to sustain patient's interest in therapy whereas Figure 9-29 presents the ratings based on the perceived difficulty of each game, depicting the level of difficulty provided by them.

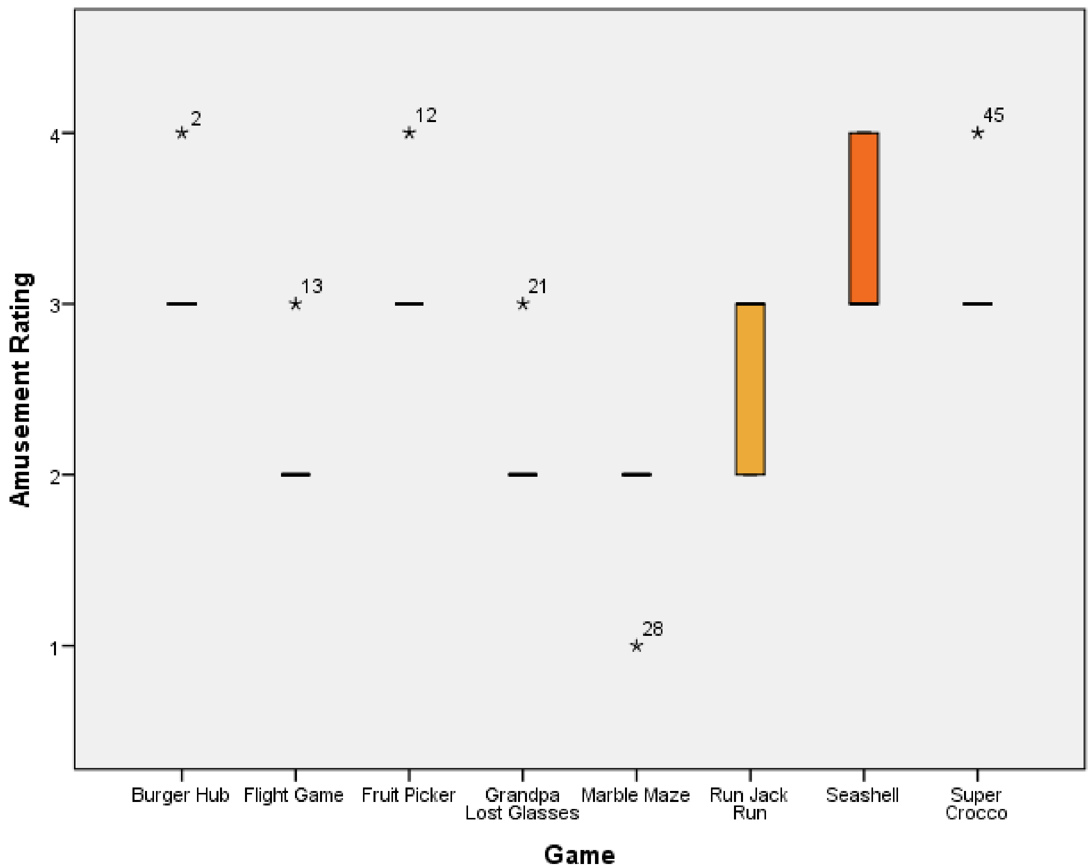


Figure 9-28 - Patient's weekly rating of the played games based on amusement

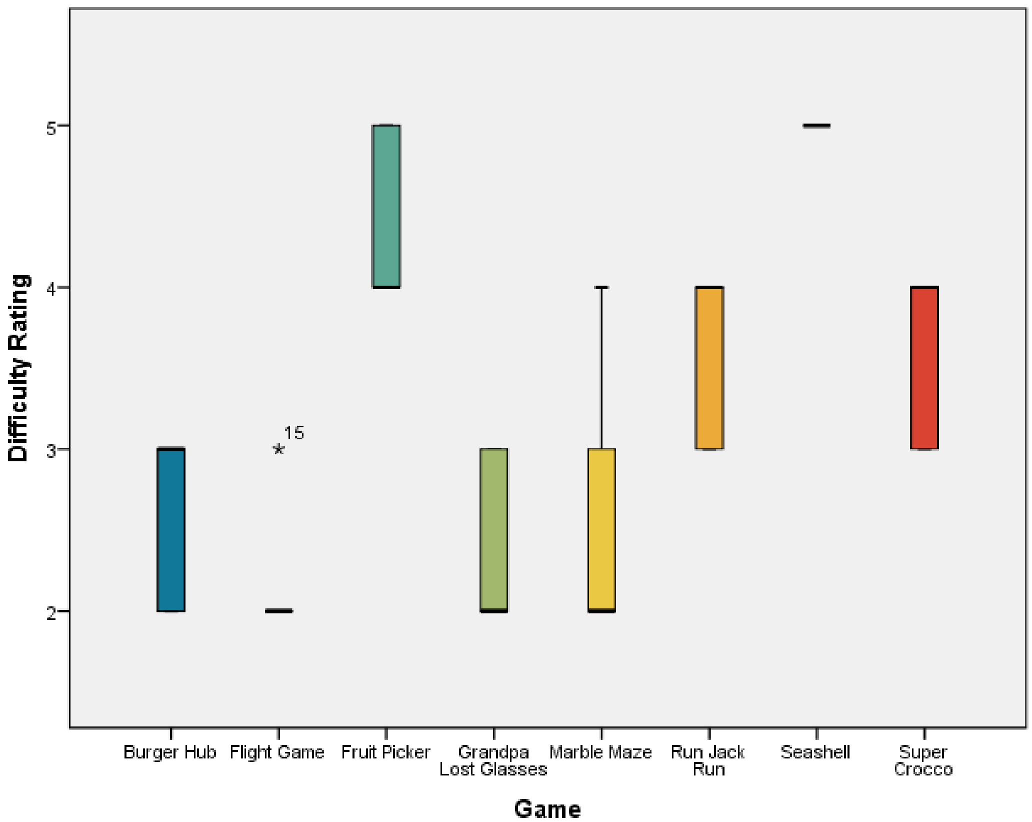


Figure 9-29 - Patient's weekly rating of played games based on difficulty

On the amusement scale, the Burger Hub, Sea Shell, Super Crocco, and the Fruit Picker game were rated with a median score of 3.00. Run Jack Run was rated with a score of 2.50 while Flight Game, Grandpa Lost Glasses, and Marble Maze game were rated with a score of 2.00.

On the difficulty scale, Sea Shell game was rated the least difficult amongst all with a median score of 5.00. This was followed by Fruit Picker and Super Crocco games with a score of 4.00. Run Jack Run was given a score of 3.50 while Burger Hub was rated with a score of 3.00. The Flight Game, Grandpa Lost Glasses, and Marble Maze were all rated somewhat difficult with a median score of 2.00.

Feedback about the games and the system was also collected at the end of each week by the visiting HCP. The feedback specific to games presented in Appendix III identified the concerns and problems faced by the patient during that week's training.

- The patient reported tracking issues making it hard to play in most of the games. Games such as Run Jack Run, Burger Hub, and Grandpa Lost Glasses, and Marble Maze, requiring lateral movement of the arm were reported to be difficult to play since the game would not recognize the movements. This may have been due to limited availability of light in the room.
- The patient also reported the gesture recognition system to be too sensitive in the Flight Game and the Run Jack Run game.
- When performing a grasping gesture, the marker also moved making it harder to perform grasping gestures on a specific location of the screen.
- In the Run Jack Run game, the player found the turning of the character too quick.
- In the Burger Hub, the player had problems grasping ingredients requiring forward and backward movement of the arm.

Furthermore, in order to measure the patient's level of motivation an IMI questionnaire was presented to be filled by the patient at the end of the training period. Figure 9-30 presents the mean scores for the different IMI survey sub-scales depicting the intrinsic motivation of the patient.

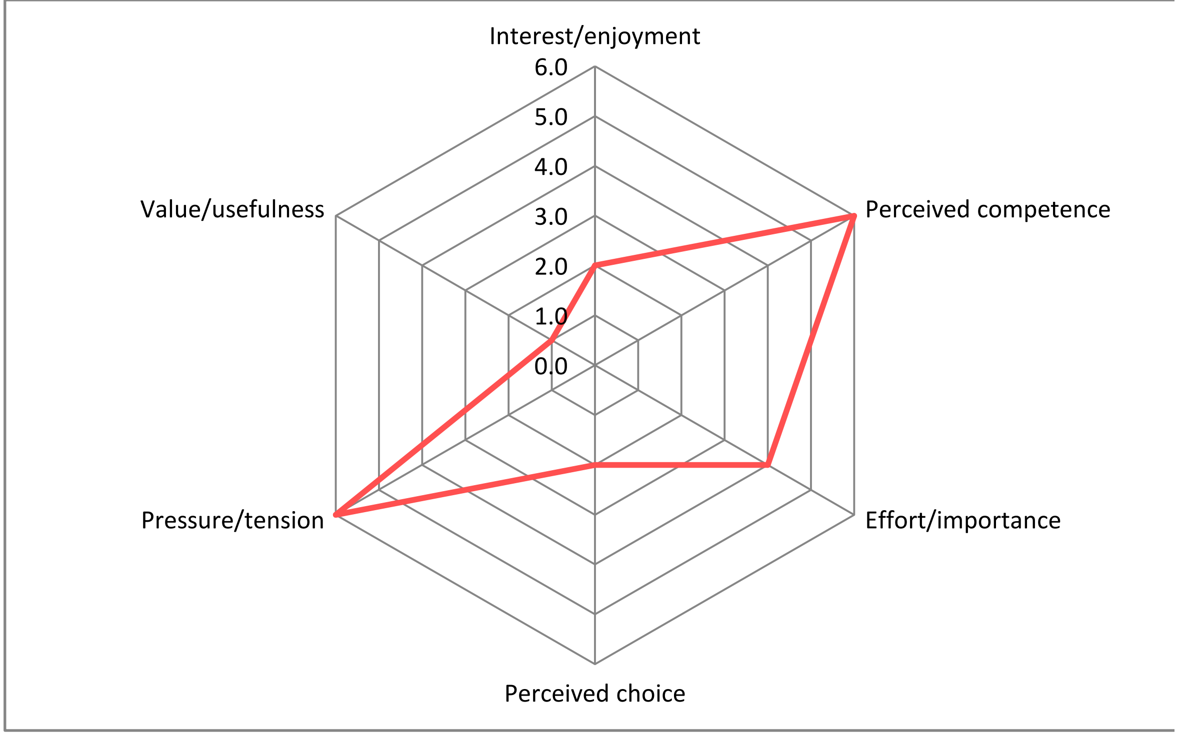


Figure 9-30 - IMI Survey results (median)

9.4.2.8. DISCUSSION

Analysing the results in correlation to each other, we observe the different effects of game design techniques on the patient's motivation, compliance and patient participation. In order to identify the effects of the parameters we look at the results of each of the three different games.

In contrast to the first patient, this patient found the Marble Maze a little boring. This may have been due to the problems with the tracking issue making the game very hard to play. For the game's played sessions, we looked into the paths followed by the marble in each level and observed that the patient actively worked towards collecting the rewards and avoiding the punishments. In order to collect the rewards, the patient often had to deviate from the shortest path to the goal increasing the overall duration of the game and increasing the patient activity. These results suggest that the operant conditioning prolonged the activity and increased patient participation in the exercise.

Amongst the different games provided it can be seen that the Run Jack Run game was played the most during the training period. As the training progressed, more gestures were added resulting in more exercises being practiced. Looking into the scores achieved and the game speeds which are adjusted automatically by the game depending on the patient's performance, we observe that the patient performed well in the game.

The effects of the difficulty balancing parameter can be seen on the difficulty scale representing the level of challenge provided by the game. This suggests that the balancing of the game's difficulty according to the patient's performance can influence the game's perceived difficulty.

Moving on, we looked at the results of the third most played game; Burger Hub. Since the Burger Hub game is based on ADL tasks, the game requires natural movements of the arm and hand. This resulted in higher number of movements per minute and a relatively better performance than the other games. Similar results can be seen in Fruit Picker game. Looking into the performance results, we compare the patient's average performance per week amongst all the games. We observe that the patient performed the best in the Fruit Picker and Burger Hub game. The performance is measured in terms of the score achieved per minute in a game session which relates to the patient's activity during the game. Since both the games; Fruit Picker and Burger Hub, are based on ADL tasks, the games require combination of continuous and gesture based movements, the results suggest that in games based on more natural movements the patients can relate to real life tasks resulting in a higher activity.

Looking into the weekly durations, we observe that the patient focused more on the games requiring hand and arm movements e.g. Runner 1, Burger 2 and Fruit Picker compared to the games requiring wrist. Thus, similar to the results of the Patient 1, we note that the game's influence on prolonged activity is not only dependant on the game itself but also on the movements required to play the games.

In addition to the game design parameters and movement impairments, the training is also affected by the system's usability as the patient reported some technical problems with the system making the games less effective. The patient reported problems with both the hand tracking and wrist movements. The hand tracking seemed to have been affected by the limited availability of light in the room, which caused difficulties playing games requiring lateral movements of the arm. Also, issues with recognition of wrist extension and flexion gestures were also reported for Run Jack Run, Marble Maze, and Super Crocco game which made the games hard to play. These issues may have affected the control of the games affecting the desirability of the games as shown by the interview results.

It is notable that SCRIPT passive systems were customised to each patient's hand size, and that each patient involved in studies reported here used a different hand orthosis due to this customisation. Therefore it is conceivable to have different technical issues affecting access to different games when these are compared between patients.

9.4.3. *PATIENT 3*

9.4.3.1. PATIENT PROFILE

- **Age:** 40
- **Gender:** Male
- **Time since stroke:** 8 months, 3 weeks.
- **Stroke type:** Ischemic/Infarction
- **Affected side:** Left
- **Dominant side:** Right

9.4.3.2. MARBLE MAZE

The patient played the Marble Maze game for 40.55 minutes in total (out of total 443.43 minutes). In the 6 weeks of training, the patient played the game only in the first, third, and sixth week. After the first week of training, the duration decreased and the game was not played consistently.

To measure the patient's activity, we calculated the length of the path followed by the marble in each level. This path length was then summed up to calculate path length for each week of the exercise.

Figure 9-31 presents the duration for which the game is played and the sum of the lengths of the paths taken during each week. It can be seen that as the length of the path increases, the duration of the played time increases.

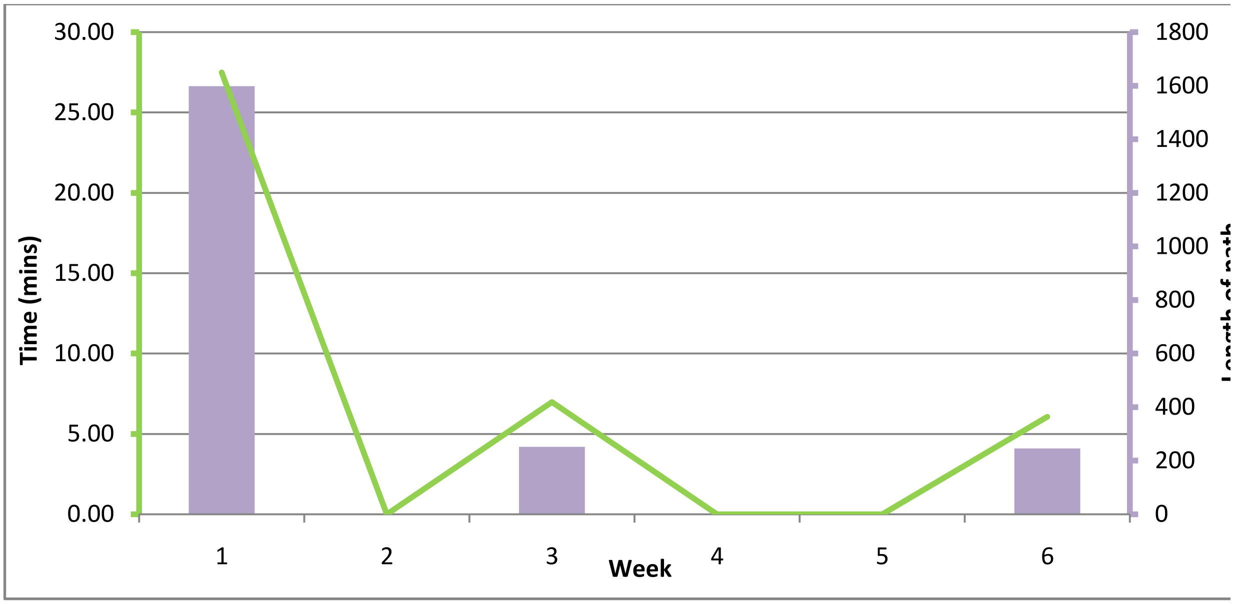


Figure 9-31 - The game play durations of Marble Maze and the sum of lengths of paths followed by the marble per week

Figure 9-32 represents the paths taken by the patient in the first level of the game amongst all sessions. The paths represent the route taken by the patient to reach the goal and the coins collected on the way. It can be seen that the patient, in almost all the sessions, deviates from the shortest path to collect the coins. The figures showing the paths and their lengths for all the levels played in each session are included in Appendix II.

Figure 9-33 presents the length of path covered per minute of the game's duration depicting the patient's performance efficiency.

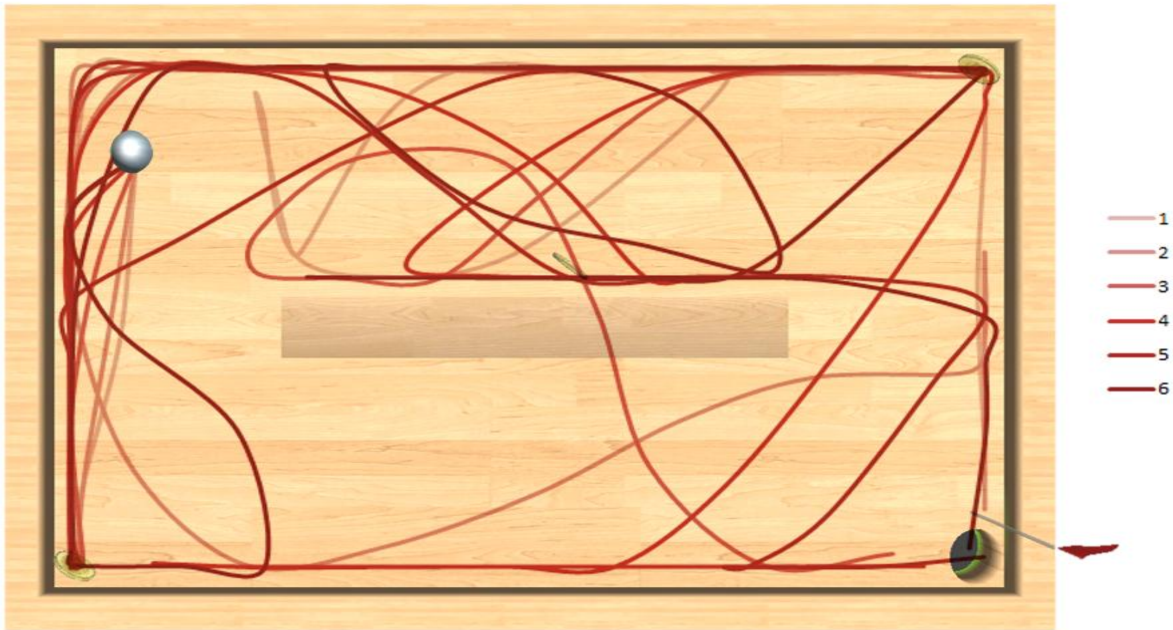


Figure 9-32 - Paths followed by the marble in Level 1 of Marble Maze amongst all the sessions of the game

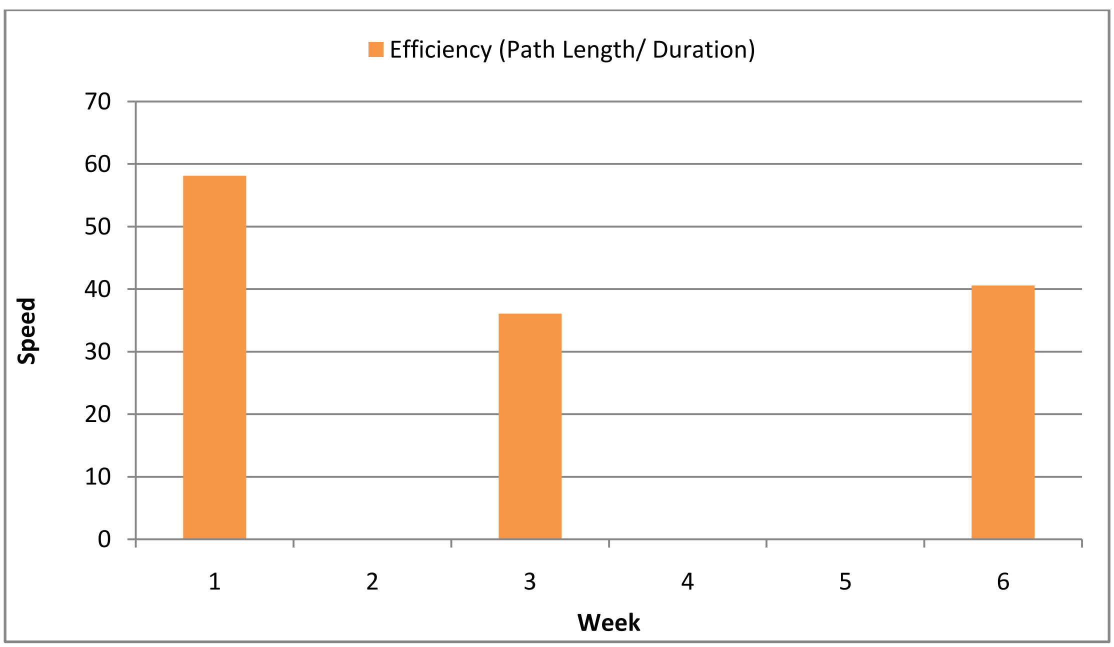


Figure 9-33 - Efficiency of patient's performance in Marble Maze game

[Figure 9-34](#) presents the patient's rating for the Marble Maze's amusement and difficulty in comparison to the duration played per week. On the amusement scale the Marble Maze was rated with a median 2.50 during all the weeks while on the difficulty scale, it was rated with score median of 3.00.

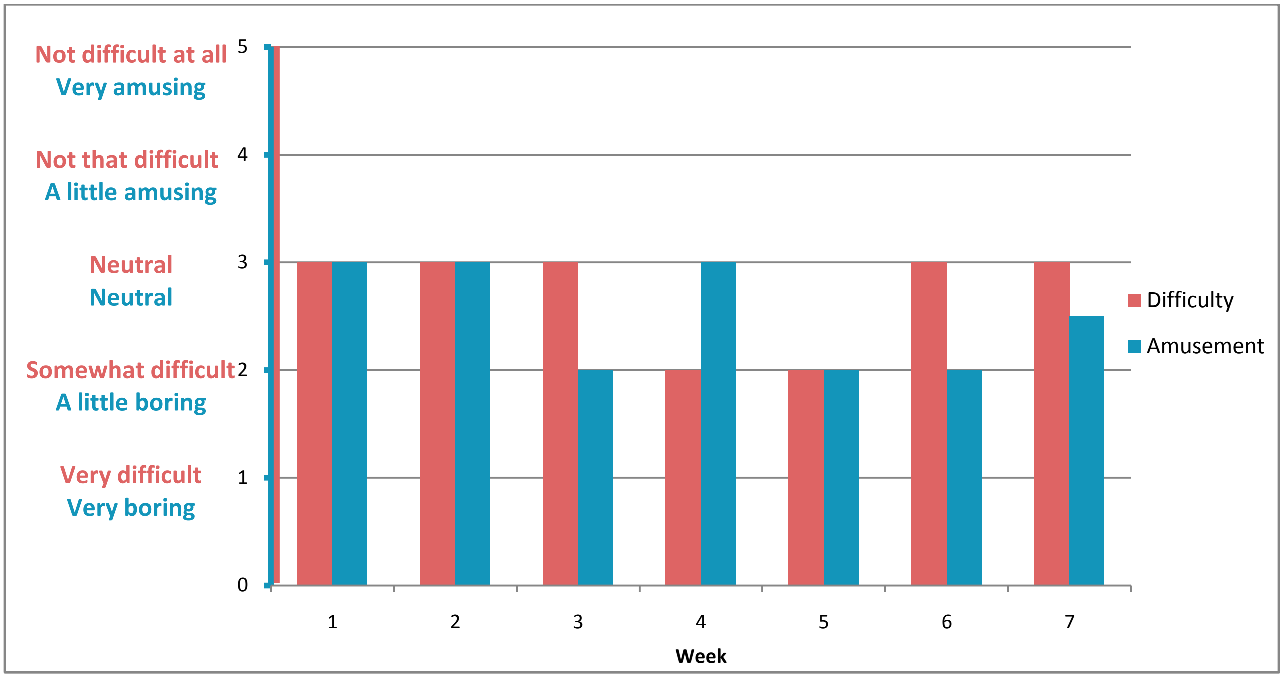


Figure 9-34 - Amusement and difficulty rating of the Marble Maze game per week

The game's amusement and difficulty level may have also been affected by other external factors. In order to identify which, feedback for each individual game was collected at the end of each week regarding the systems' usability, reliability, personal preferences, and the patient's level of impairment. In the feedback presented in Appendix III, patient mentioned that he found the game to be boring and that he had to really think about the movements to perform to make the marble roll in the right direction that's why he didn't play the game much.

9.4.3.3. RUN JACK RUN

Figure 9-35 presents the played duration of the Run Jack Run and the score in the game per week. The figure shows that the game was played for 27.78 minutes in total (out of total 443.43 minutes); played the most in the second week and the least in the fifth week (13.82 minutes and 2.03 minutes, respectively). In the second week, the Runner 1 category of the game was played with lateral movements of the arm and hand grasping gestures. Runner 2 category, with hand grasping and wrist flexion and extension gestures, was played in the third, fifth and sixth week.

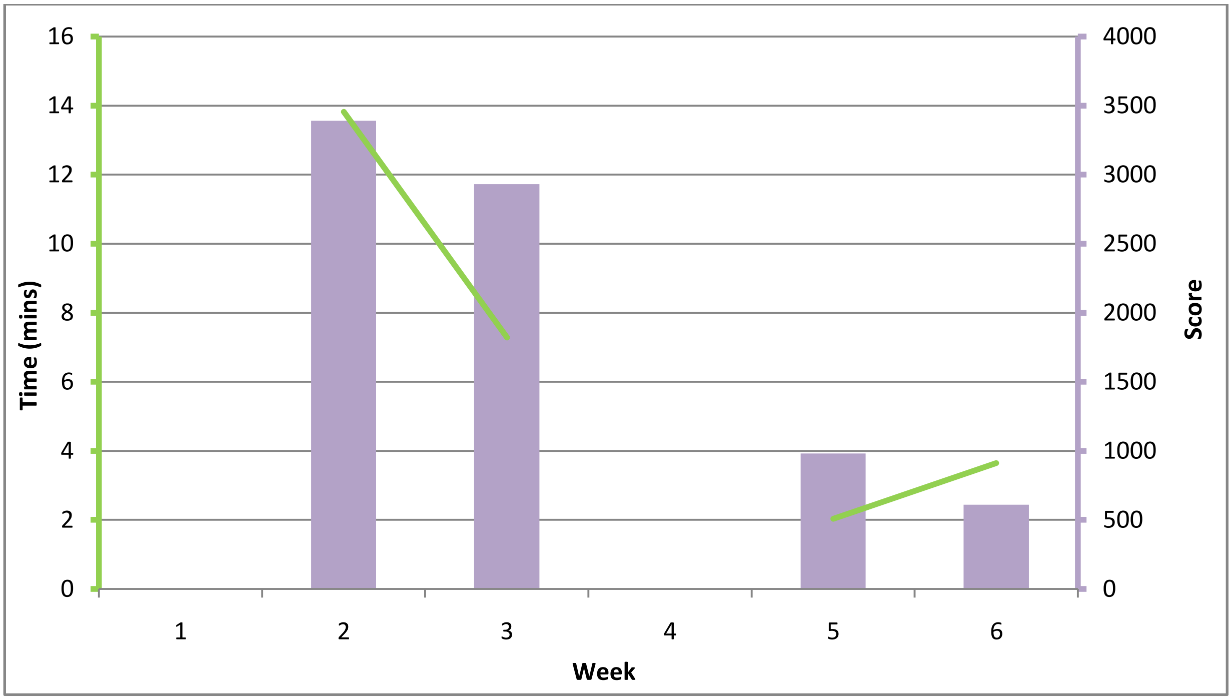


Figure 9-35 – The Run Jack Run game play durations and the score achieved

The dynamic difficulty balancing parameter built in the Run Jack Run game adjusts the difficulty of the game (the speed of the game) according to the patient's performance. The game monitors the patient's performance for each gesture and adjusts the speed of the game when that specific gesture is required according to the performance. Figure 9-36 shows the maximum speed reached for different gestures achieved per week.

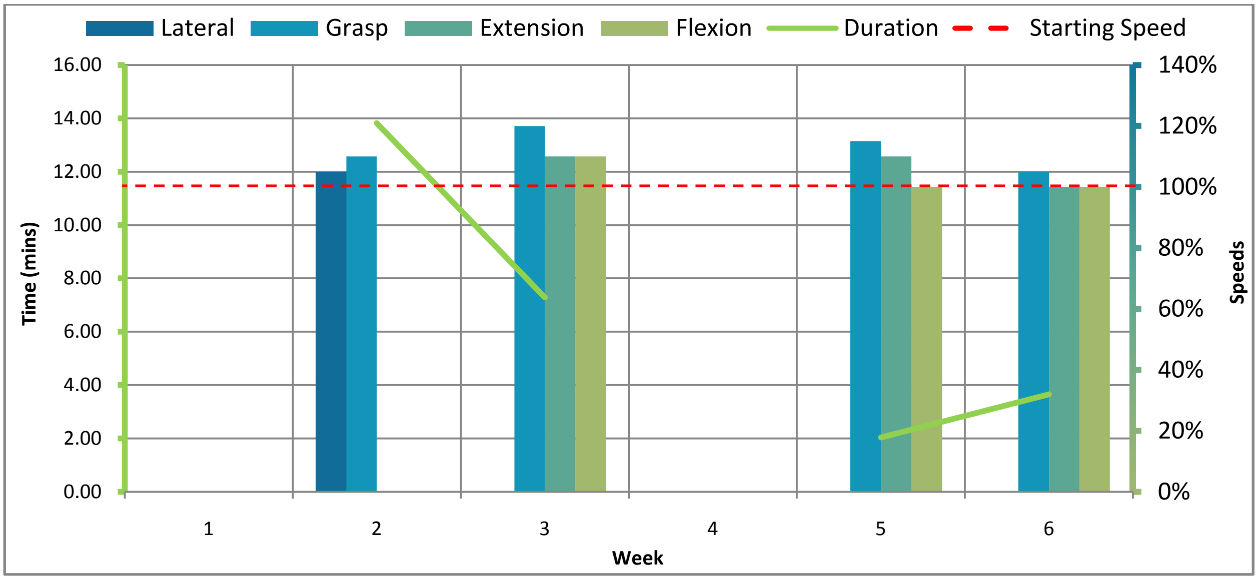


Figure 9-36 – Maximum speeds for different gestures in Run Jack Run and played duration per week

Furthermore, Figure 9-37 presents the qualitative data presenting the ratings of the game on the amusement and the difficulty scale. The results show that the patient found the Runner 2 category of the game introduced in the third week very amusing. Overall, the game received a median score of 4.0 on the amusement scale and 3 on the difficulty scale.

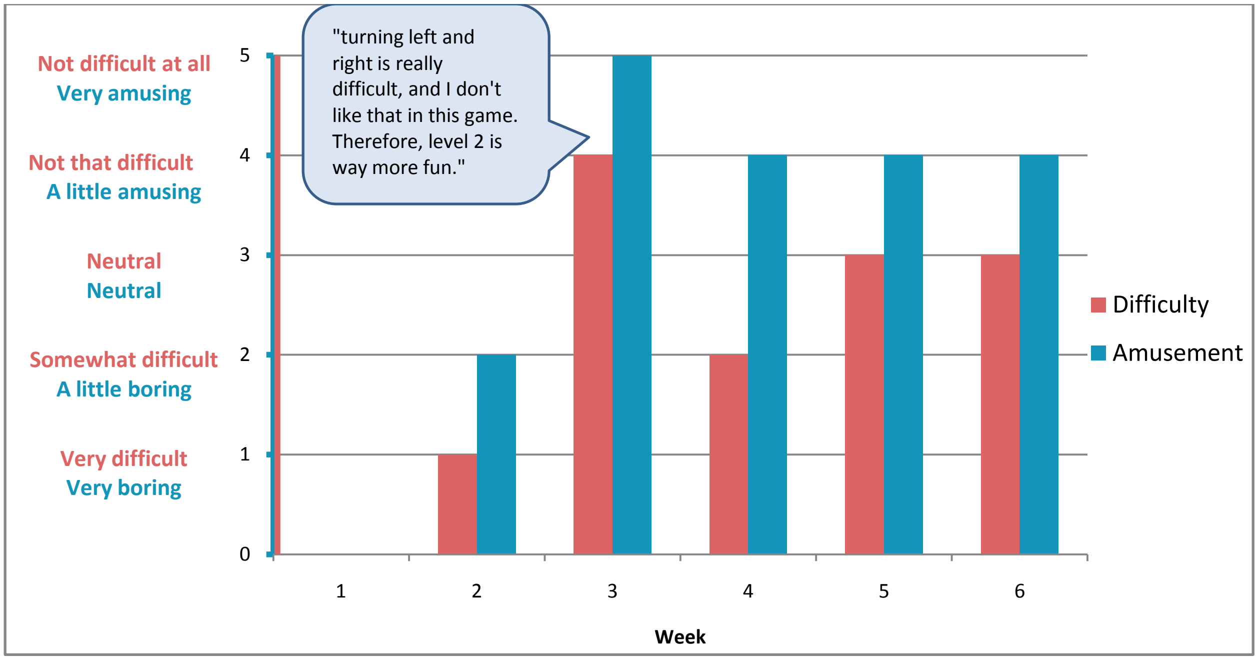


Figure 9-37 - Amusement and difficulty rating of the Run Jack Run game and the game play duration per week

The feedback ratings of the game were also influenced by the technical issues reported by the patient. The patient reported problems with the system's hand tracking making it difficult to make lateral arm movements. Therefore, the patient liked the category with wrist movements a lot more.

Furthermore, in the feedback presented in Appendix III, the patient also reported problems with restarting the game which may have affected the game's play time.

9.4.3.4. BURGER HUB

The Burger Hub was added to the portal by the HCP in the fourth week of the training. The Burger 1 category was played during the fifth and sixth week requiring lateral movements of arm and wrist flexion and extension. The Burger 2 category was played during the fourth and sixth week of the training period requiring lateral movements of the arm, and hand closing and opening gestures to play the game.

Figure 9-38shows the duration of the game played and the score achieved per week. In total, the Burger Hub was played for 46.60 minutes (out of total 443.43 minutes); most in the fourth week and least in the sixth week (6.81 minutes and 6.0 minutes, respectively).

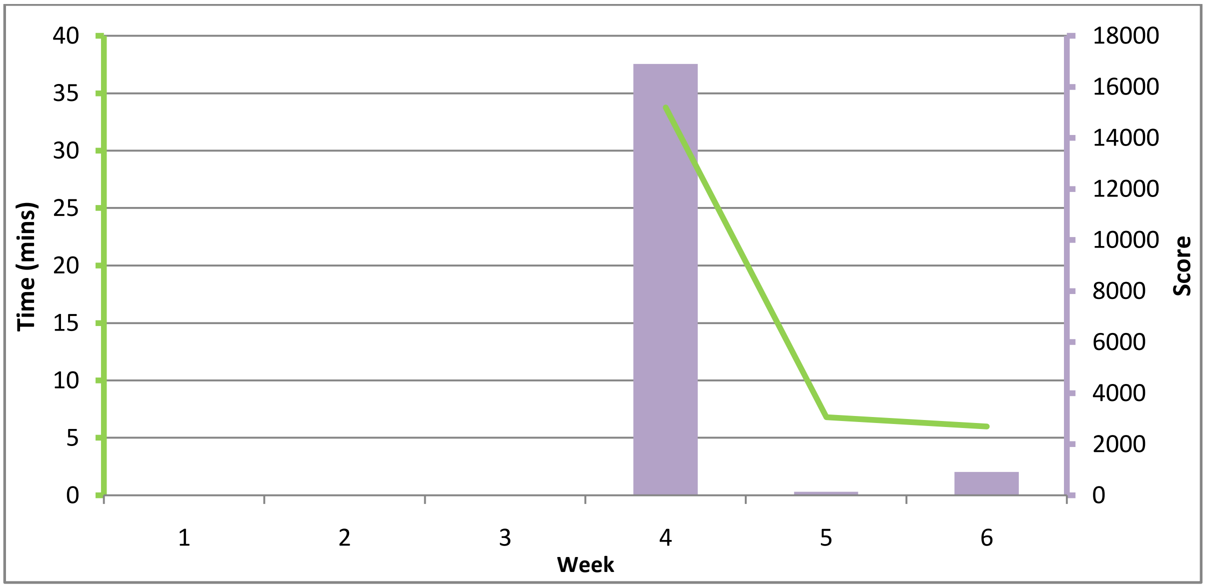


Figure 9-38 - Duration of Burger Hub game played and score achieved per week

Figure 9-39 presents the rating of the Burger Hub game on the amusement and difficulty scale. The game received a score with a median of 4.0 on amusement scale and the 2.0 on the difficulty scale.

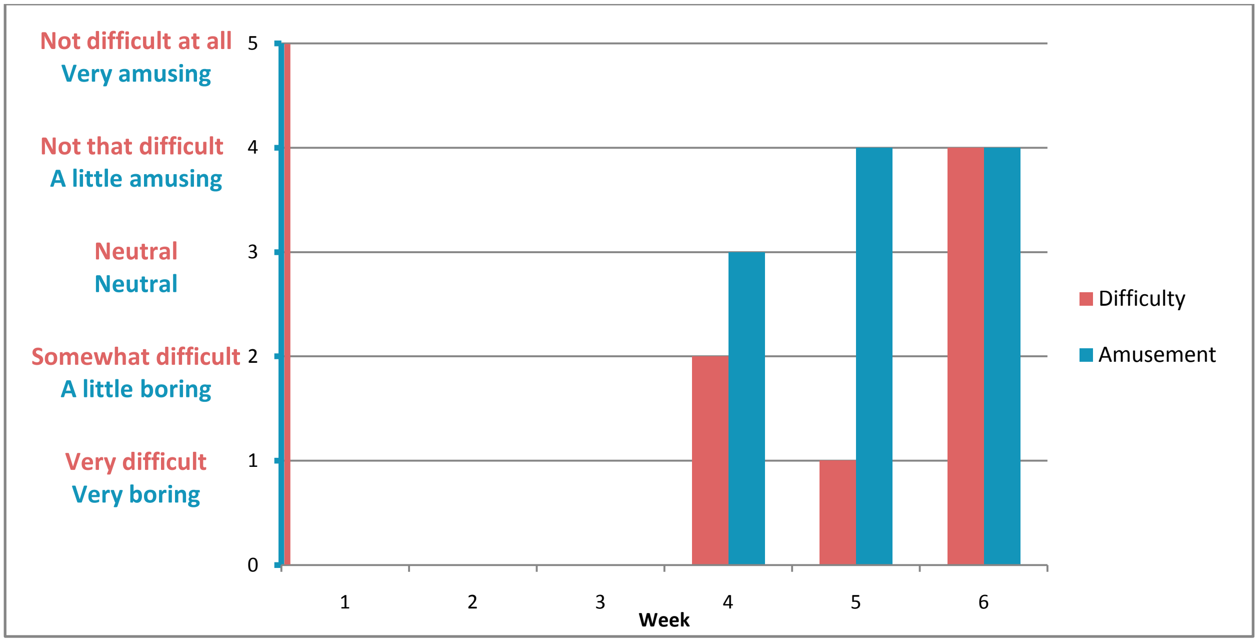


Figure 9-39 - Amusement and difficulty rating of the Burger Hub game and the game play duration per week

In the feedback logs of the game, the patient reported problems with the tracking of the system which made the virtual arm on the screen very jerky making it difficult to control the game. The patient also reported problems in picking up objects requiring forward and backward movements of the arm. In the feedback presented in Appendix III, patient also reported to have found cutting vegetables as very difficult hence found the Burger 2 category a lot more amusing than the Burger 1 category,

9.4.3.5. GAME DURATION IN COMPARISON TO OTHER GAMES

The results show that overall the patient trained using the system for 443.43 minutes during the six-week period with an average of 55.43 minutes of training per week. Figure 9-40 shows the total duration of the games played during the training period. The Super Crocco game was played the most amongst all the games.

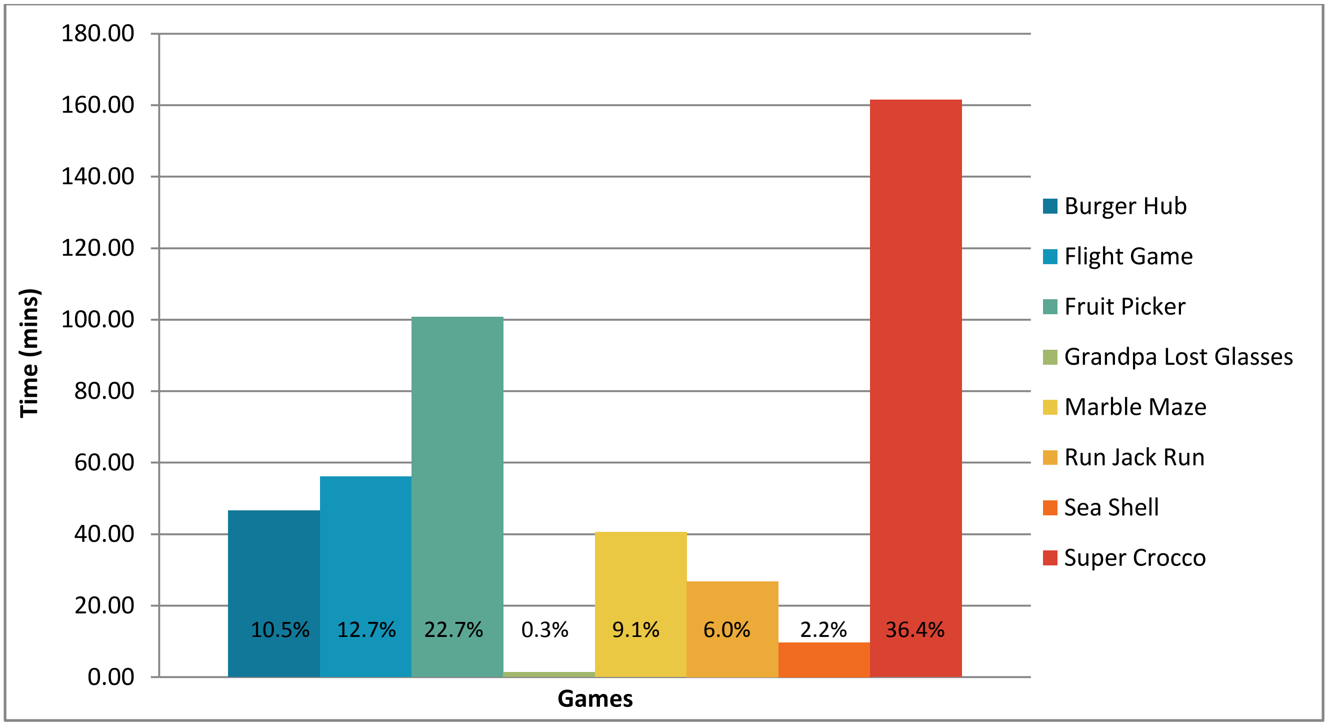


Figure 9-40 - Total duration of the games played during the 6 weeks training period

Figure 9-41 shows the total duration of each game played per week of the training period.

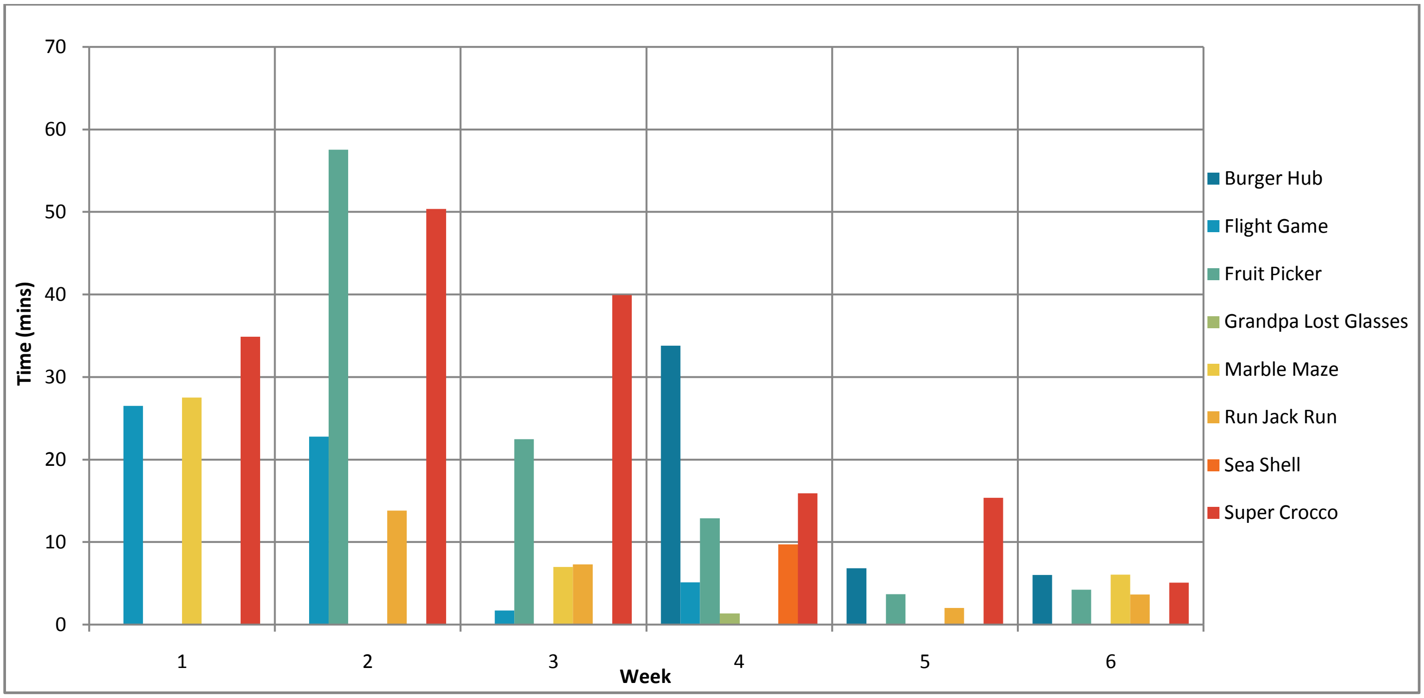


Figure 9-41 - Total duration of the games played per week of the training period

9.4.3.6. GAME PERFORMANCE IN COMPARISON TO OTHER GAMES

Figure 9-42 presents the performance statistics of each game showing the score/min achieved per week of the training period. The score/min parameter identifies the patient's performance in each game during the six weeks.

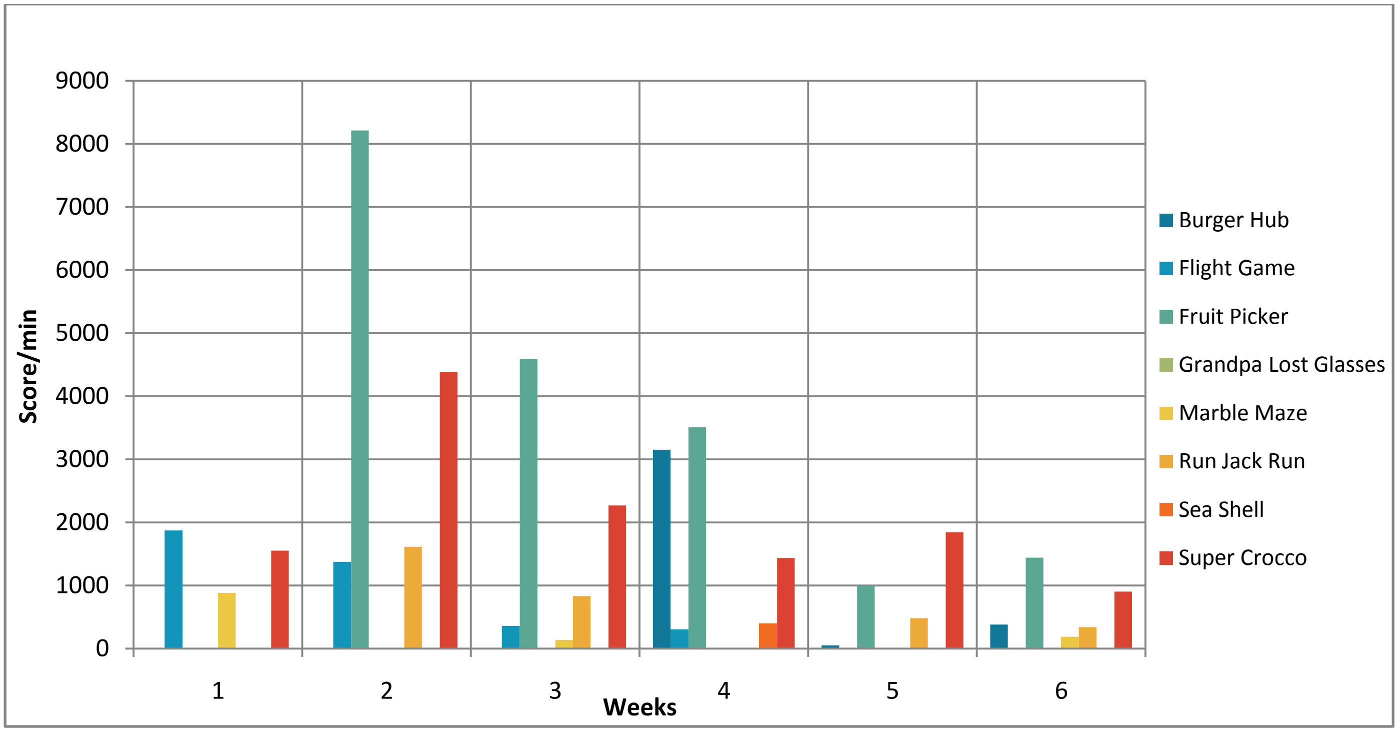


Figure 9-42 - Score/min achieved in games per week

The results show that the patient's best performance was achieved in the Fruit Picker game achieving an average of 3751.37/min per week. This was followed by Super Crocco (2063.67), Burger Hub (1195.17), Flight Game (979.00), Run Jack Run (818.09), Marble Maze (402.63), and Sea Shell game (400.86). The patient did not achieve any score in the Grandpa Lost Glasses game.

9.4.3.7. INTERVIEW QUESTIONNAIRES

The results of the structured interviews are presented in the Figure 9-43 and Figure 9-44. Figure 9-43 presents the ratings given to each game by the patient based on the perceived amusement at the end of each week while Figure 9-44 presents the rating based on perceived difficulty of each game per week.

On the amusement scale the games Run Jack Run, Burger Hub, Fruit Picker, and Super Crocco were all rated as a little amusing with a median score of 4.00. The Marble Maze game was rated with a median score of 2.50, followed by Grandpa Lost Glasses with 2.00, Flight Game with 1.50, and lastly Sea Shell with a median score of 1.00.

On the difficulty scale, the Fruit Picker, Run Jack Run and the Marble Maze game all were rated as neutral with a median score of 3.00. Super Crocco was rated with a score with median 2.50, while Sea Shell, Burger Hub and Flight Game were all rated with a score of 2.00. The Grandpa Lost Glasses game was reported to be very difficult with a median score of 1.00.

In addition to the structured interviews, feedback about each game was collected at the end of each week by the visiting HCP. The feedback specific to games presented in Appendix III identified the concerns and problems faced by the patient during that week's training.

- The patient reported tracking issues making the marker on the screen very jerky which made playing games with lateral movements of the arm, such as Run Jack Run, Fruit Picker, and Burger Hub very hard to play and led to frustration.
- The patient found the burger making level of the Burger Hub a lot more amusing than the cutting level. However, the tracking issues caused the virtual hand on the screen to be very jerky which the patient did not like in the game.
- The Flight Game, Marble Maze, and the Sea Shell game were found to be boring.
- The patient mentioned he liked the Super Crocco game a lot however with the addition of more gestures in the game, the game became very difficult to play as the patient had to really think about which gesture to make to perform the correct action.
- In the Marble Maze game too, the patient had to think about which movement to make to make the marble roll in the right direction making the game hard to play.
- In the Run Jack Run game, the patient reported problems with tracking making turning very difficult. Also, the patient reported issues restarting the game which may have influenced the play time.

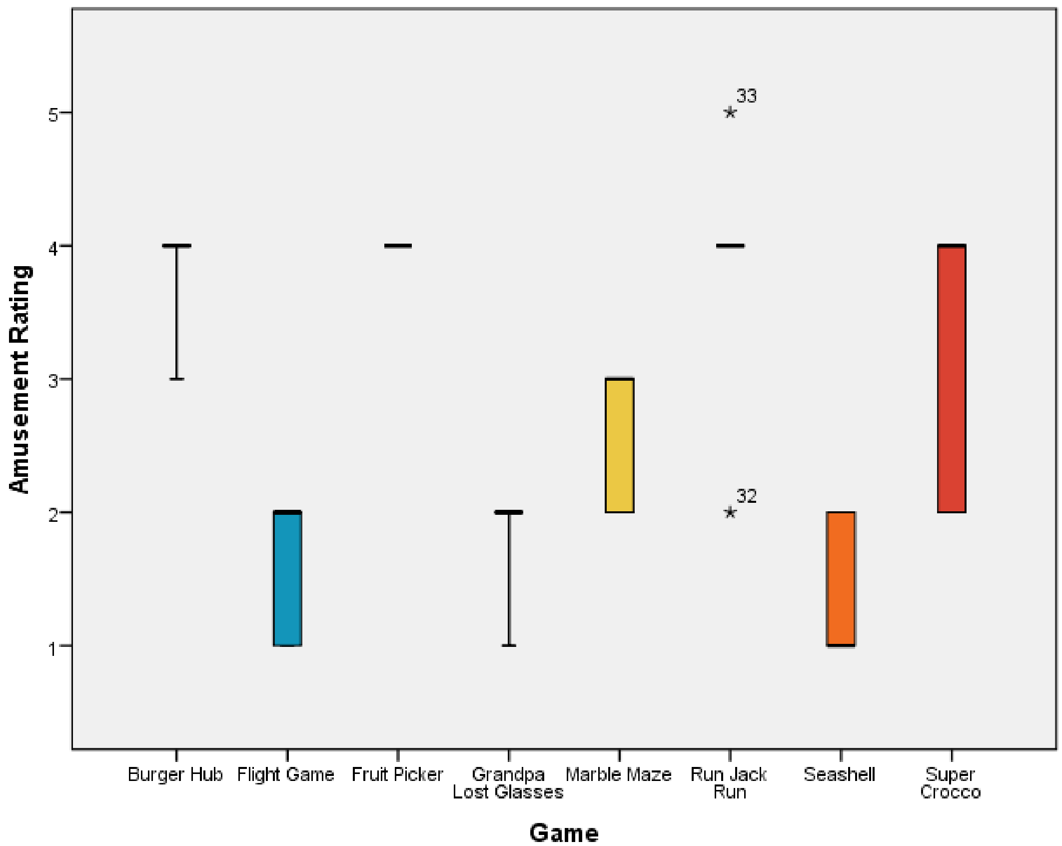


Figure 9-43 - Patient's weekly rating of the played games based on amusement

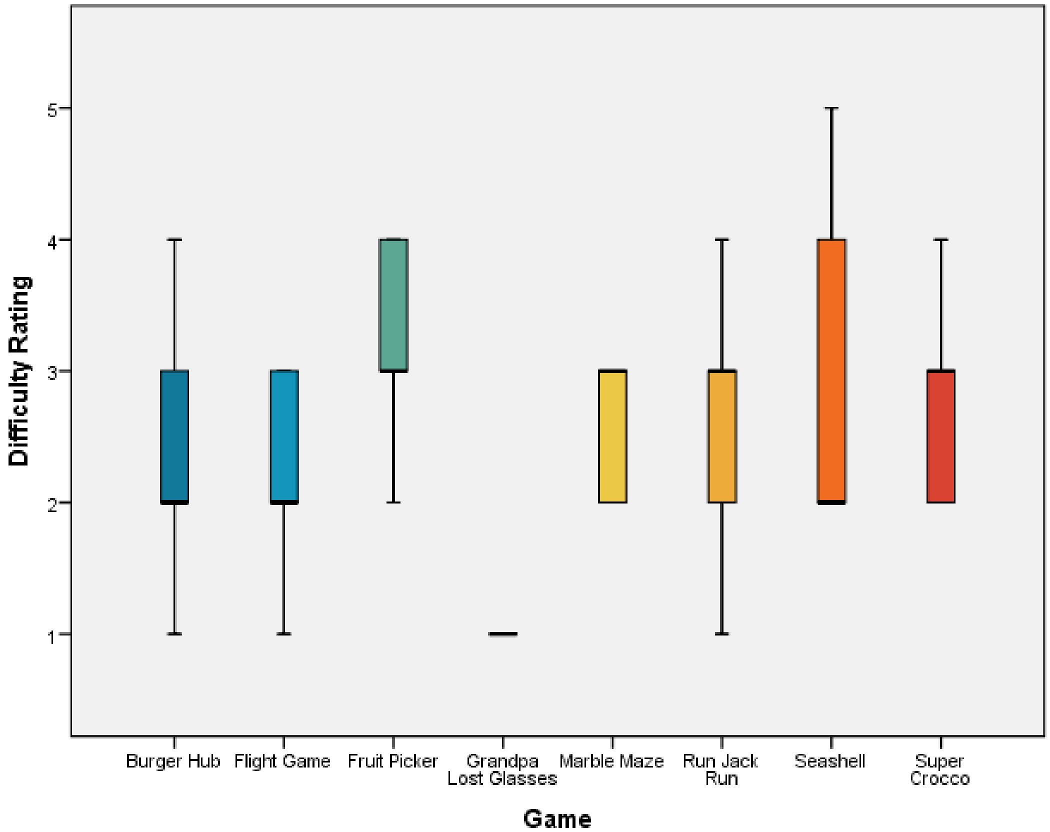


Figure 9-44 - Patient's weekly rating of played games based on difficulty

Furthermore, in order to measure the patient's level of motivation an IMI questionnaire was presented to be filled by the patient at the end of the training period. Figure 9-45 presents the mean scores for the different IMI survey sub-scales depicting the intrinsic motivation of the patient.

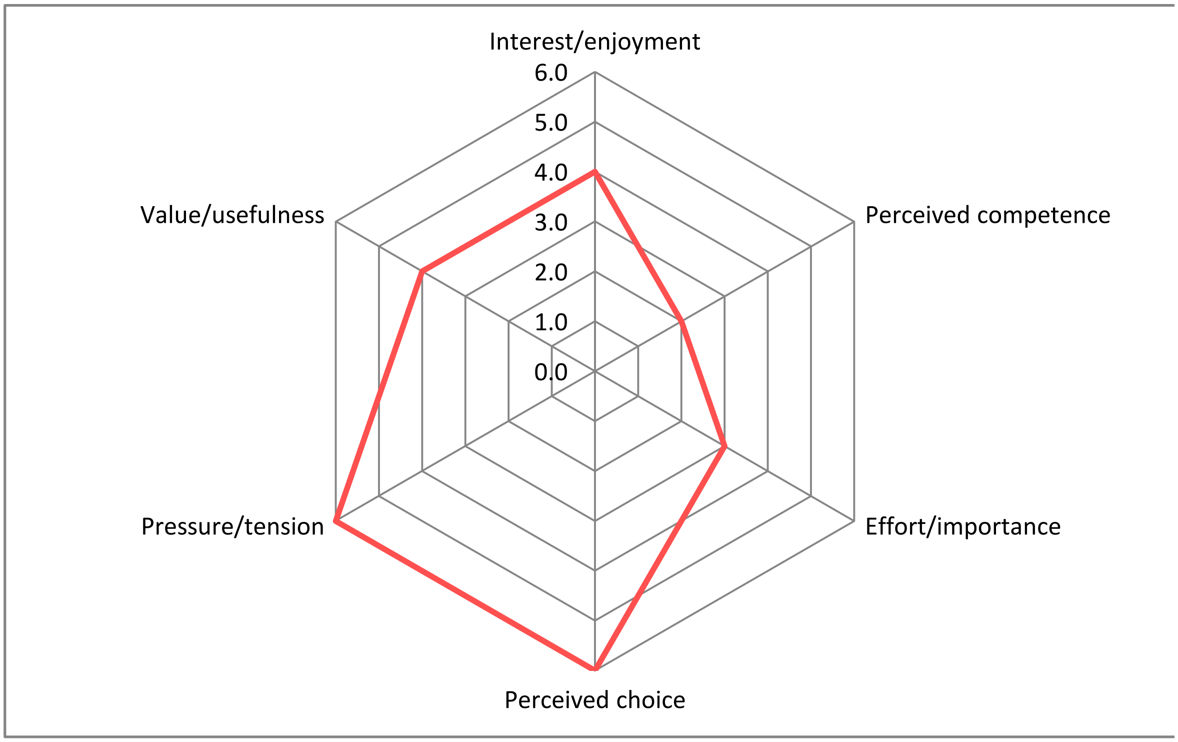


Figure 9-45 - IMI Survey results (median)

9.4.3.8. Discussion

The results presented provide us with an overview of the effects of different game design techniques on patient motivation, compliance, and prolonged activity in a home-based rehabilitation setting. The results show that the different game design techniques can influence the game's desirability promoting engagement and active participation in the rehabilitative exercises.

Analysing the results we observe different effects of the game design parameters. Amongst the various games provided to the patient, the Marble Maze game was reported to be one of the least favourite games of the patient. Due to the patient's level of impairment, the coordinated and fine movements of the wrist and hand required to play the game were found to be too difficult by the patient making it hard to play. However, amongst the sessions of the game played, we observe the patient actively working towards collecting the maximum number of coins and rewards in each level leading to prolonged activity and also active participation by the patient. This supports our hypothesis that the operant conditioning parameter and the scoring parameter prolong the patient's activity and inhibit active participation.

Run Jack Run, on the other hand, despite the technical problem with the system preventing the game to be restarted, was found to be one of the most amusing and least difficult games amongst all. Looking into the patient's performance in the game, we observe that when the patient played the game for long, he achieved higher speeds for each gesture. It was seen that the dynamic difficulty balancing parameter adjusted the game's difficulty level according to the patient's performance making it easier to play, hence the high ratings on the difficulty scale of the interview questionnaire. The results suggest that dynamic difficulty parameter can provide the patient with an optimum level of challenge resulting in higher game desirability.

Moving on, looking at the results of the Burger Hub game, we see that the game was found to be one of the most amusing and least difficult amongst all the games, similar to the Run Jack Run game. The patient found the cutting category of the game difficult to play, hence the burger making category of the game was played more and was found more amusing. Similar to the results of the previous patients, we observed that in games based on the ADL tasks such as Burger Hub and Fruit Picker, the patient achieved a higher score suggesting that games based on simulated ADL tasks promote higher performance.

Furthermore, analysing the results in correlation to each other, we observe that the Super Crocco was the most played game during the training period. Looking at the weekly durations we observed again that there is a novelty period of two weeks after which the total training duration decreases. In addition to this, the decrease in the use of the system is also influenced by systems' usability and reliability. As reported in the feedback log and interview questionnaires, the hand tracking of the system did not function very well making it difficult to play some of the games. This caused frustration and demotivation towards the use of the system. Also, in games with indirect mapping, the cognitive load increased making it difficult for the patient to perform well in the game. This suggests that direct mapping of the controls is important.

9.5. CONCLUSIONS

Analysing the results, we observed the effects of different game parameters on the patients' motivation, performance, and compliance. Although the different characteristics of the patients lead to an inclination in preferences towards different games, they all showed similar response to the in-game parameters. It was observed that the game's desirability is affected by a number of different aspects of the training including personal preference, patient's impairment, competence in performing the game, cognitive challenge, and the overall system's usability.

With all three patients, we observed that there is a novelty period of about two weeks after which we see a dying trend in terms of the use of the system over the weeks. However, the system proved to be useful in providing patients home-based tele-rehabilitation which they lacked without such a system. Also, the durations for which the patients used the systems relied completely on the patient's choice hence we propose that the duration times can be improved if the patients are encouraged to practice more by the therapist. In the case of SCRIPT evaluation, patients were free to practice as long as they wanted with the recommendation of 30 minutes per day, while this recommendation is hardly met frequently by the three patients reported here.

One of the major limitations of the experiment was the small sample size and the lack of control over the experiment. The evaluation of the games was dependent on patient recruitment and availability of customised hand and wrist orthosis for each patient. Once suitable patients were recruited, the availability of a certain game to the patient was dependent on therapist who added the game to the patient portal based on patients' skill level. Some of the games were added in the later weeks of the training period and we had no control over the process of when the games are being played, or what levels are they being set to.

In chapter 8, we presented the formative evaluation which included test of games with healthy subjects using SCRIPT device in assessing system usability. While this was a step to ensure games work with the device efficiently, a home-based experiment faced unanticipated technical errors which made some of the games unplayable due to the overall system failures, some of which have been reported by the feedback, for example tracking issues and data-logging errors. Hence, no control over the device's reliability may also have clouded some of the results.

However, provided that a game was playable, we see that the games had a positive impact on the patient's motivation and the overall use of the system. The Table 9-4 shows the resulting effects by the different parameters of the Marble Maze, Run Jack Run, and Burger Hub games.

As discussed above, the operant conditioning and the scoring parameters put together in Marble Maze increased the sessions' durations as well as the sessions' activity. The effects of operant conditioning in Run Jack Run were influenced by the system's reliability issues while Burger Hub's category with operant conditioning was not played by Patient 1 and 3.

In Run Jack Run, the dynamic difficulty balancing parameter was designed to provide an optimum level of challenge to the patient but the results were influenced by the system's usability and reliability issues.

The Burger Hub's design based on ADL tasks promoted increased motor activity in the sessions.

Table 9-4 - Summary of results of game parameters

Marble Maze						
	Increase Duration by OC-SC (per session)	Sustain compliance (played every week when available)	Increased Motor Activity (collection of rewards/ avoidance of punishment)	Improved performance (weekly)	Amusement (overall median) out of 5	Difficulty (overall median) out of 5
Patient 1	✓	✓	✓	✓	5	4
Patient 2	✓	✓	✓		2	2
Patient 3	✓		✓		2.5	3
Run Jack Run						
	Increase Duration by OC-SC (per session)	Sustain compliance (played every week when available)	Increased Motor Activity (per session)	Improved performance (weekly)	Amusement (overall median) out of 5	Difficulty (overall median) out of 5
Patient 1	affected by impairment & system reliability	✓	✓	✓	3	2
Patient 2	✓ affected by system reliability	✓	✓		2.5	3.5
Patient 3	affected by system reliability		✓		4	3
Burger Hub						
	Increase Duration by OC-SC (per session)	Sustain compliance (played every week when available)	Increased Motor Activity (per session)	Improved performance (weekly)	Amusement (overall median) out of 5	Difficulty (overall median) out of 5
Patient 1	n/a	✓	✓		2	3
Patient 2	✓	✓	✓		3	3
Patient 3	n/a		✓		4	2
*medians calculated using Microsoft Excel						

Overall the table shows support for different parameters evaluated, based on number of achieved objectives, with a small number missed due to technical issues. These are considered within chapter 10, alongside future work and potential improvements that might address some of the limitations of this work.

10. CONCLUSIONS

This chapter presents the conclusions drawn from the studies carried out in this research. The chapter highlights our major achievements including (i) the identification of key game design parameters and a proposal of framework to catalogue rehabilitation games based on these parameters, (ii) game design and formative evaluation of designed games with healthy subjects and people recovering from stroke, and (iii) the research outcomes from the use of these games in patient's home, during a 6 weeks clinical evaluation. The chapter also presents suggestions for the future direction of research.

10.1. Review of Work Done and Research Questions

This section briefly summarises the work done during the research to address the research questions and how the findings from these studies answer them. The research questions set prior to the studies are re-presented below:

RQ1. Can the game design parameters used in commercial games affect the motivation of healthy players, their performance, and sustain prolonged activity within a set of rehabilitation games?

RQ2. Do game design techniques and parameters affect rehabilitation games' desirability influencing motivation of stroke patients undergoing therapy, increasing compliance and activity, prolonging duration, and sustaining interest?

10.1.1. Literature Review

Following our research on the background of stroke, its effects and different stroke rehabilitation techniques, we identified a need for an augmented therapy to provide stroke survivors a more engaging and motivating environment for therapy. As video games have been associated with high user engagement, we followed the path of creating rehabilitation games specifically for stroke patients which could be used to influence patient motivation towards actively participating in their therapy. In order to do so, we looked in to different game design techniques and identified the key design parameters used in commercial games in order to attract and engage players. We hypothesized that by incorporating these game design parameters in rehabilitation games we can make the therapy more fun and engage stroke patients into actively participating in their exercise regimes.

To further strengthen our analysis, we conducted a literature review of different studies using rehabilitation games for upper-limb stroke therapy in order to identify the extent of developments in the field and to observe the effects of these game parameters. To our findings we observed that many of the games used these studies use no or minimum game design techniques, or have not reported their use as they focus more on the hardware aspects of the platform for which the games were designed for. Furthermore, we identified that although some commercially available games could be used for rehabilitation, using an interface that makes them usable for patients, they lack some of the important parameters. These parameters, important for rehabilitative purposes, include lack of feedback on movements, customizability within the game or dynamic difficulty balancing. To address some of these issues, we proposed a framework through which rehabilitation game developers can catalogue and document their games' design allowing understanding of the effectiveness of these parameters with regards to rehabilitation therapy. Below is an example of the framework describing the designed games:

Game Description	**Designed for:**	**Movements**
Marble Maze: Player has to solve the puzzle and roll the marble to the goal location	Upper-limb stroke rehabilitation	Continuous hand lateral movement. Continuous wrist flexion/extension.

Hardware	**Genre**	**Movement Calibration**	**No. of Levels**	**Scoring**	**Rewards/ Punishments**	**Feedback**	**Haptics**	**Dynamic Difficulty Balancing**	**Multiplayer option**
SCRIPT System	Puzzle	Yes	15	Yes	Yes	Audio/Visual	No	No	No

Game Description	**Designed for:**	**Movements**
Run Jack Run: Player has to guide the avatar on a path avoiding obstacles	Upper-limb stroke rehabilitation	Gesture based hand lateral movement Gesture based wrist-flexion/extension

		Gesture based hand grasp/release

Hardware	Genre	Movement Calibration	No. of Levels	Scoring	Rewards/ Punishments	Feedback	Haptics	Dynamic Difficulty Balancing	Multiplayer option
SCRIPT System	Platformer	Yes	Infinite	Yes	Yes	Audio/Visual	No	Yes	No

Game Description	Designed for:	Movements
Burger Hub: Player has to make burger and prepare ingredients in order to run a café.	Upper-limb stroke rehabilitation	Continuous based hand lateral movement Gesture based wrist-flexion/extension Gesture based hand grasp/release

Hardware	Genre	Movement Calibration	No. of Levels	Scoring	Rewards/ Punishments	Feedback	Haptics	Dynamic Difficulty Balancing	Multiplayer option
SCRIPT System	Simulation	Yes	Infinite	Yes	Yes	Audio/Visual	No	No	No

10.1.2. Study I (Addressing RQ 1)

The study aimed to investigate the effects of the identified game design parameters on player motivation and how they can be used to influence prolonged activity without compromising on player enjoyment. The study was based on game designing with these parameters incorporated. The methodology was initially tested during a pilot study with limited number of participants followed by a main experiment.

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10.1.2.1. Pilot Study

The goal of the pilot study was to carry out a formative evaluation of the game identifying any playability issues with the design and the control before moving on to an evaluation with a larger number of participants. The results showed a positive influence of the parameters on the player motivation while also identified some minor usability issues with the game which were addressed by modifying the game's design and appearance.

10.1.2.2. Experiment I

The objective of this study was to test some of the key game design parameters and investigate their effects on player motivation, enjoyment and game play times. The experiment protocol was designed to test the game, played using the Phantom OMNI device, with and without these parameters analysing their effects through IMI questionnaires and player performance data collected. The results obtained from this study suggested that addition of a combination of both, operant conditioning as well as scoring parameter, results in higher motivational scores and influenced prolonged activity.

10.1.3. Study II

Following the formative evaluation of the game parameters with healthy subjects, we aimed to incorporate the parameters in rehabilitation games to create a motivating home-based rehabilitation environment to be used by patients. In order to design and develop rehabilitation games suitable for stroke patients with limited motor abilities, we followed the path of using player centric design technique. By involving designers, healthy subjects, stroke patients, formal carers, and health-care professionals in an iterative design process we developed games specifically for stroke patients. In order to make games suitable for stroke subjects, this research was carried out in collaboration with the SCRIPT project. The games were adapted to be used with the SCRIPT device.

This study formatively evaluated these games with healthy subjects and stroke subjects analysing the effectiveness of involving the target user in the design process from the start of the development and test the usability of the games using the SCRIPT device.

By collecting feedback from the patients through qualitative and quantitative data, the results of the study provided an insight of what aspects of game design to focus on to create an optimum rehabilitation platform for stroke patients suitable for home-based therapy. The study showed the games to be playable by stroke patients and ready for the comprehensive evaluation.

10.1.3.1. FORMATIVE EVALUATION WITH HEALTHY SUBJECTS

The resultant games were tested with healthy subjects as part of the formative evaluation. The quantitative results from the experiment supported the our previous findings, showing that that participants actively worked towards collecting the rewards and the challenges put forward by the operant conditioning parameter prolonged the activity. Furthermore, the qualitative results showed high rating in the IMI categories proving the games to be motivational. The results showed that the games were playable using the SCRIPT system and were ready for testing with stroke subjects.

10.1.3.2. FORMATIVE EVALUATION WITH STROKE SUBJECT

The results from the evaluation with the stroke subject proved that the game is playable by players with limited ability while some problems were faced performing actions requiring collaborative movements of wrist and hand. The results also showed similar findings as the healthy subjects where the patient worked actively towards collecting the rewards and despite the punishments built in, the player did not feel frustrated.

Subject to minor changes suggested by the results of the formative evaluations and the feedback from the iterative design process, the games proved to be ready for comprehensive evaluation with a larger number of stroke subjects in home-setting.

10.1.4. *Study III (Addressing RQ2)*

The objective of the study was to examine effects of games in 6 weeks of home-based technology-supported arm/hand training. The study focused on testing the perceived usefulness of games based on different game design parameters in sustaining long-term engagement during therapeutic interaction. The study involved three stroke patients, each of which played the developed games along with the library of different games in the SCRIPT system. The results from the study show that the game's desirability is affected by a number of different aspects of the training including personal preference, patient's impairment, competence in performing the game, cognitive challenge, and the overall system's usability. The study concludes that the potential for introducing rehabilitation games that support specific exercising is significant; despite technological challenges users really enjoyed this element of SCRIPT, specifically the interactive and therapeutic games.

10.2. Main Achievements

Lack of motivation is one of the major reasons post-stroke patients do not complete home exercises as recommended. Our research during this PhD has identified various key design parameters which could create an engaging environment for the patients enhancing their experience with rehabilitation robotic systems. The research shows us that games can be used as more than just a visual representation of the exercise tasks and different parameters can be used to influence player motivation, engaging them into actively participating in their exercises. These design techniques could become a key contributor to the design of experimental set-ups and studies in clinical and home-based settings.

Games designed within this study were formatively evaluated before being used within a pre-defined clinical evaluation within the SCRIPT project. Results from 3 patients from this evaluation provided further evidence on utility and adherence while highlighting other important elements that contribute to patient adherence, mainly technology reliability and ease of use, as well as potential to practice can be preferred choice of games.

10.3. Limitations

Perhaps the biggest limitation of this research was the university's limited access to stroke patients. The early studies conducted during this PhD included participants who willingly volunteered to take part in the experiments. Due to the duration and location constraints, the majority of the participants in our studies belonged to the student community from the University. The studies, therefore, did not benefit from the representation of the participants from a wider spread of age, ability, and background.

In order to gain access to stroke patients, we collaborated with the on-going SCRIPT project which involved adapting the developed games to their system's standards. Since the experiments were carried out by the clinical partners of the project (based in The Netherlands), only in-direct access to the patients was possible (through HCPs). Furthermore, only a limited amount of qualitative data could be collected. Although the collaboration provided us access to the stroke patients, the sample size was still too small for qualitative analysis, this we relied on quantitative analysis instead.

Furthermore, the results from the home-based evaluation highly depended on the usability of the system. Therefore, any technical issues faced with the use of the system may have affected the performance of the patients in the games, thereby affecting the overall motivation of the patients. This was observed prominently with the tracking issues of the system which made it difficult for the patients to perform well in some of the games affecting the amusement/difficulty ratings of the games.

Although by conducting pilot studies and usability evaluation, we had aimed to improve system usability, the nature of stroke with a varying degree of impairment meant that any remaining usability issue with the device could impact the assessment as well as performance of the designed games.

10.4. Future Direction

As the studies during this PhD involving stroke patients had a small sample size, the future work with this research would include continued testing of the games with stroke patients and therapists in order to fully understand the effects of the game parameters on the patient motivation. With a further understanding of how these parameters affect the patients, more of the identified parameters could be incorporated in the games in order to create an optimum gaming solution for stroke rehabilitation. Parameters such as storylines or multiplayer options (as suggested by one of the patients in the Study 3's feedback) involving collaborative/competitive play can be further investigated.

Personal preference towards a certain genre of game also affects the patient's motivation to play that game. It is important to have a wide variety of games of different genres in order to allow patients to choose games of their liking. Most rehabilitation games focus on simpler genres like *Arcade*, *Action-Adventure* and *Sports*. These genres have simpler storylines and are usually based on achieving a highest score. These genres have a high replayability value hence; similar settings in rehabilitation could be used to achieve high compliance. Some simulation games have also been used for rehabilitation purposes. These games present real-life tasks in a virtual environment, and hence can be used to practice physical movements. Other genres like Role-Playing-Games and Adventure games which have more complex storylines and hence are very engaging should also be further explored. Furthermore, the previously defined design parameters can be incorporated with these genres of games to further enhance their effects on motivation of the patients.

With proper documentation of these games, based on the cataloguing framework suggested in this research, an open portal of different rehabilitation games' library can be created with multi-platform compatibility allowing the games to be tested on various systems in order to filter the results influenced by the systems' usability.

Furthermore, in addition to the interview questionnaires and game logs, additional data such as brain EEG (electroencephalography), body temperature, and heart rate of the patient could be collected in order to analyse the emotional state of the patients while playing the game. The data collected in addition to the player’s performance could be used as feedback to control the game parameters making the games adaptable to the player’s emotional as well as physical state.

Operant conditioning, scoring, challenge, and feedback are some of many parameters through which game developers can improve the home-based rehabilitation of stroke patients. A much detailed insight into these parameters is needed to answer as to how these can be implemented and further research with game design techniques can potentially produce rehabilitation games with improved behavioural and health outcomes.

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12. APPENDIX I – FEEDBACK FROM FOCUS GROUPS

12.1. Summary of results of two sessions of cognitive walkthrough with researchers in the Netherlands

Session	Burger Hub	Run Jack Run	Marble Maze
1	**Information is clear**	**Graphics are good**	**Graphics are OK**
	Good functional game	There is no information on the screen labeled information ⇓ All information screens are now complete.	**The game offers a lot of variation**
	Sounds need adjusting, the background music is too soft and the games music too loud ⇓ Re-equalized the volumes	The information provided is shown over images making it difficult to read ⇓ Based on this we avoided overlapping text/graphics, in all the UIs	The arm movements required to control the game are unclear – is it left/right or pronation/ supination? ⇓ At that stage, both were offered, and the UI may have been inconsistent. We chose lateral movements as prone-supination may have been limited by the arm support. It might be difficult for some people to achieve the goals of this game We added 10 easier levels
	Easy to get bored – it would be good to add the option of cutting the food ⇓ We designed, as for other games, three categories, two of which included a cutting level	Game sounds could be louder Volume control is available	The time given to complete each level is not enough Increased to 2 minutes per level
	The correct arm should be shown on screen / The arm shown should reflect the affected arm of the user ⇓ The correct arm is shown, based on the therapist's setting on the portal	**Good that gestures are given on screen when encountering an obstacle – is a reminder**	When the player wins the game needs to be clear – congratulations or applause ⇓ The game goes into pause with a feedback screen congratulating

	It should be possible to pause the game by touching anywhere on the screen ⇓ It is now possible.	**The bar which is counting back helps to ensure a correct gesture**	The exit button does not work in the pause screen – only possible to close the system to close the game ⇓ Software bug now fixed
		Not clear whether game requires arm movements ⇓ We added a tutorial mode with dedicated instructions screen	
		Good game structure – game gets more challenging with increasing levels	
		Person with stroke should be able to play levels 1 and 2 but may get too difficult after this + Game might be too fast for someone with stroke ⇓ We have an online adaptation mechanism which reduces/increases speed in case of failures/successes	
		The number of 'lives' at each level of the game might be reduced from 10 to 5 ⇓ It now starts with 5. Game did not automatically restart after 10 lives were lost ⇓ Software issue, now fixed	
2	**Clear instructions –**	**Games instructions are**	**Clear instructions – know**

	know how to play before starting – this is missing in other games	**very clear**	**how to play before starting -** this is missing in other games
	Suggestion to omit information screens for expert user or only access this information when hitting ‘play demo game’ button ⇓ To be addressed	Suggestion to reconsider how this text is presented for easy reading ⇓ We changed the font in this game to a simpler (Arial).	
		Suggestion to omit information screens for expert user or only access this information when hitting ‘play demo game’ button ⇓ Addressed in this way	Suggestion to omit information screens for expert user or only access this information when hitting ‘play demo game’ button ⇓ To be addressed
		Visualization is good – game is enjoyable	
		The movements used for calibration (left to right arm movement) was not then used in the game Might be better to provide a different order of gestures for playing to include this movement as the most easy and ending with grasping as most difficult ⇓ Gestures are introduced progressively in this game, hence it is possible that in this short demo the part where the lateral movements were required was not reached	

12.2. Summary of results from focus group (USFD, UK) with people with stroke, carers, and HCPs during the design workshop

Session	Burger Hub	Run Jack Run	Marble Maze
1	**Graphics good**	Participant **successfully played** the game and **liked the graphics and** game **sounds** and **enjoyed playing**	Calibration not working
	Confused by 'more information' button	**Information** to play game **was clear**	User did not understand movements required to play the game
	Initially confused by movements required to grab the food and drop onto the bun – needed prompting and then learnt to play		Graphics not clear – confusing
	Thought that 'tips' button would provide further information on how to play the game		

12.3. Summary of results from focus group (RRD, NL) with people with stroke, carers, and HCPs during the design workshop

Session	Burger Hub	Run Jack Run	Marble Maze
1	Patient 1 and Patient 3: Calibration needs improving as screen does not react to arm movements	Patient 1: easy to find correct button and could understand how to play the game. Some instructions not clear - place green marker on the red circle was helped by P3	Patient 2: games instructions and required movements to play initially unclear – should include pronation/ supination Would have liked the inclusion of gasping and finger movements

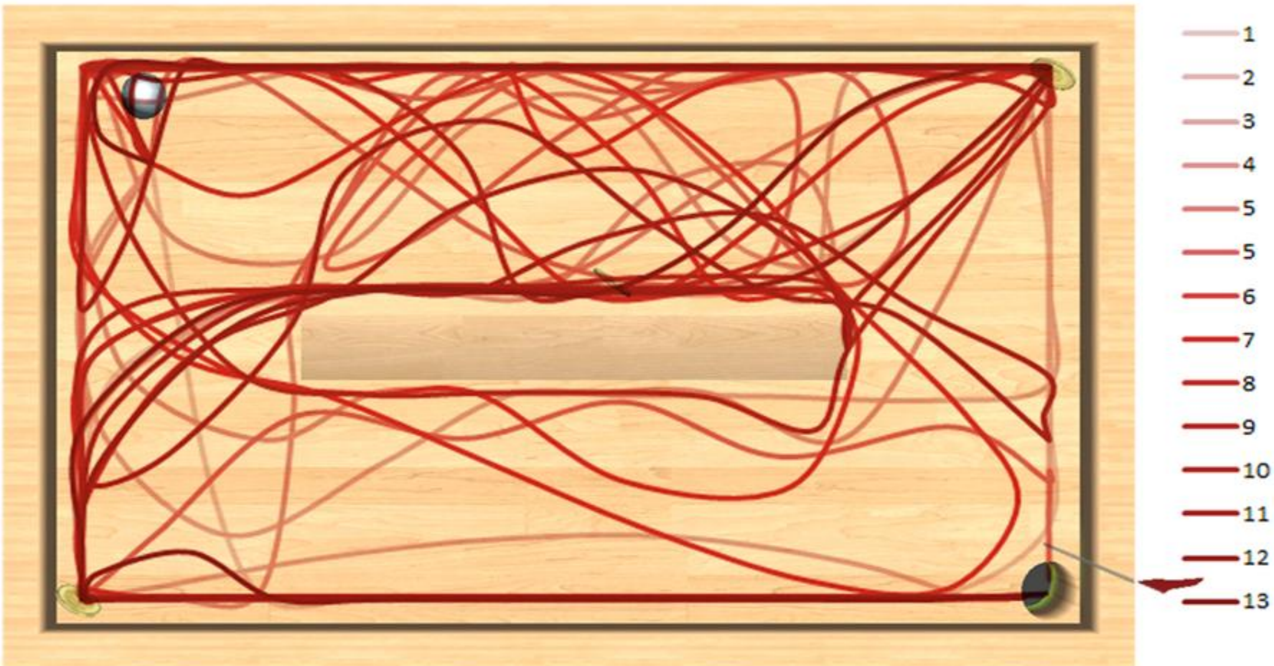
	Pause button should be larger.	Had to be reminded to use affected side to play game	
	Patient 3: Understood required movements but did not achieve tasks on screen when undertaking them	Patient 2: did not respond to playing tips on screen Color contrasts are good - music makes games fun Carer 1 agreed	
	Patient 1: Liked use of color to give feedback		

13. Appendix II – Marble Maze Game Logs

13.1. PATIENT 1

Figure 13-1(a) - Figure 13-11(a) show the paths followed by the marble in each of the level played during different sessions of the training period.

The Figure 13-1(b) - Figure 13-11(b) show the lengths of the paths followed by the marble and the score achieved in each level played during different sessions.



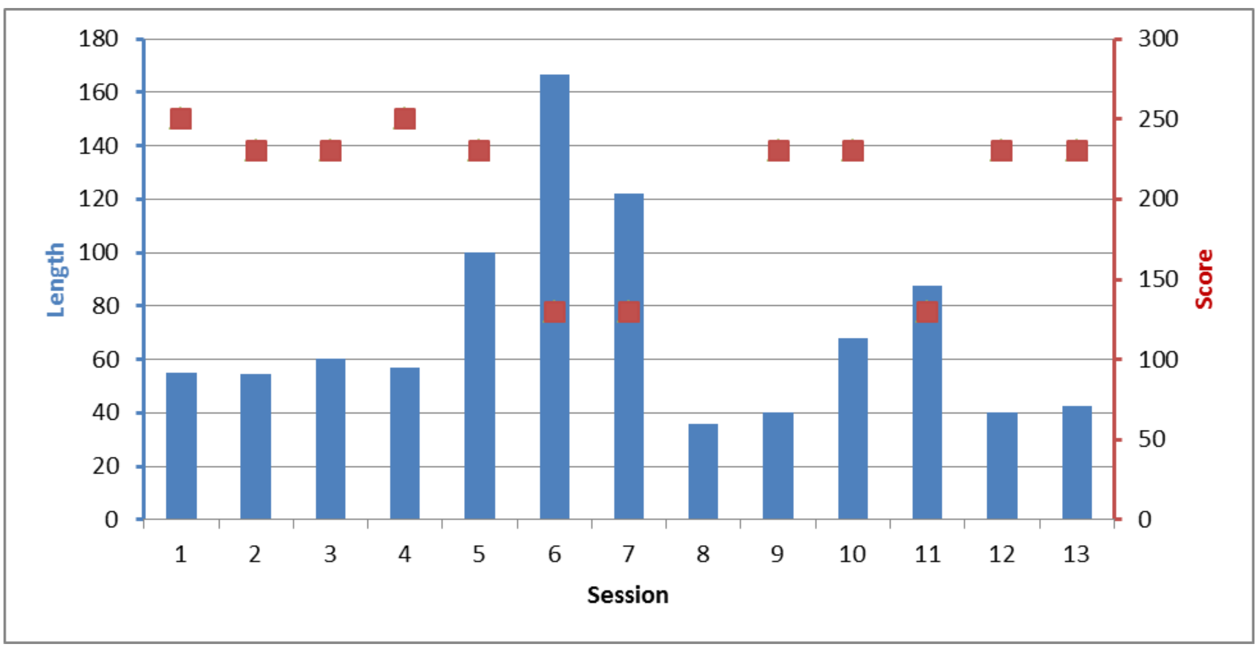


Figure 13-1 (a) Paths of the marble in Level 1 during different training sessions

(b) Lengths of the paths and score achieved in Level 1, during different sessions

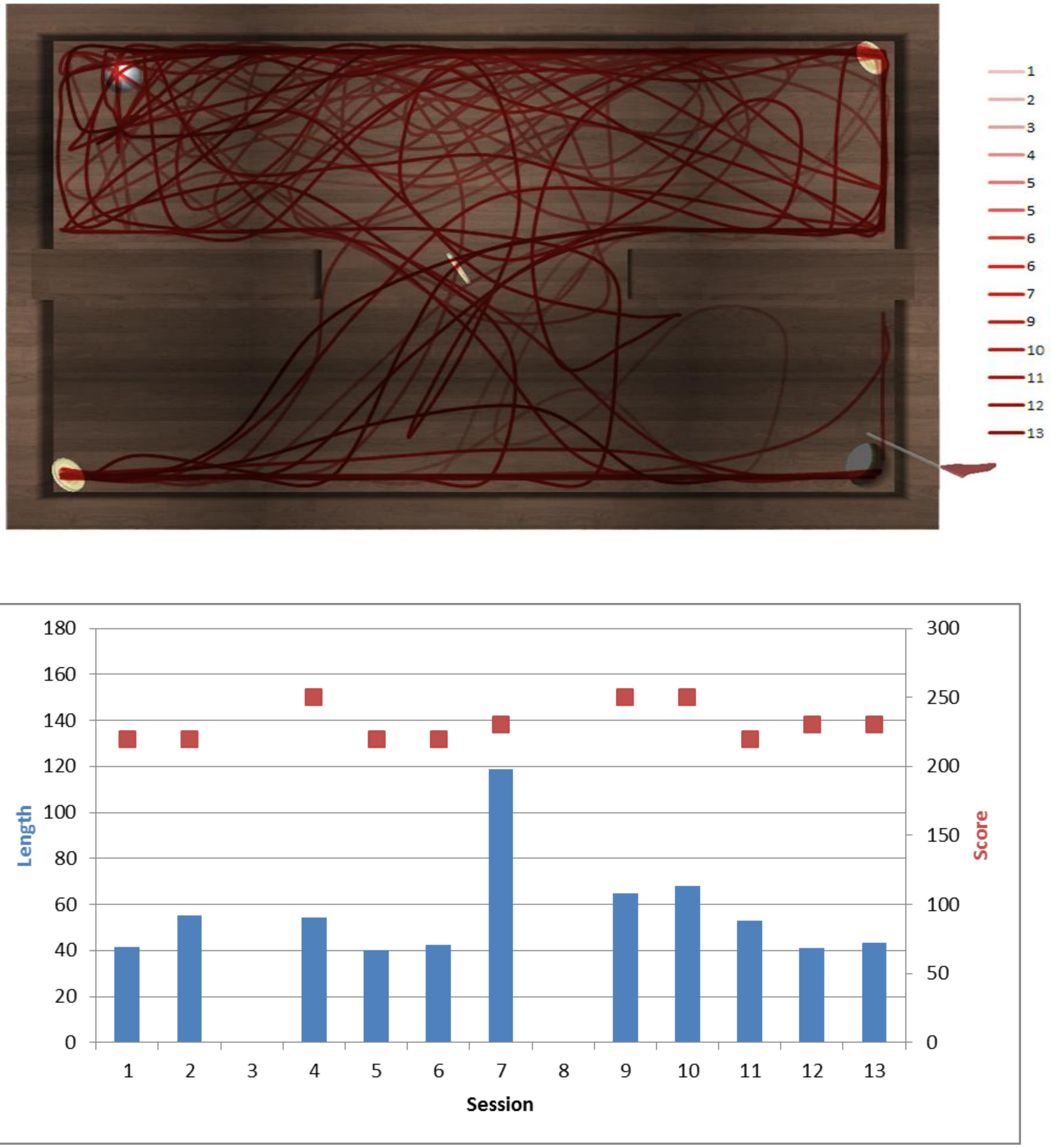
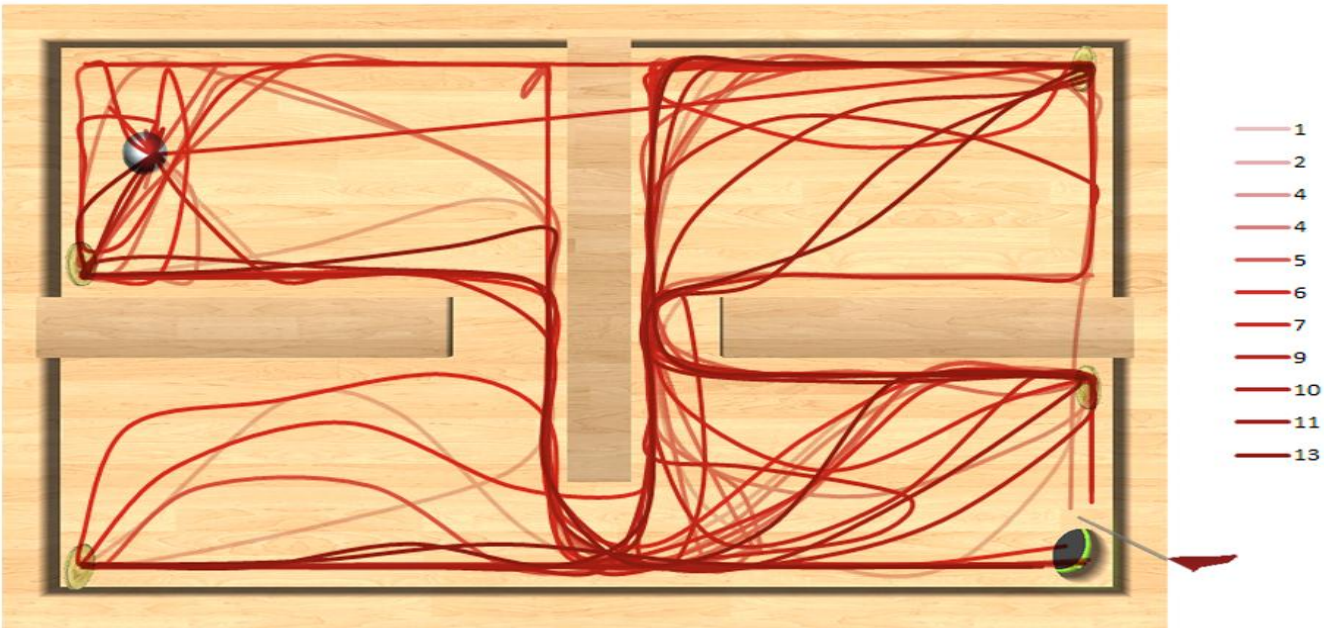


Figure 13-2 (a) Paths of the marble in Level 2 during different training sessions

(b) Lengths of the paths and score achieved in Level 2, during different sessions



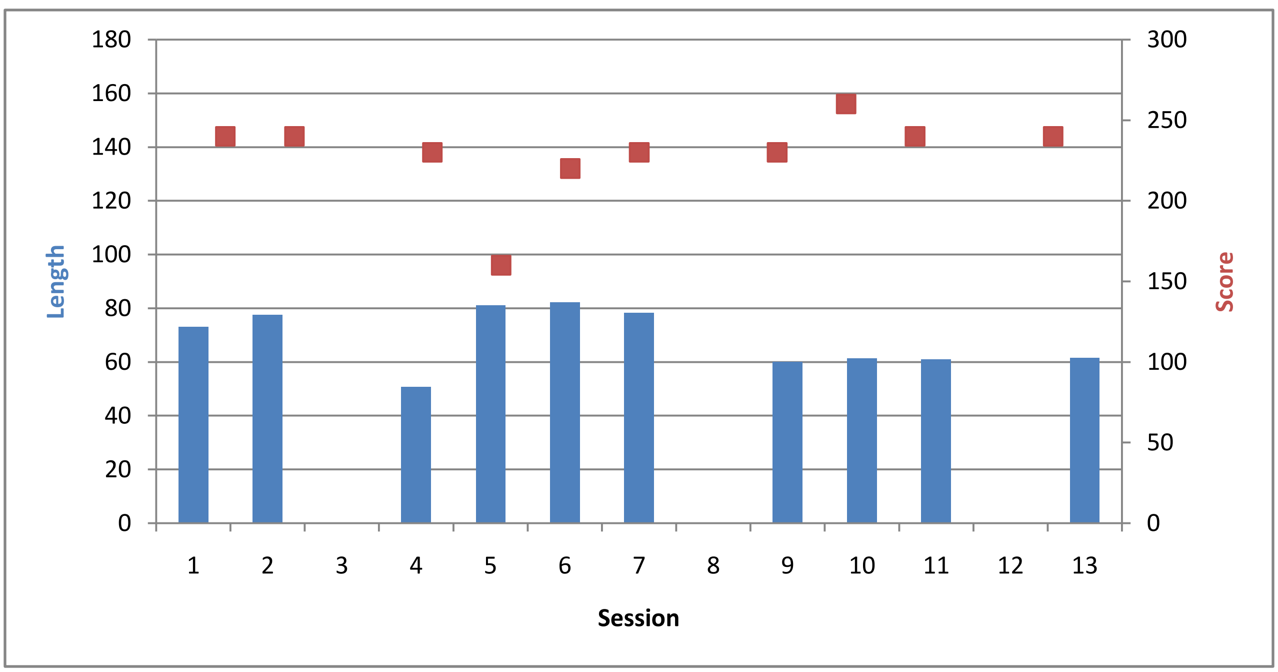
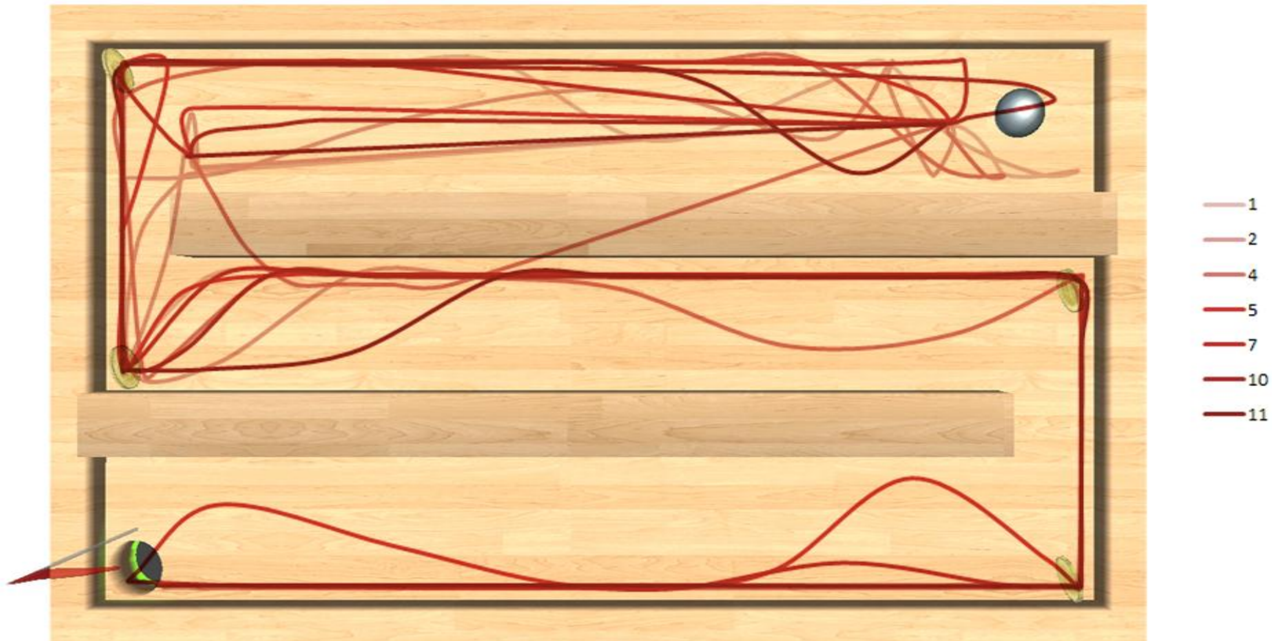


Figure 13-3 (a) Paths of the marble in Level 3 during different training sessions

(b) Lengths of the paths and score achieved in Level 3, during different sessions



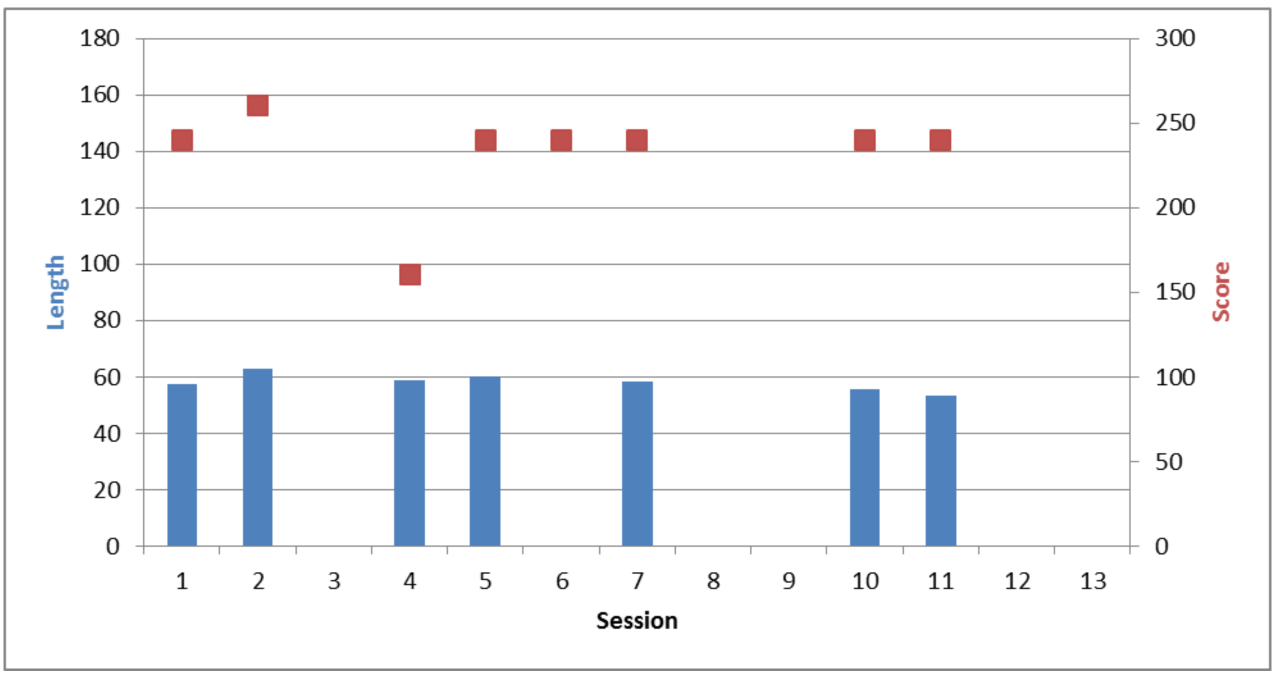


Figure 13-4 (a) Paths of the marble in Level 4 during different training sessions

(b) Lengths of the paths and score achieved in Level 4, during different sessions

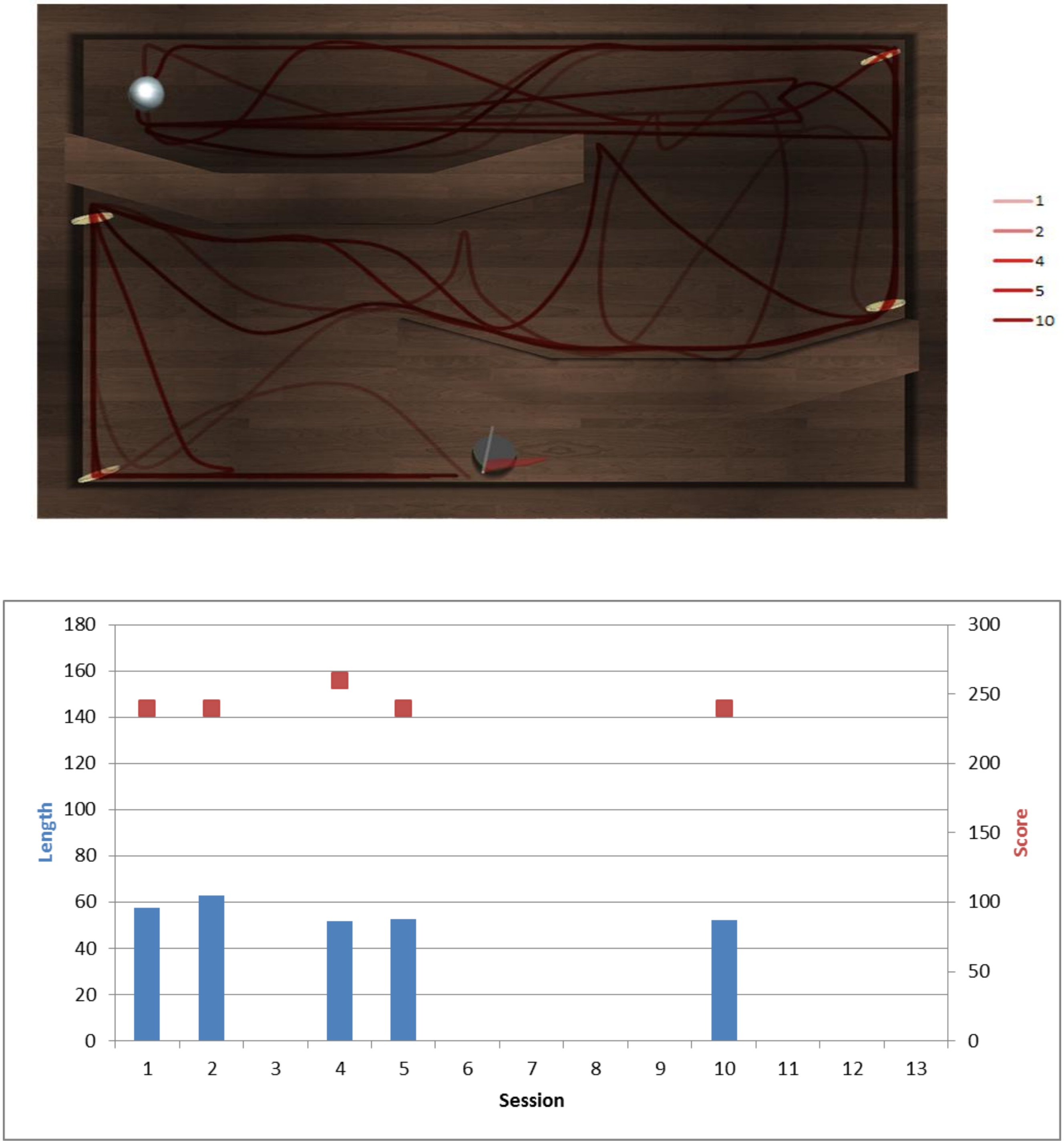
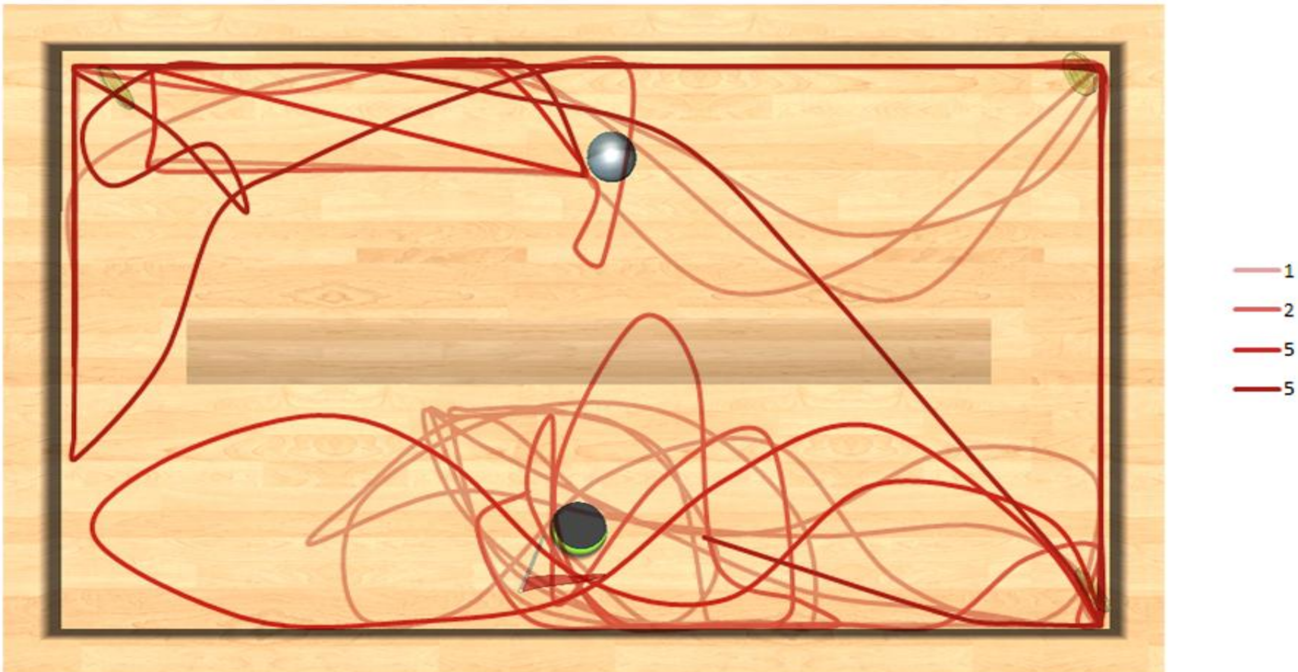


Figure 13-5 (a) Paths of the marble in Level 5 during different training sessions

(b) Lengths of the paths and score achieved in Level 5, during different sessions



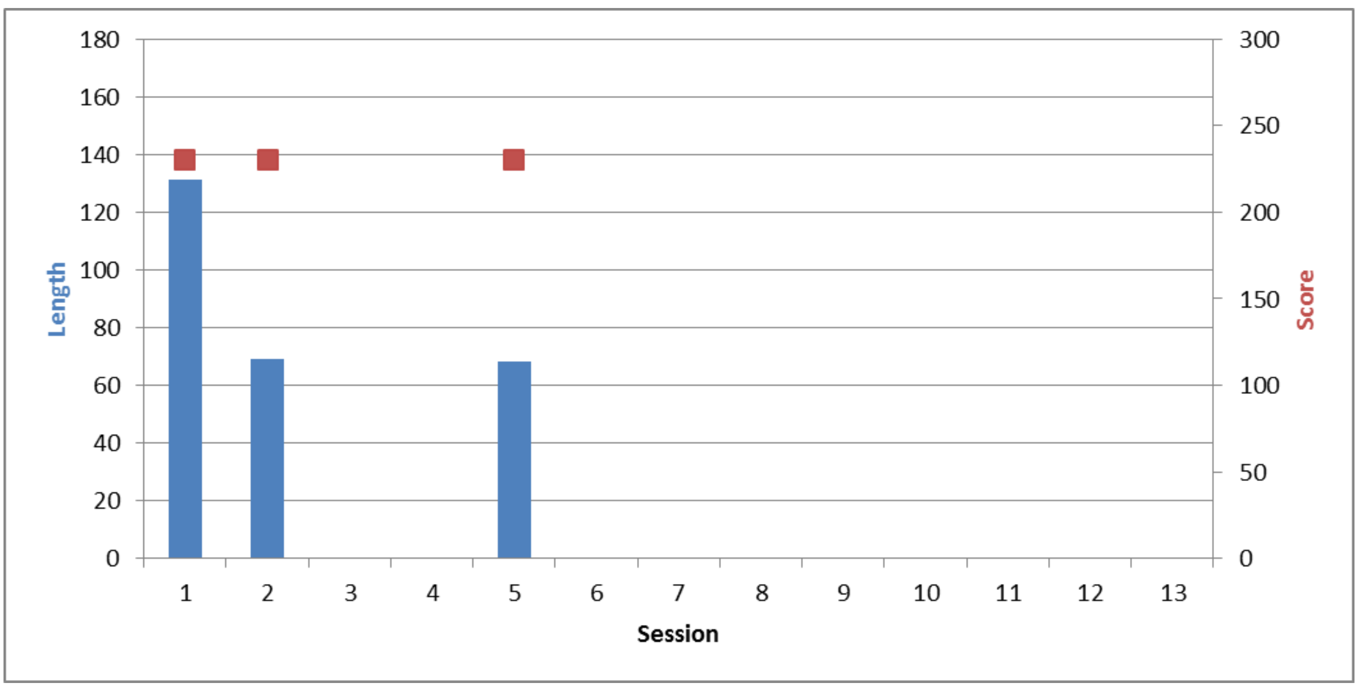
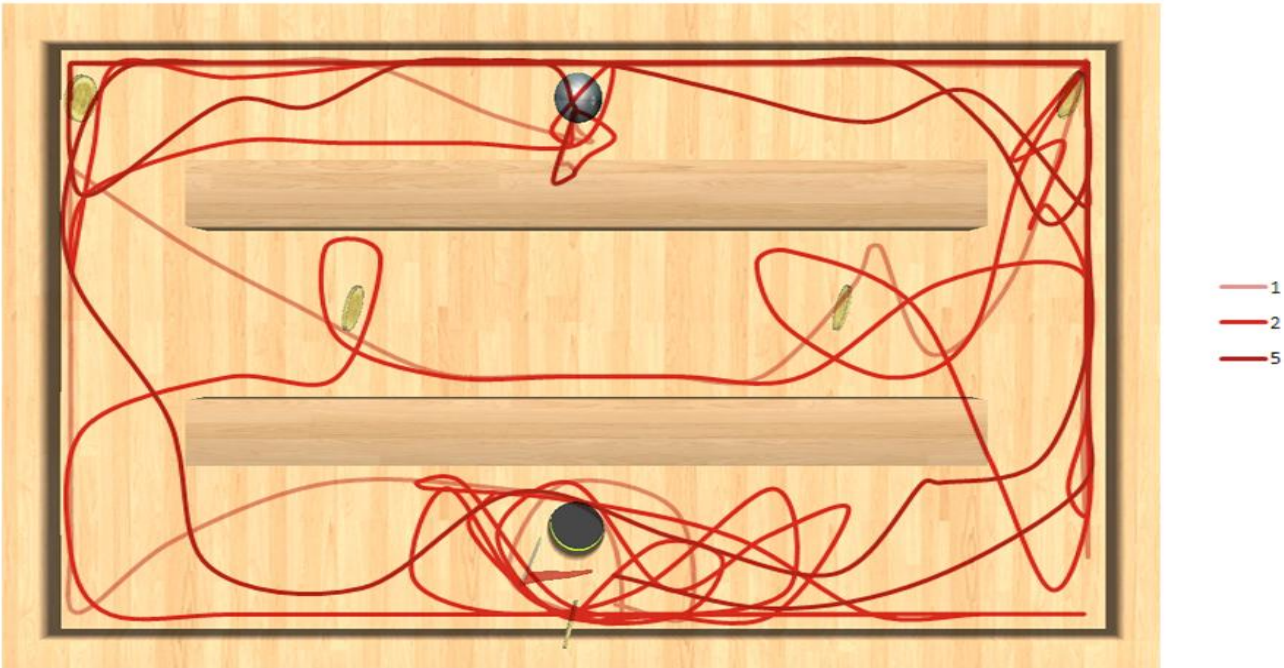


Figure 13-6 (a) Paths of the marble in Level 6 during different training sessions

(b) Lengths of the paths and score achieved in Level 6, during different sessions



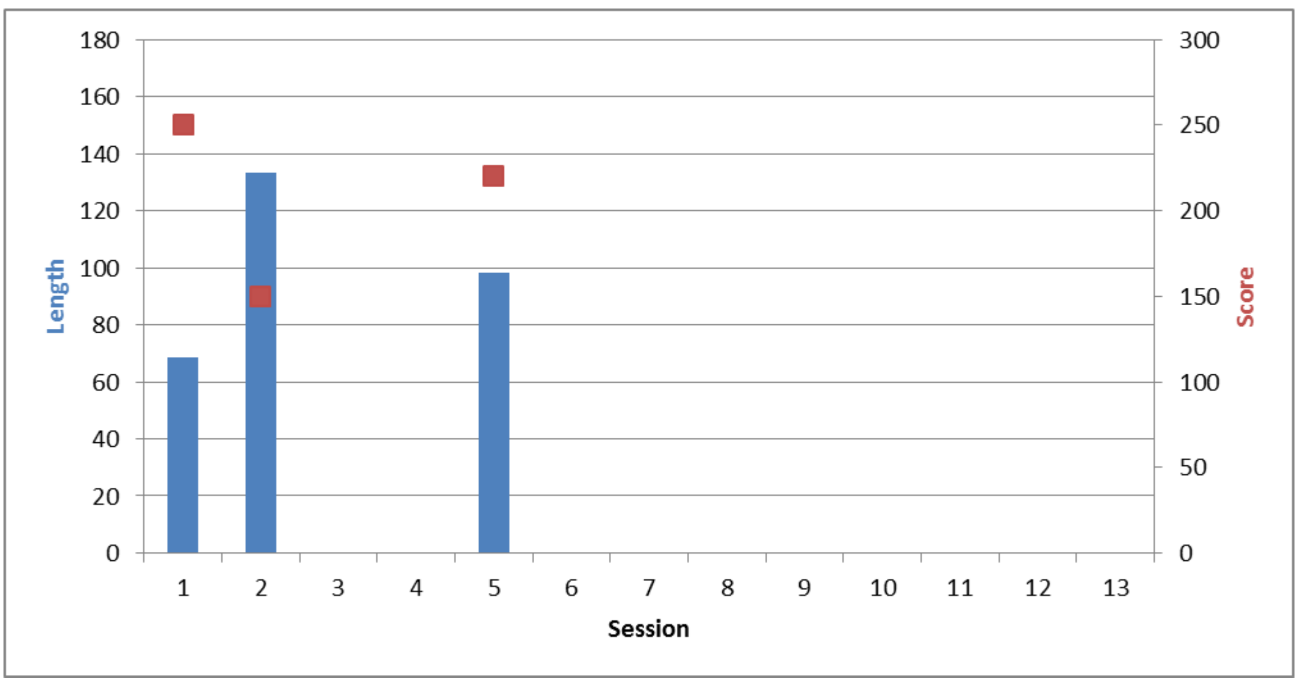
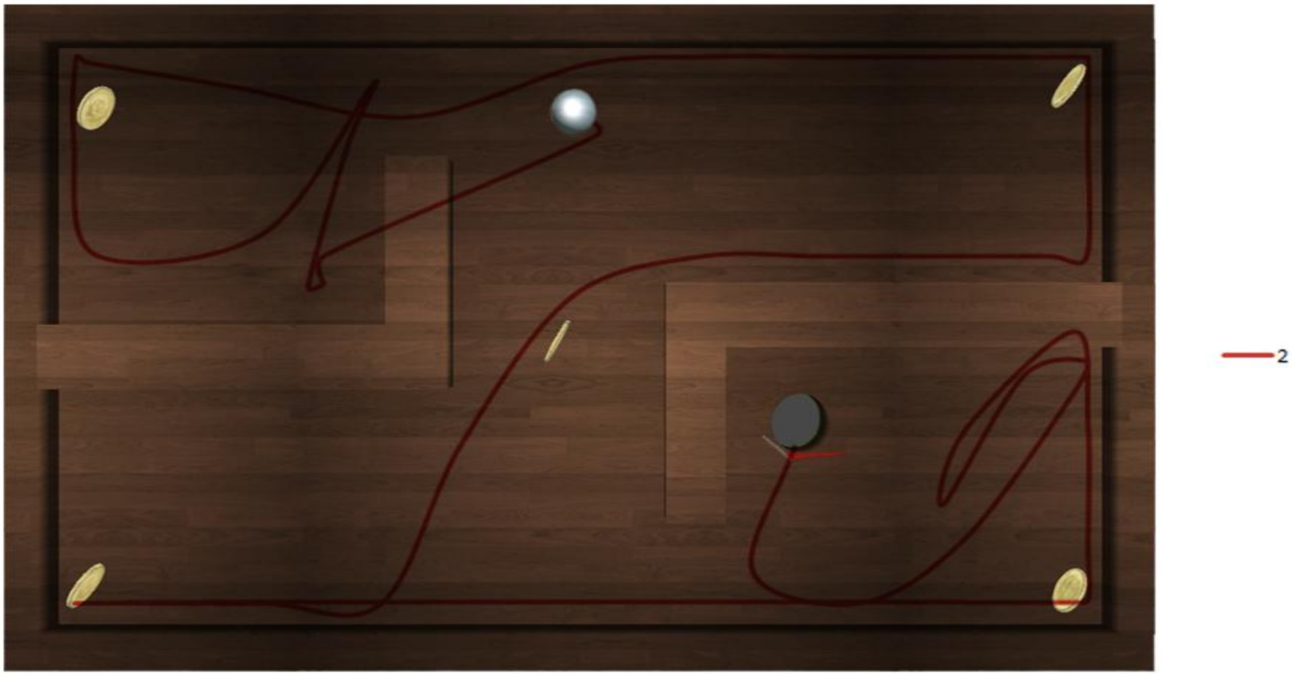


Figure 13-7 (a) Paths of the marble in Level 7 during different training sessions

(b) Lengths of the paths and score achieved in Level 7, during different sessions



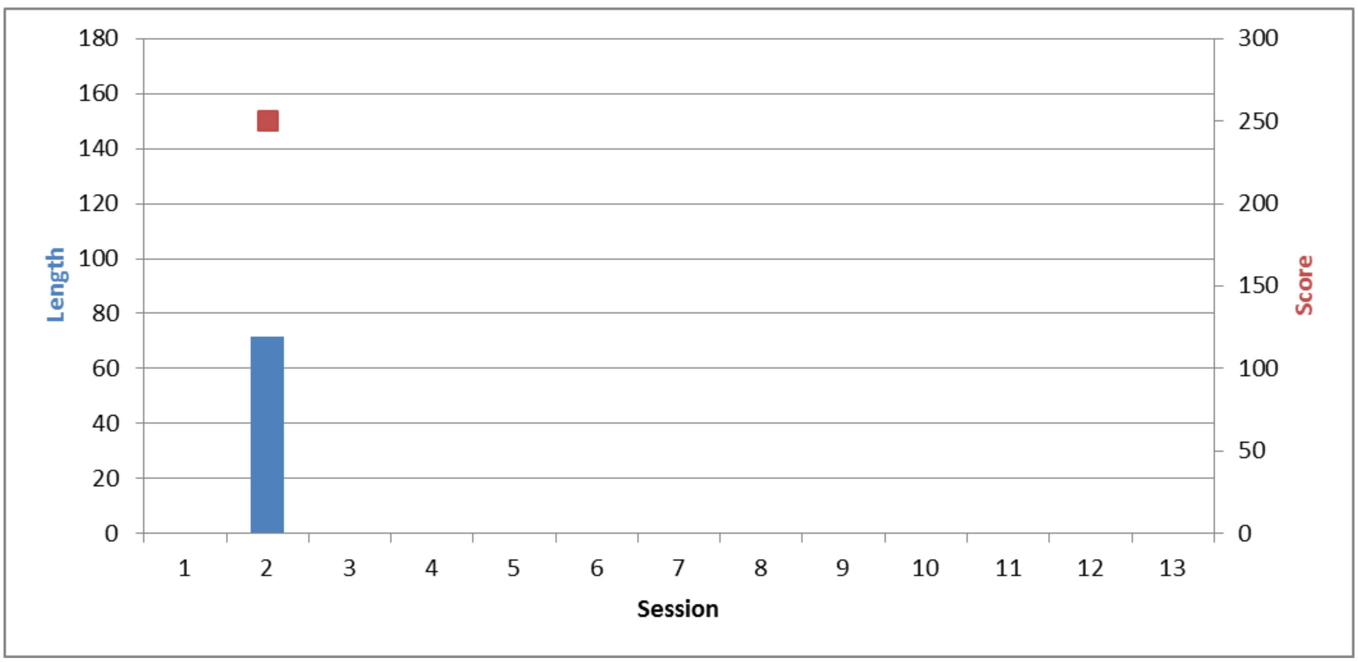
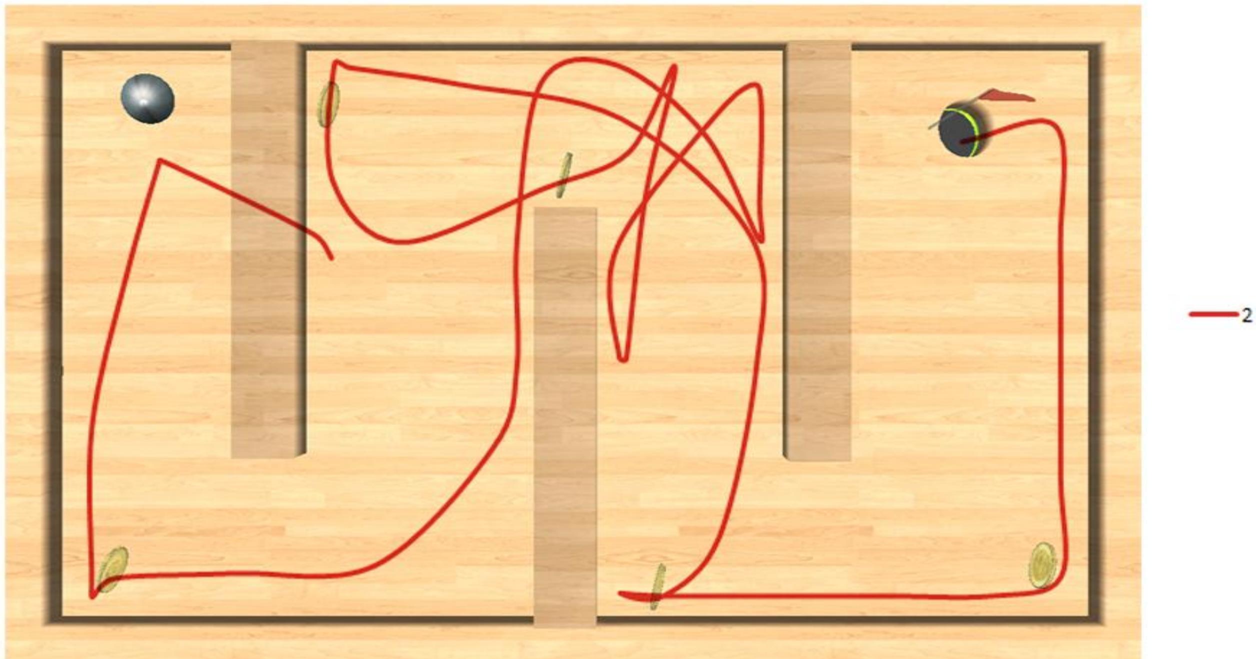


Figure 13-8 (a) Paths of the marble in Level 8 during different training sessions
(b) Lengths of the paths and score achieved in Level 8, during different sessions



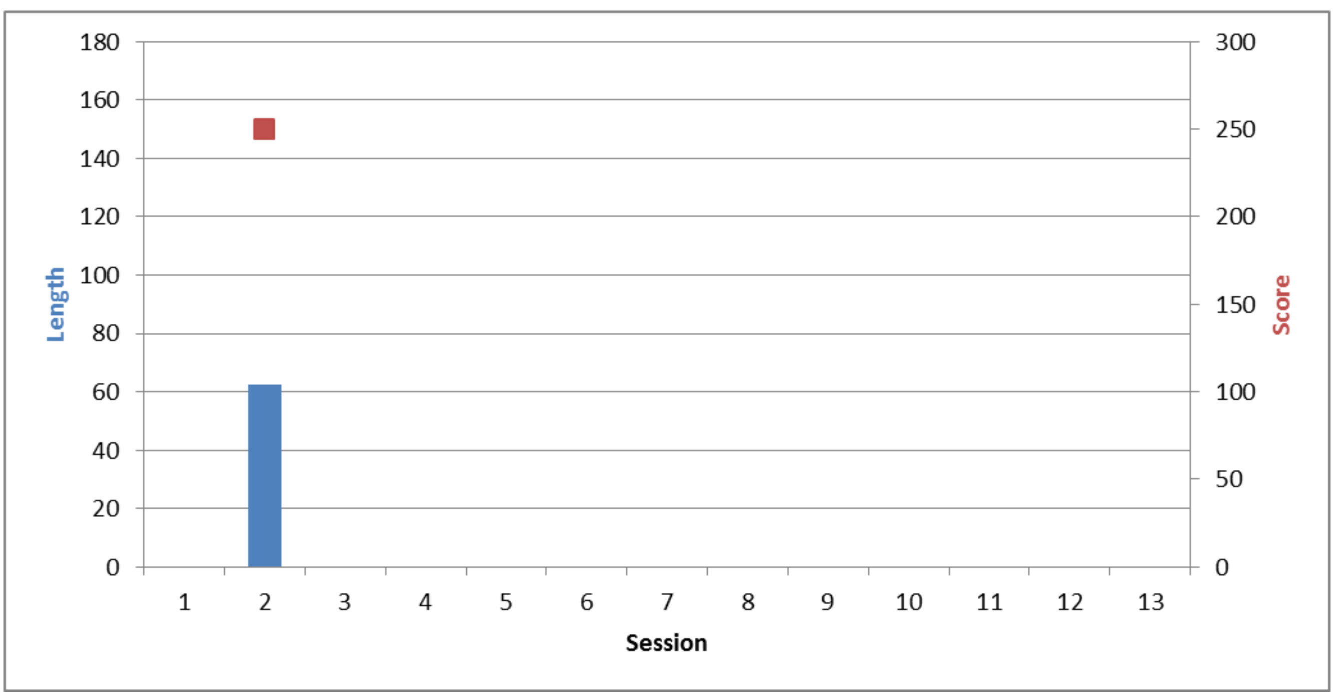


Figure 13-9 (a) Paths of the marble in Level 9 during different training sessions

(b) Lengths of the paths and score achieved in Level 9, during different sessions

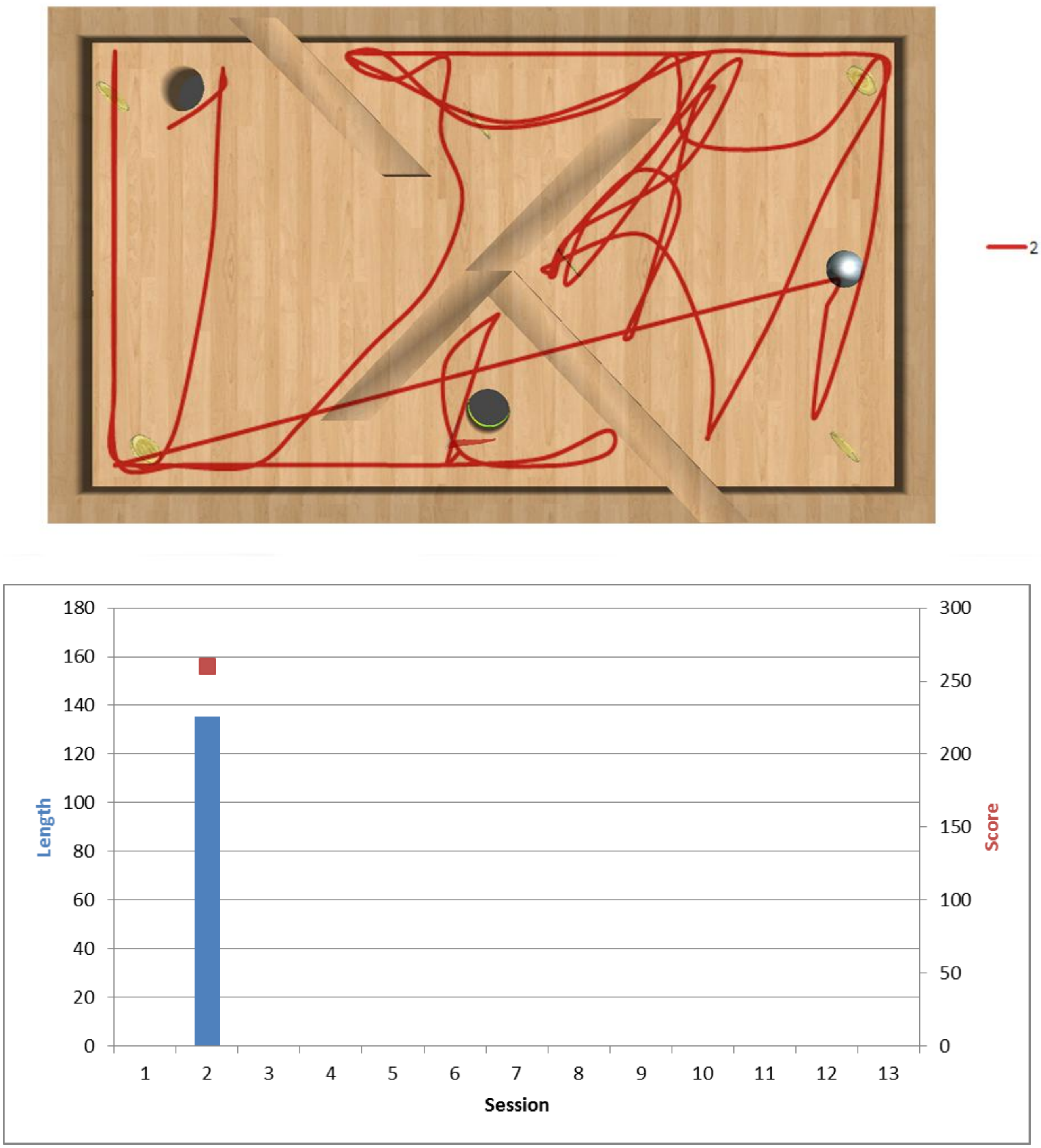
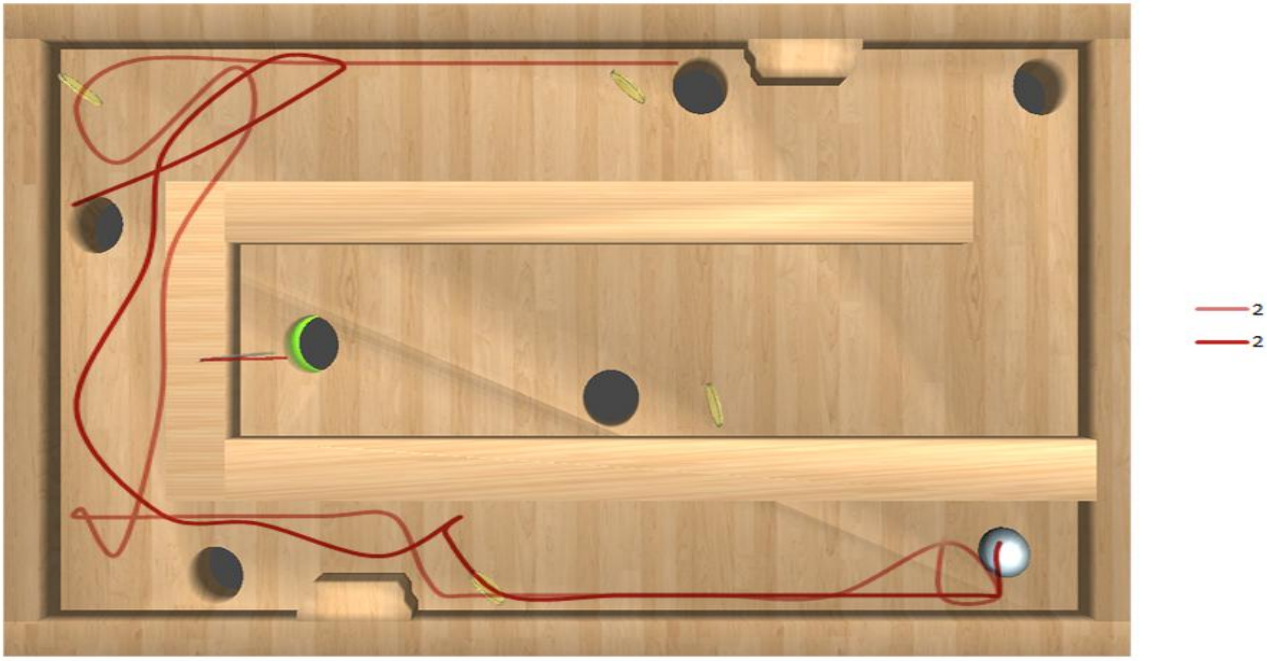


Figure 13-10 (a) Paths of the marble in Level 10 during different training sessions

(b) Lengths of the paths and score achieved in Level 10, during different sessions



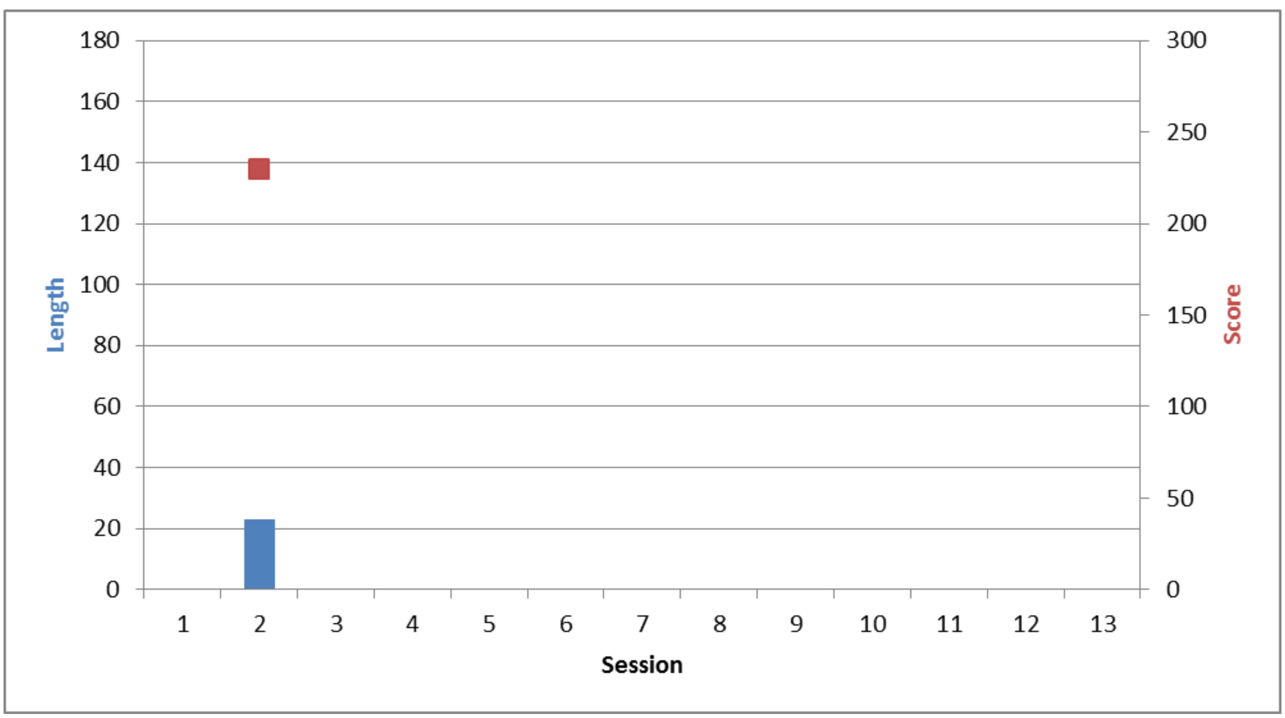


Figure 13-11 (a) Paths of the marble in Level 11 during different training sessions

(b) Lengths of the paths and score achieved in Level 11, during different sessions

13.2. Patient 2

Figure 13-12- Figure 13-22 (a) show the paths followed by the marble in each of the level played during different sessions of the training period. The Figure 13-12- Figure 13-22 (b) show the lengths of the paths followed by the marble and the score achieved in each level played during different sessions.

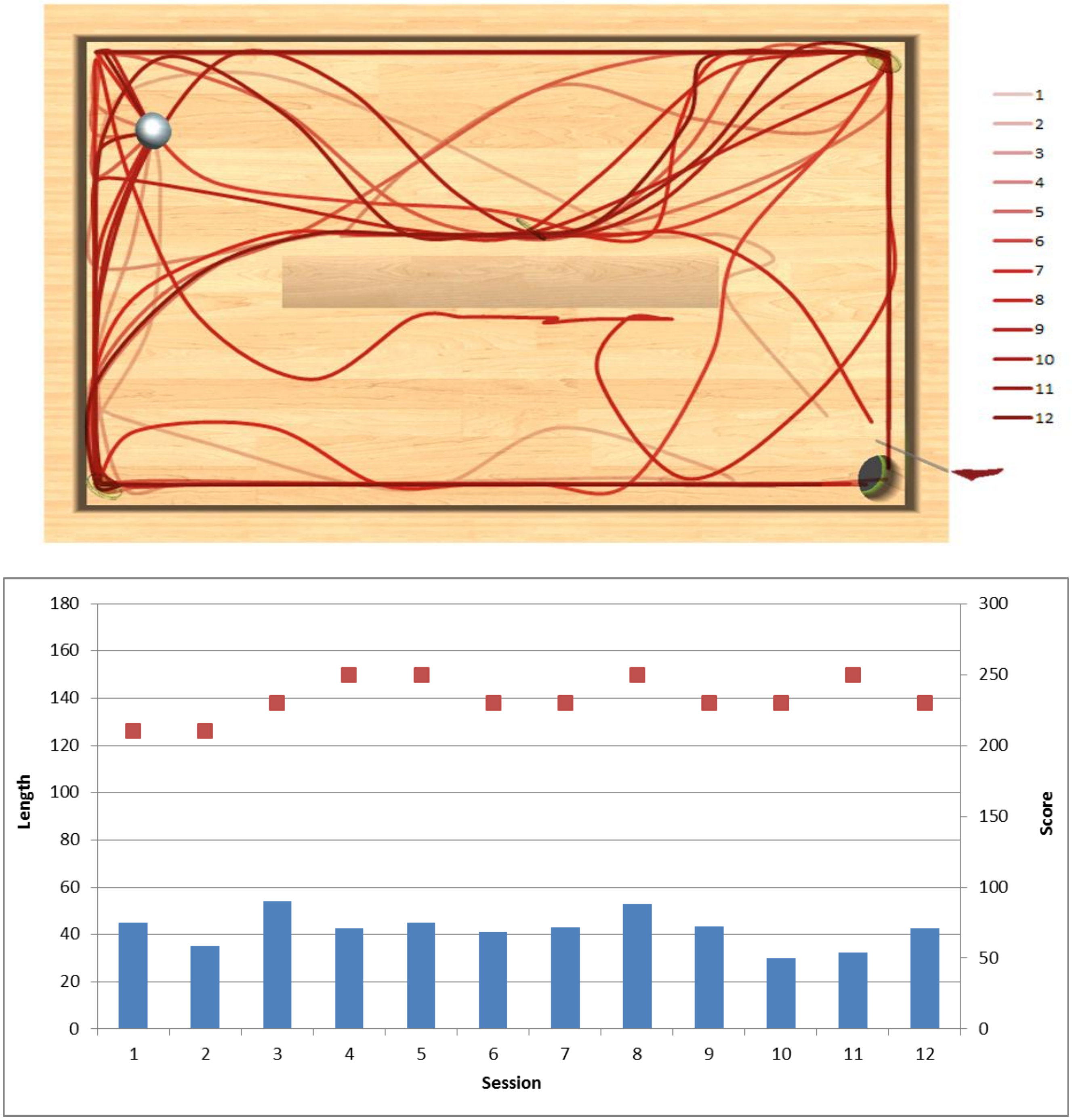


Figure 13-12 (a) Paths of the marble in Level 1 during different training sessions

(b) Lengths of the paths and score achieved in Level 1, during different sessions

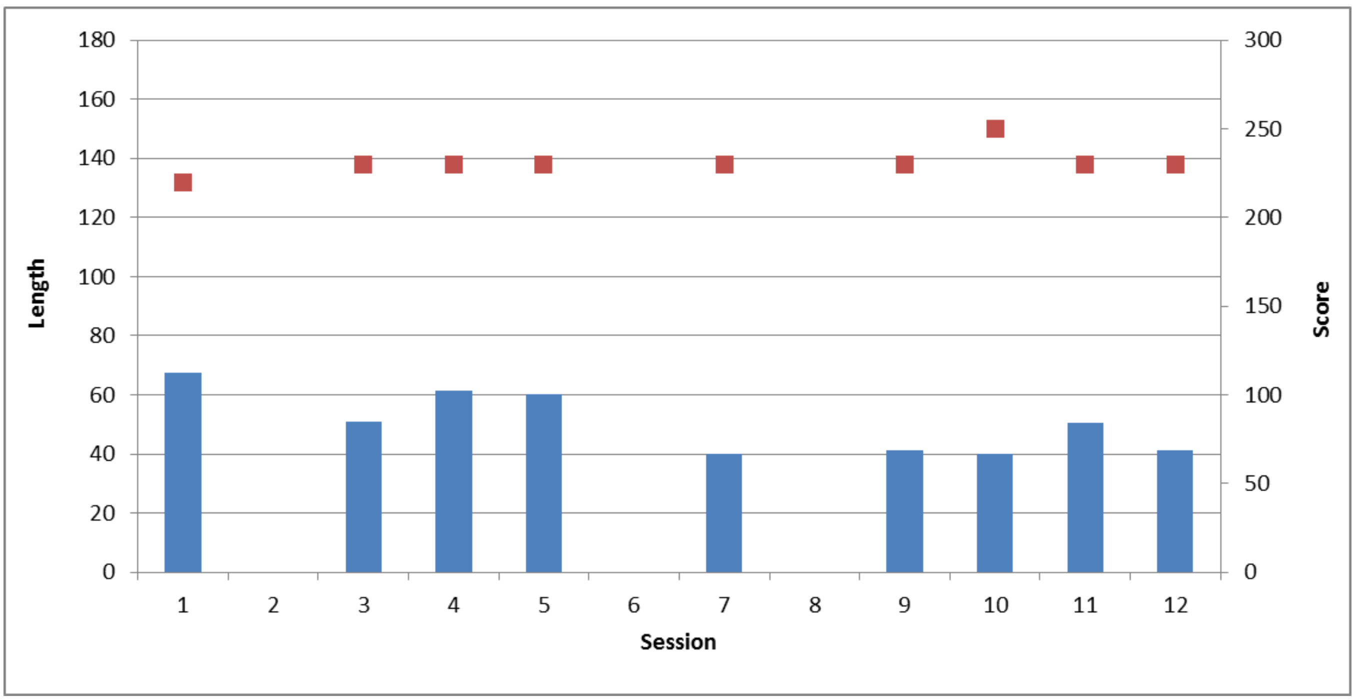


Figure 13-13 (a) Paths of the marble in Level 2 during different training sessions

(b) Lengths of the paths and score achieved in Level 2, during different sessions

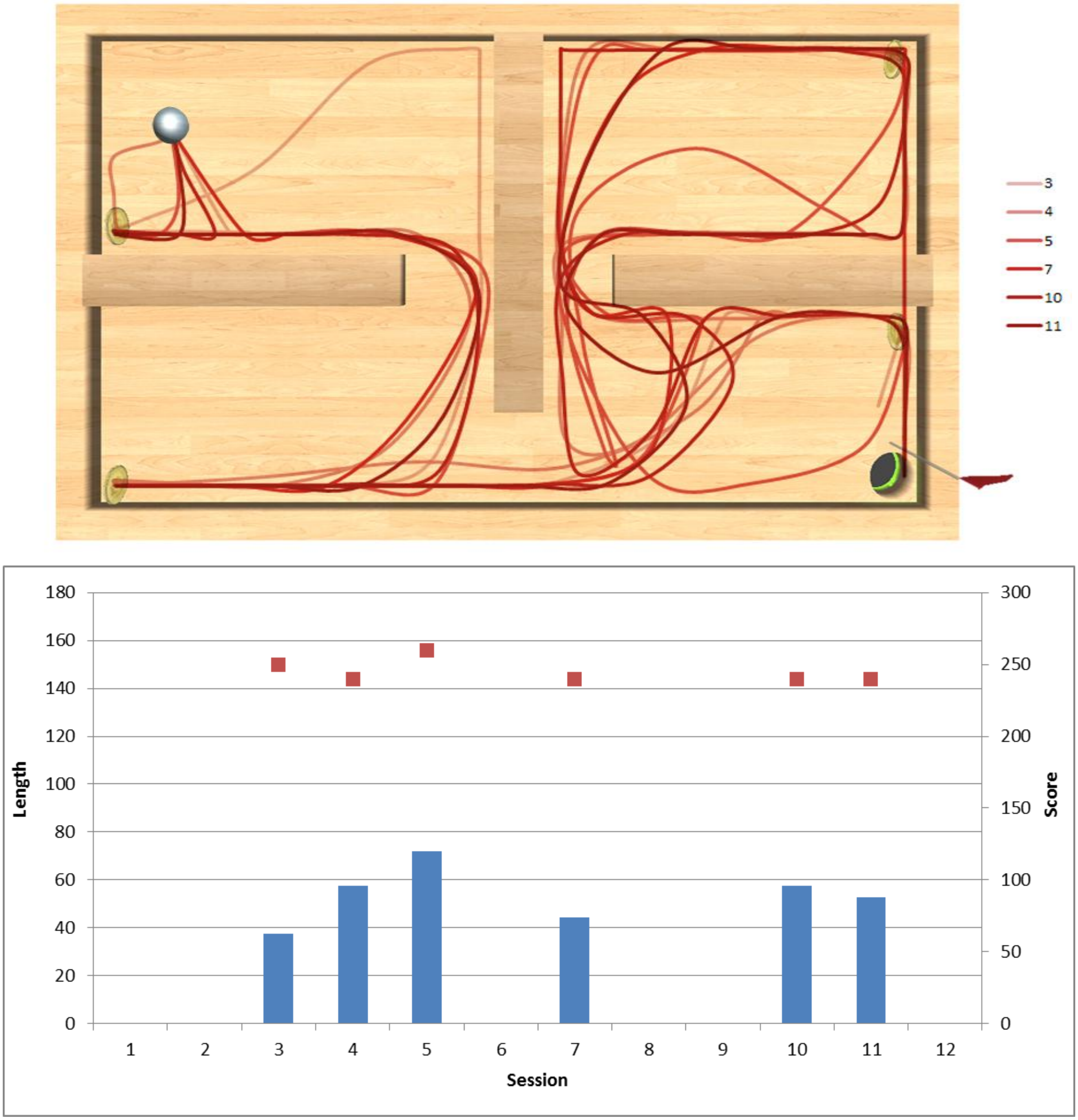
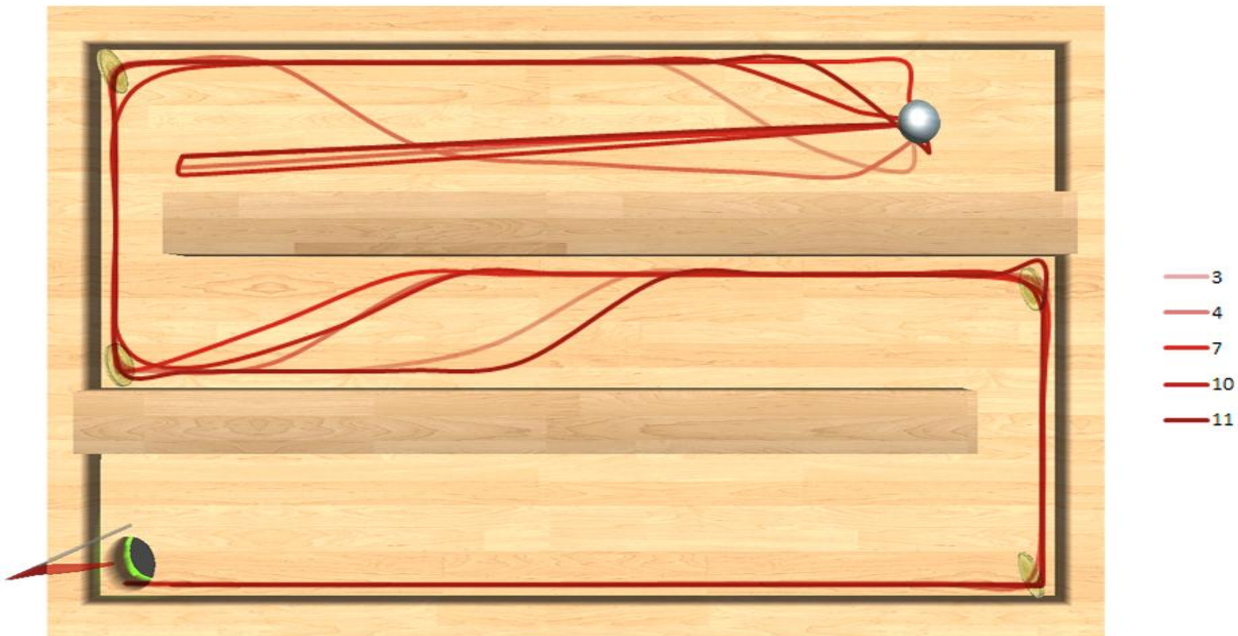


Figure 13-14 (a) Paths of the marble in Level 3 during different training sessions

(b) Lengths of the paths and score achieved in Level 3, during different sessions



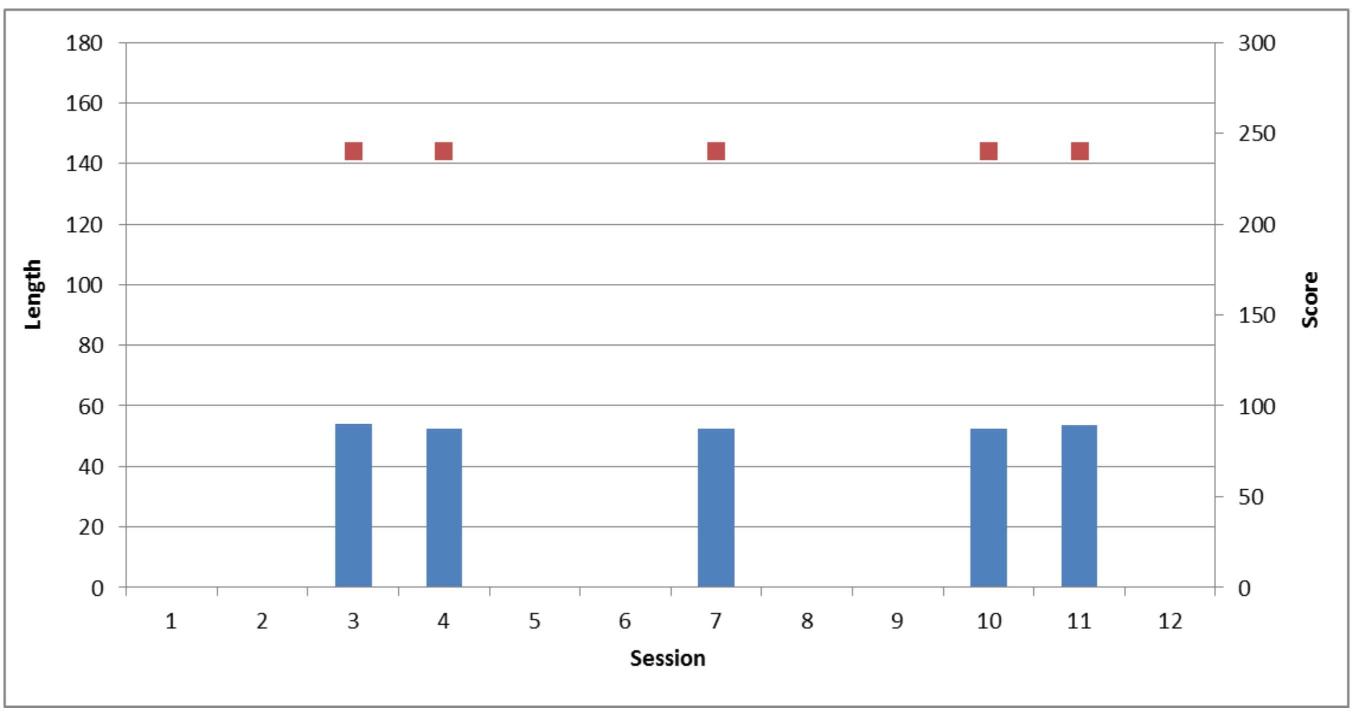
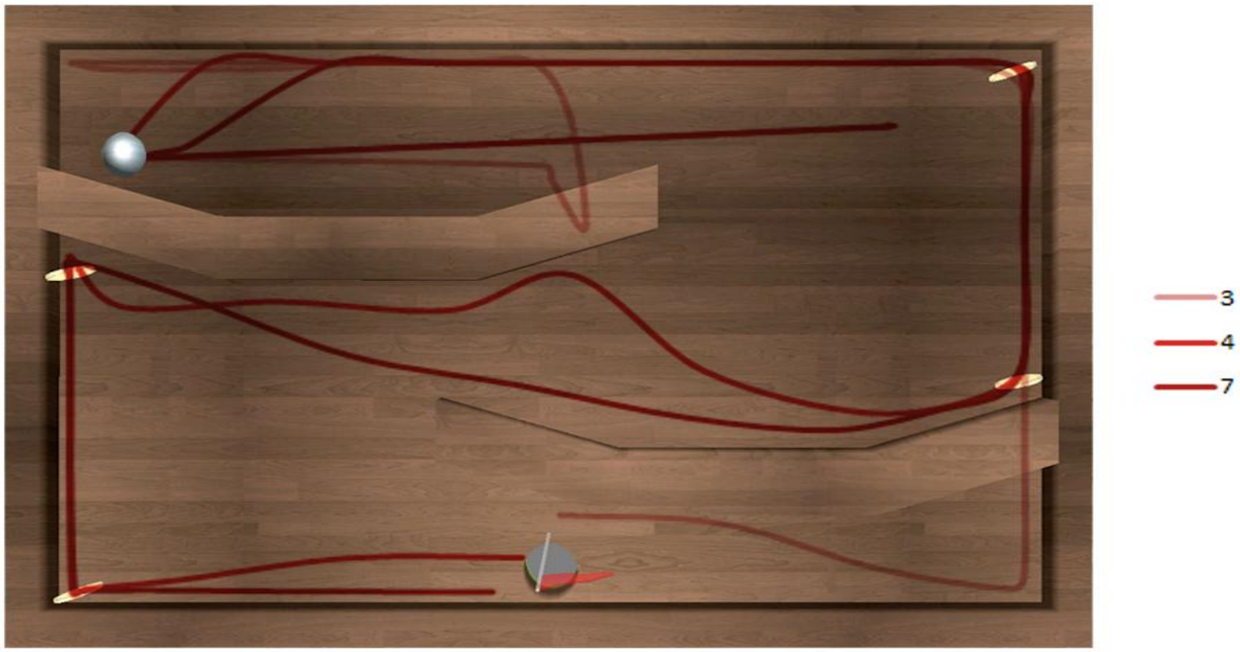


Figure 13-15 (a) Paths of the marble in Level 4 during different training sessions

(b) Lengths of the paths and score achieved in Level 4, during different sessions



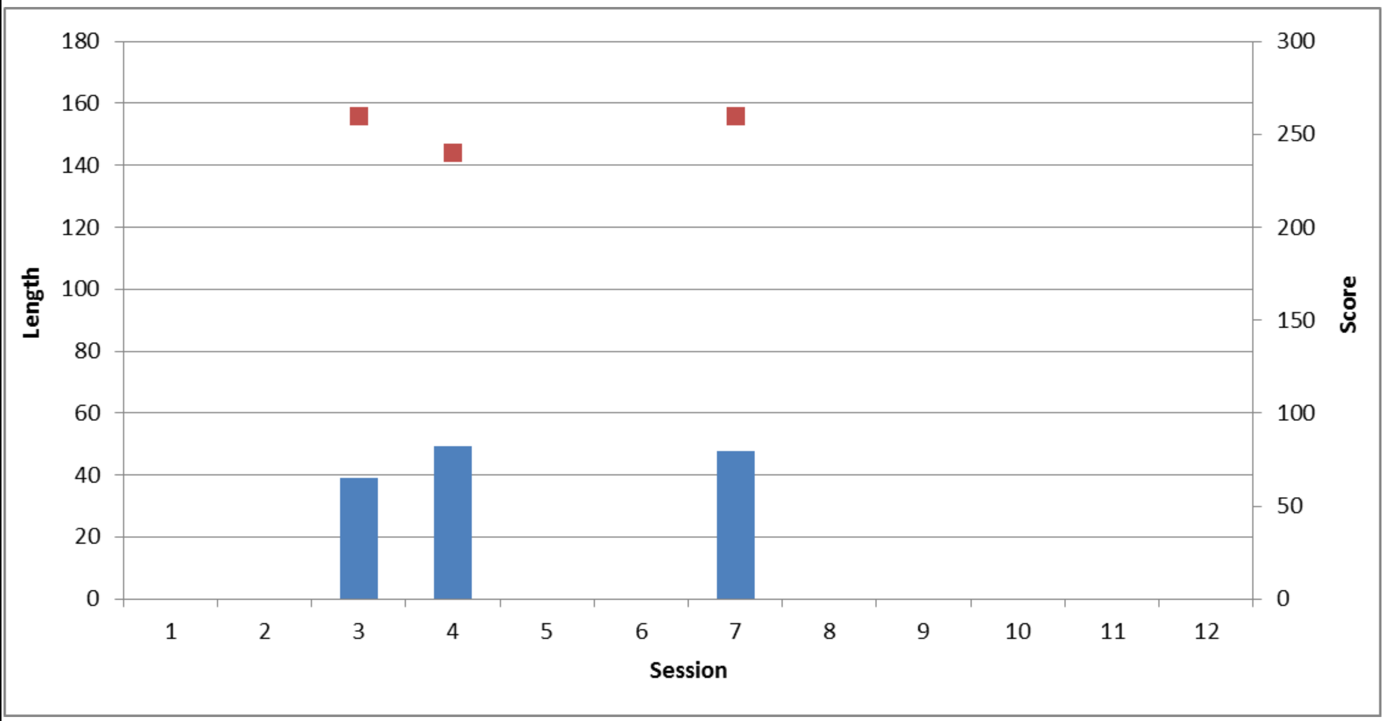


Figure 13-16 (a) Paths of the marble in Level 5 during different training sessions

(b) Lengths of the paths and score achieved in Level 5, during different sessions

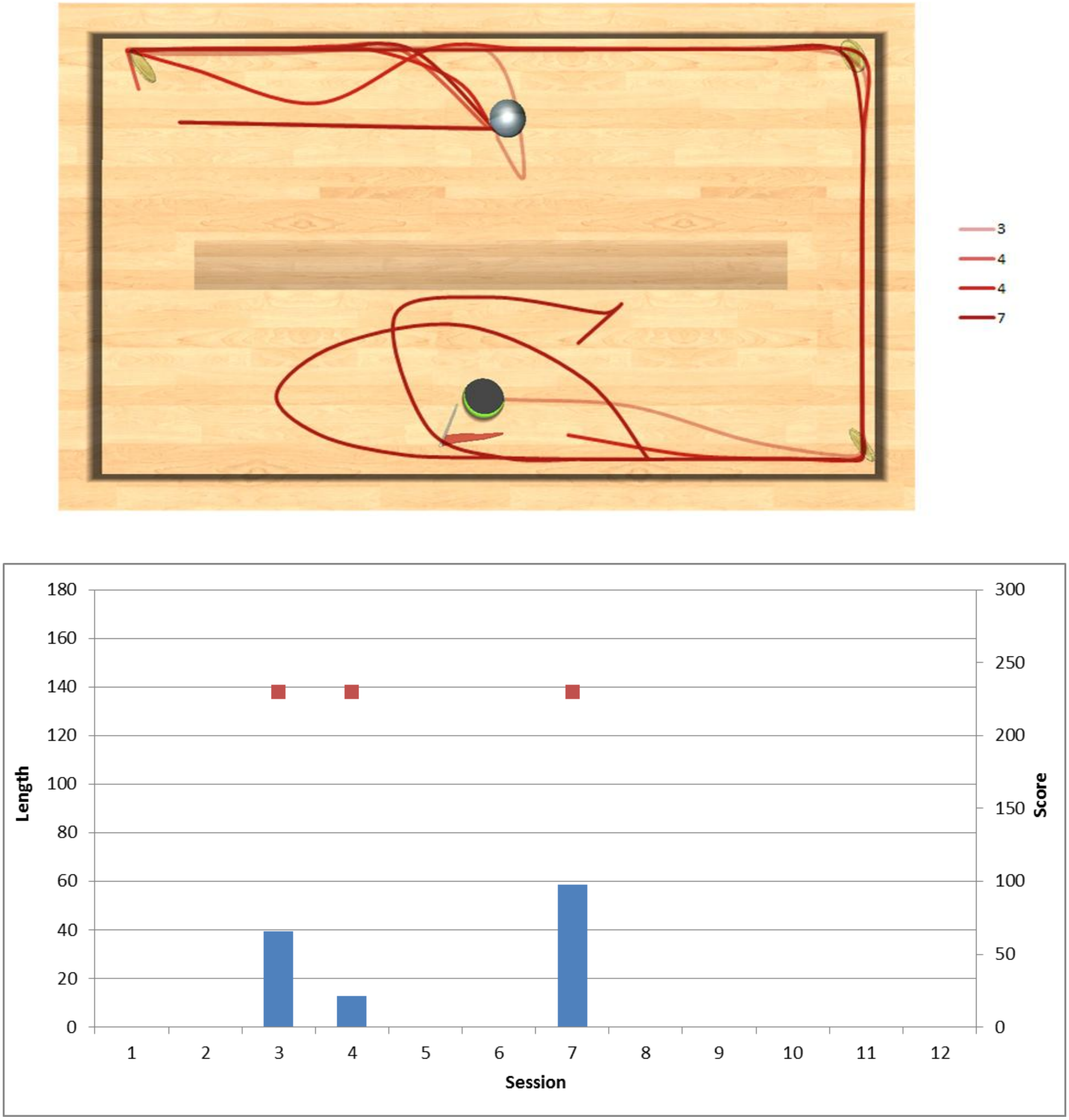
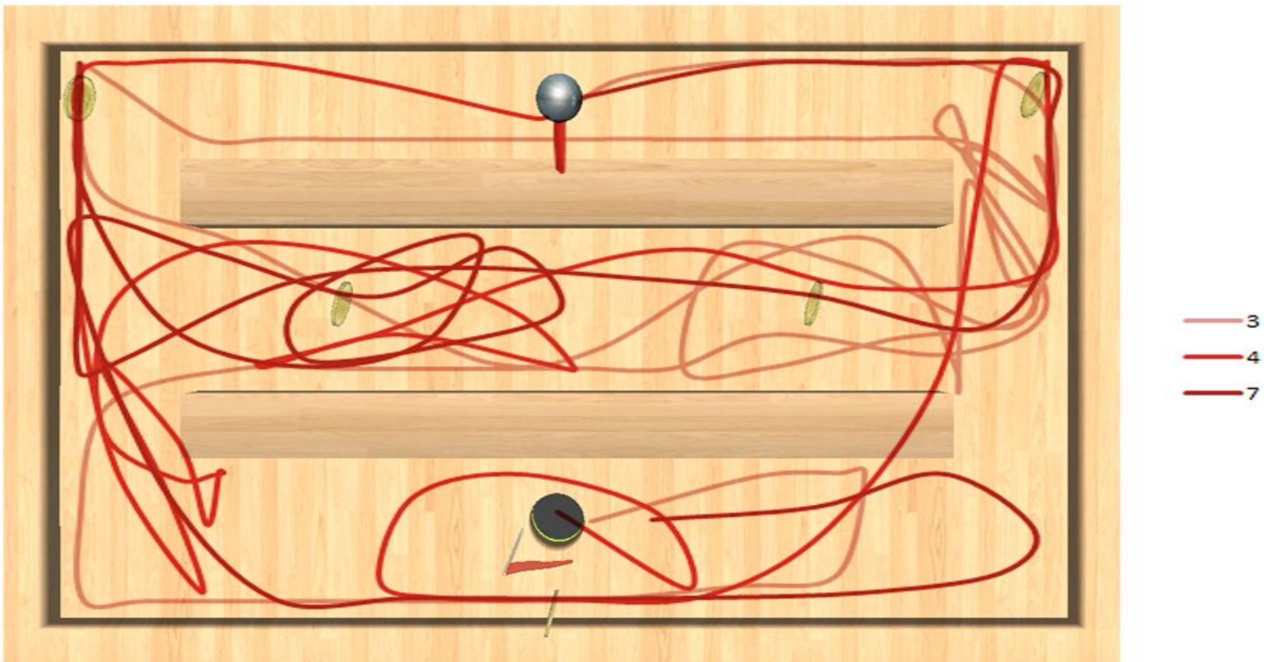


Figure 13-17 (a) Paths of the marble in Level 6 during different training sessions
(b) Lengths of the paths and score achieved in Level 6, during different sessions



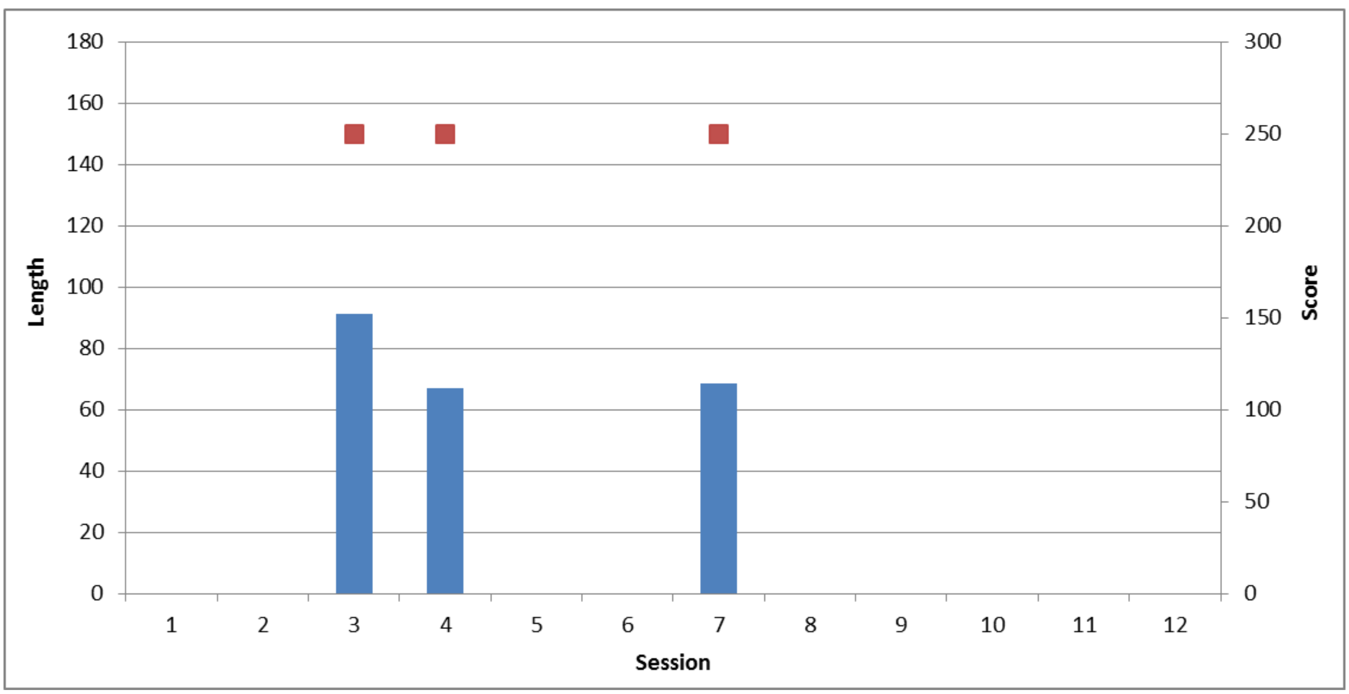


Figure 13-18 (a) Paths of the marble in Level 7 during different training sessions

(b) Lengths of the paths and score achieved in Level 7, during different sessions

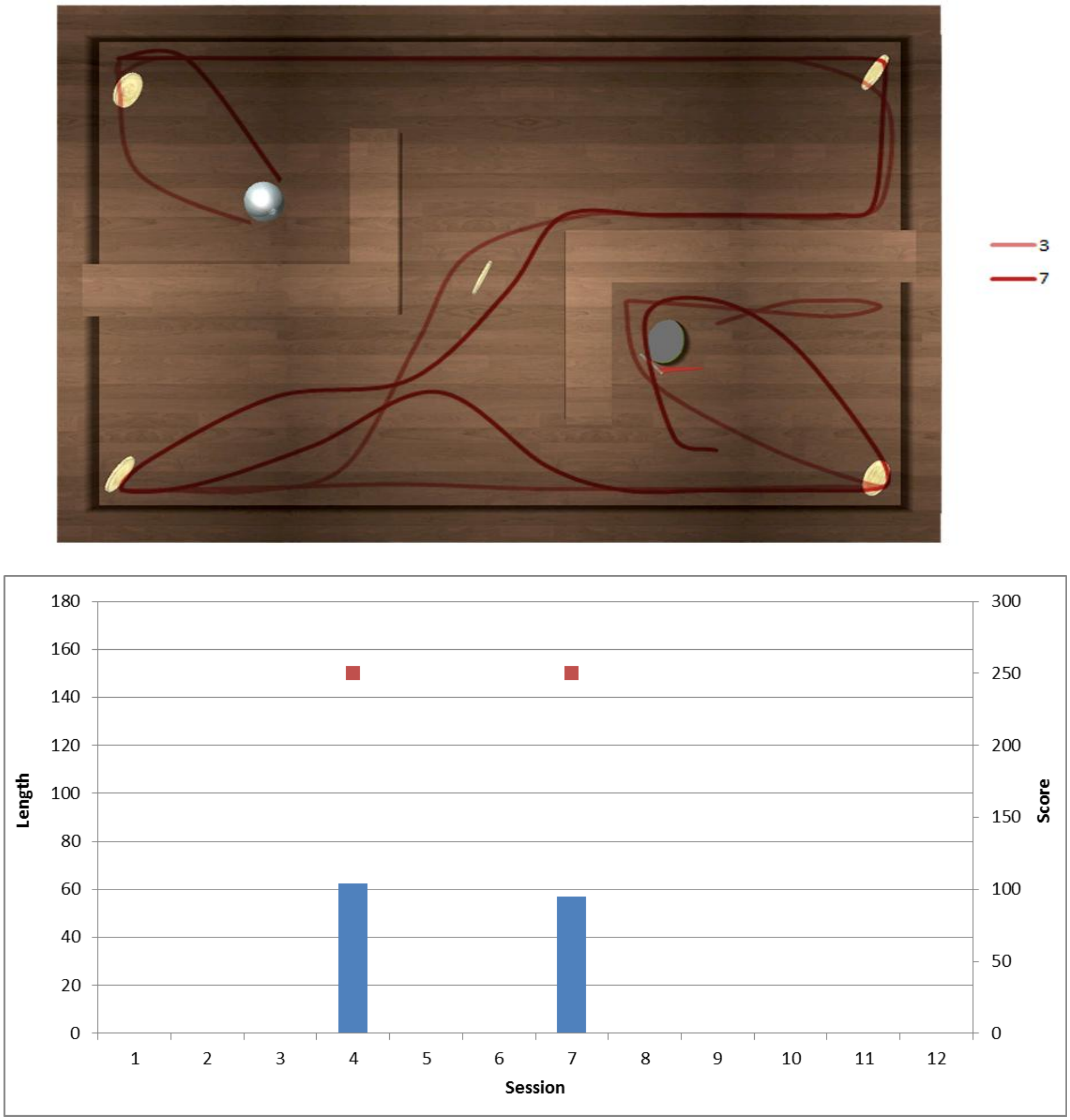
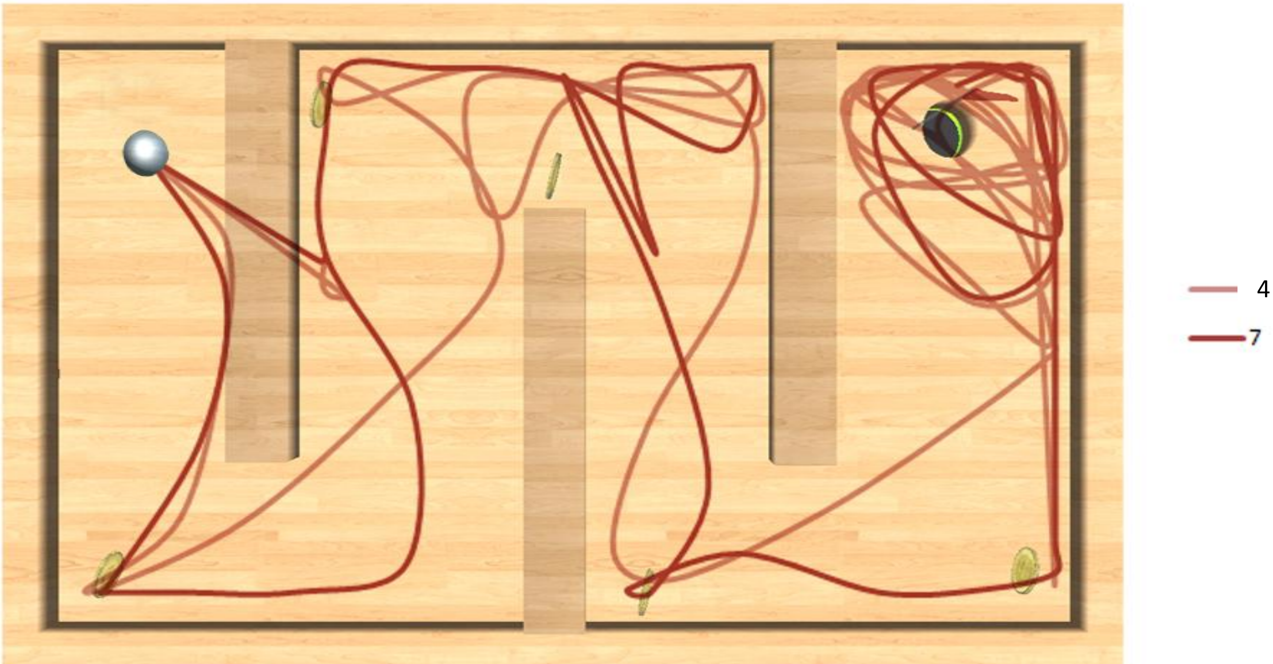


Figure 13-19 (a) Paths of the marble in Level 8 during different training sessions
(b) Lengths of the paths and score achieved in Level 8, during different sessions



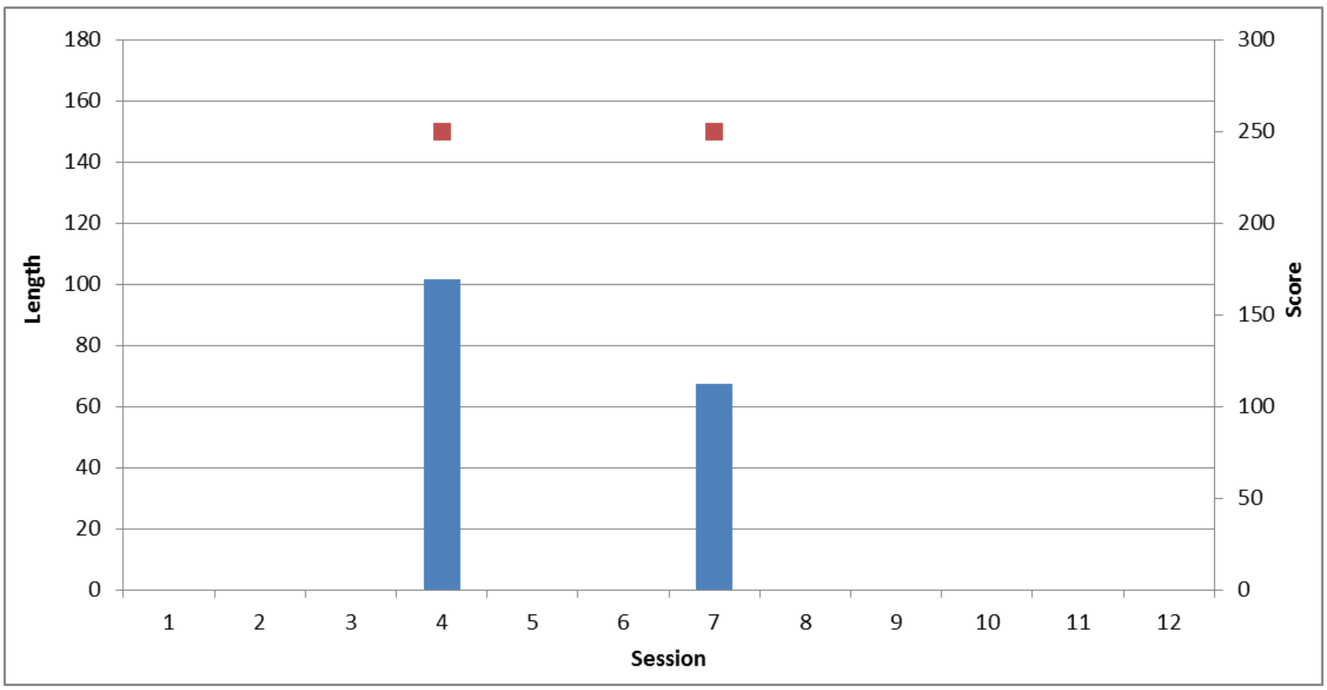
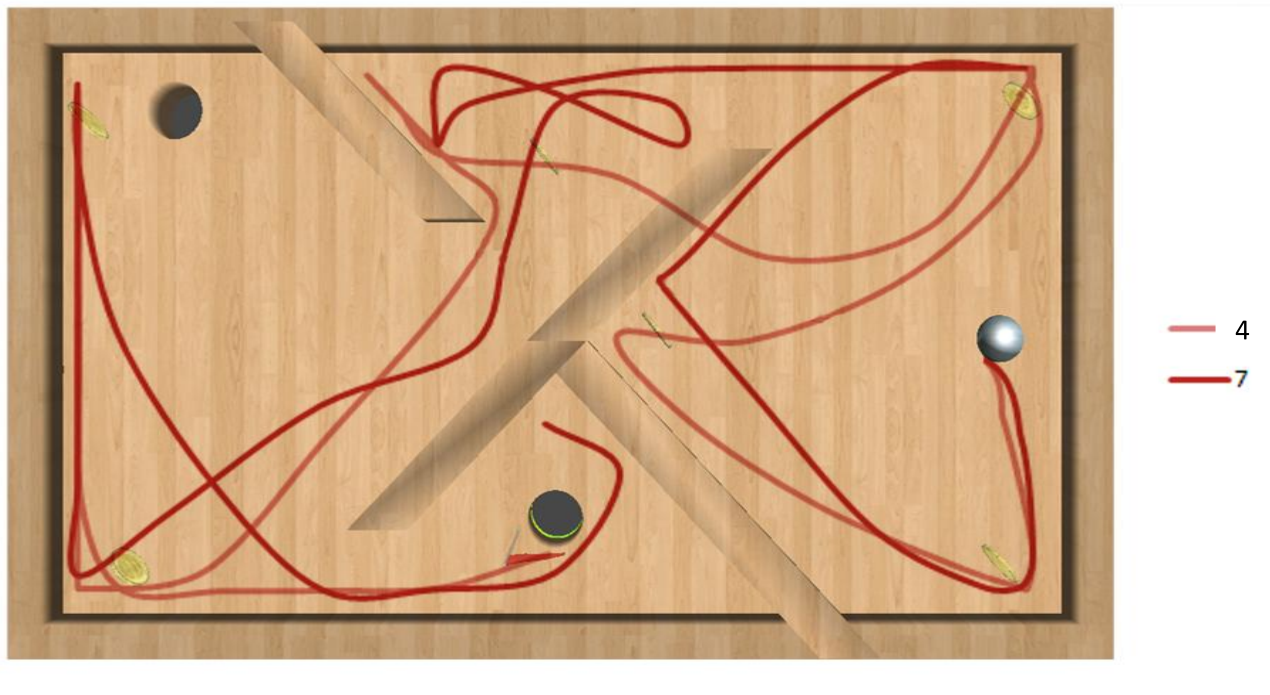


Figure 13-20 (a) Paths of the marble in Level 9 during different training sessions

(b) Lengths of the paths and score achieved in Level 9, during different sessions



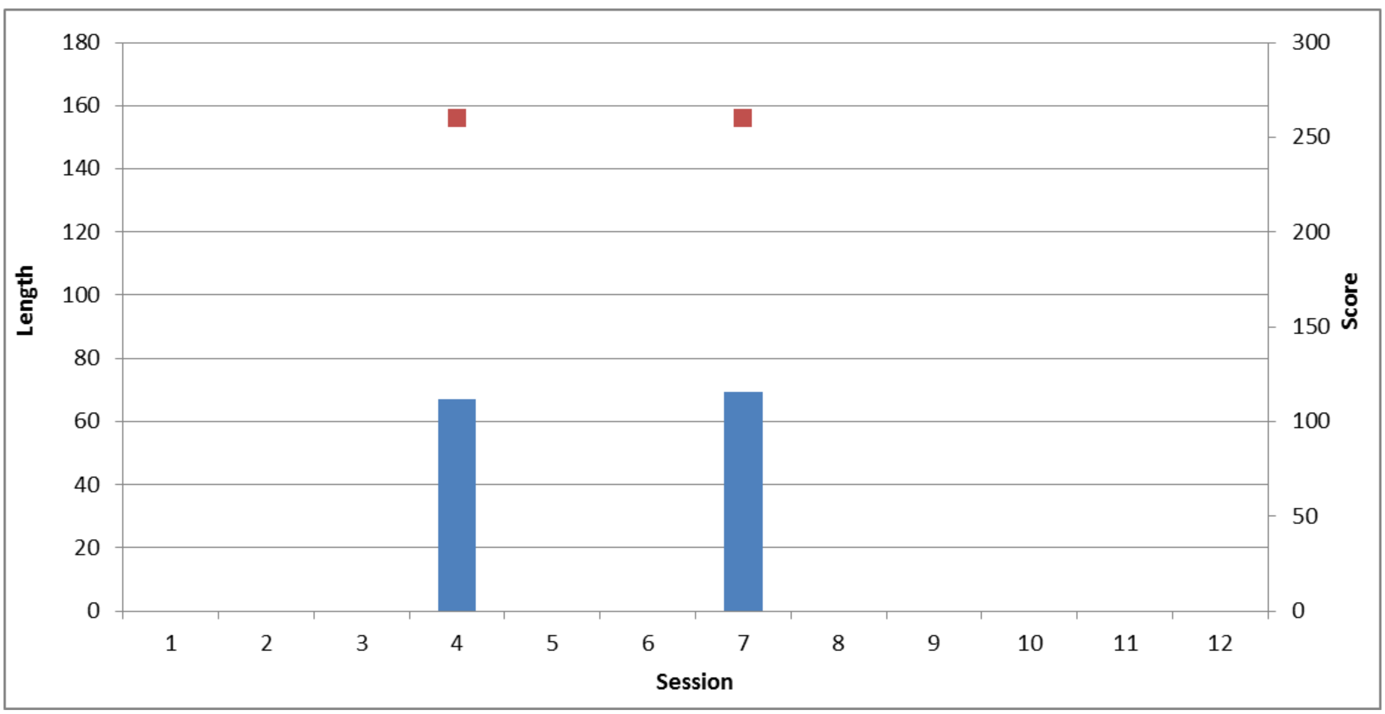
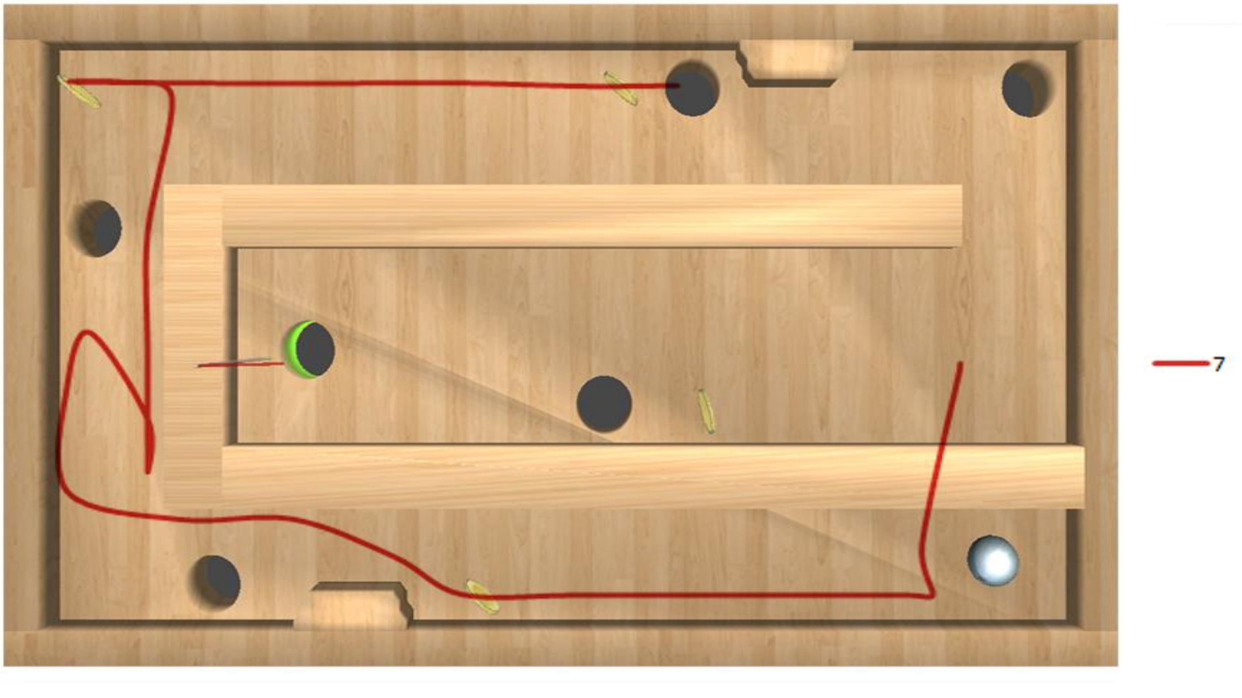


Figure 13-21 (a) Paths of the marble in Level 10 during different training sessions

(b) Lengths of the paths and score achieved in Level 10, during different sessions



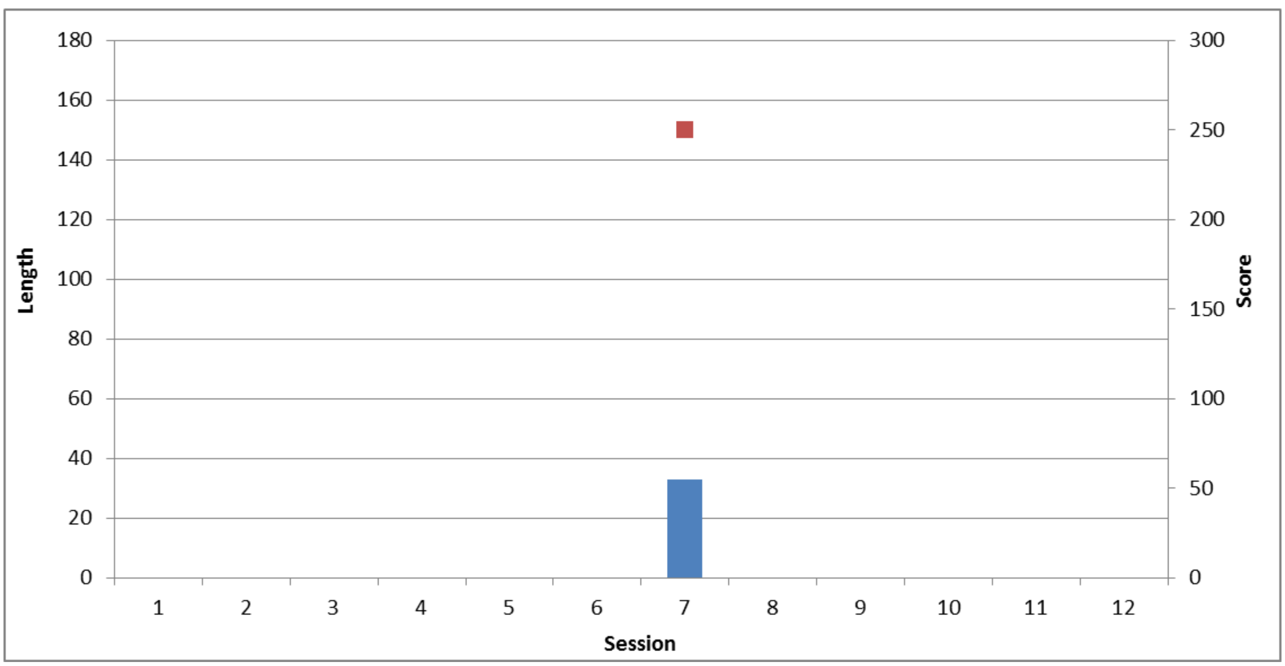
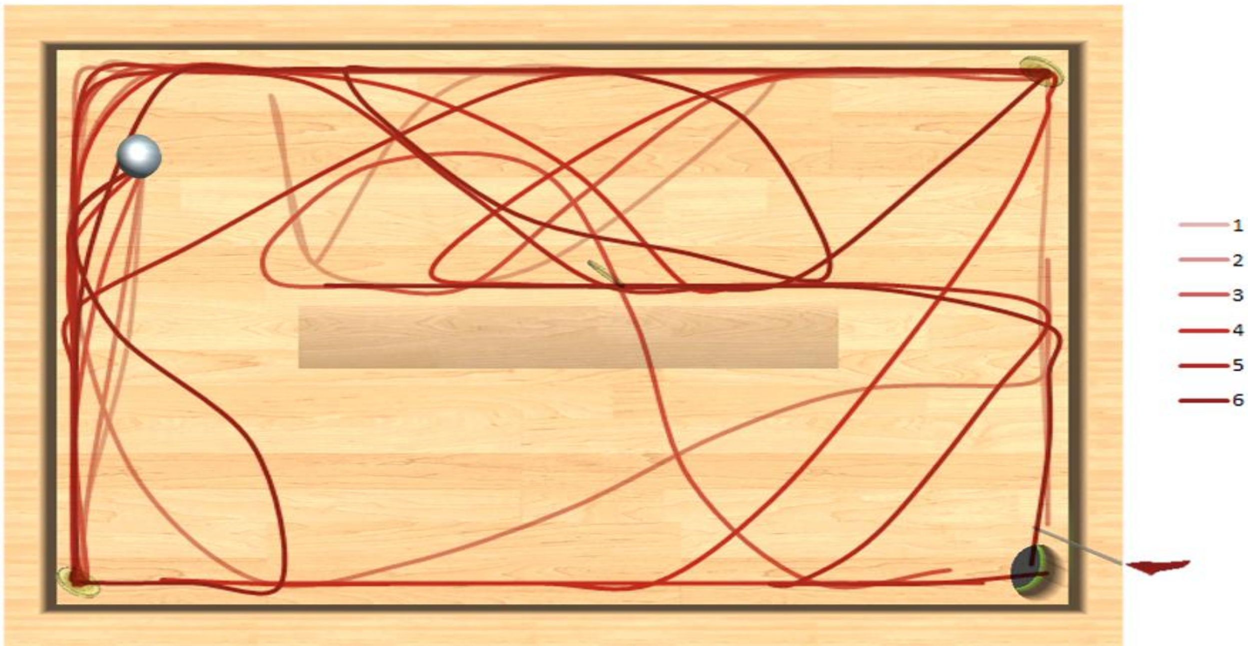


Figure 13-22 (a) Paths of the marble in Level 11 during different training sessions

(b) Lengths of the paths and score achieved in Level 11, during different sessions

13.3. PATIENT 3

Figure 13-23 - Figure 13-32 (a) show the paths followed by the marble in each of the level played during different sessions of the training period. The Figure 13-23 - Figure 13-32(b) show the lengths of the paths followed by the marble and the score achieved in each level played during different sessions.



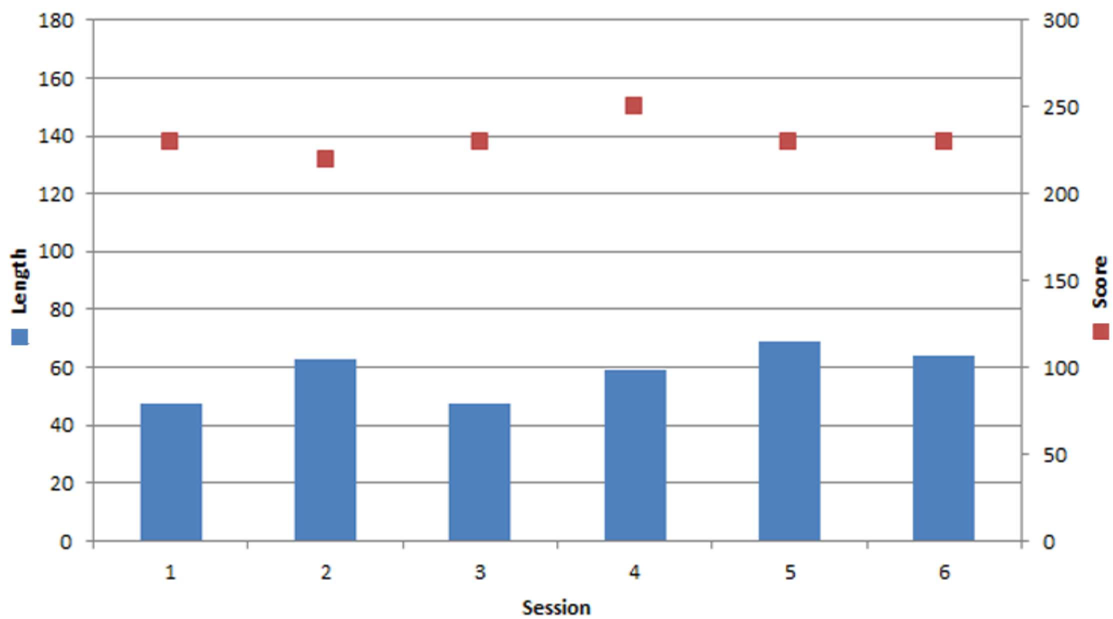


Figure 13-23 (a) Paths of the marble in Level 1 during different training sessions
(b) Lengths of the paths and score achieved in Level 1, during different sessions

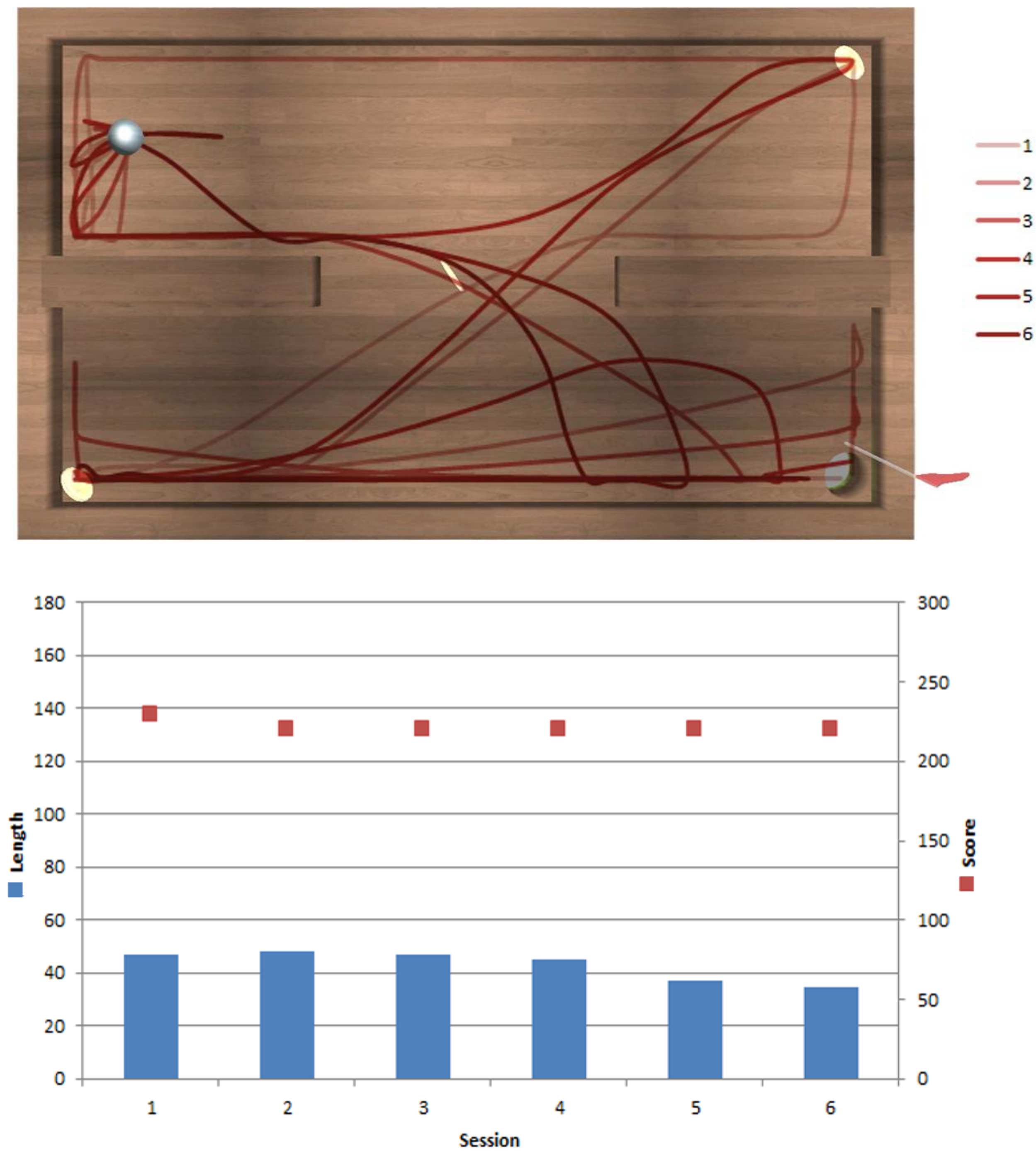


Figure 13-24 (a) Paths of the marble in Level 2 during different training sessions

(b) Lengths of the paths and score achieved in Level 2, during different sessions

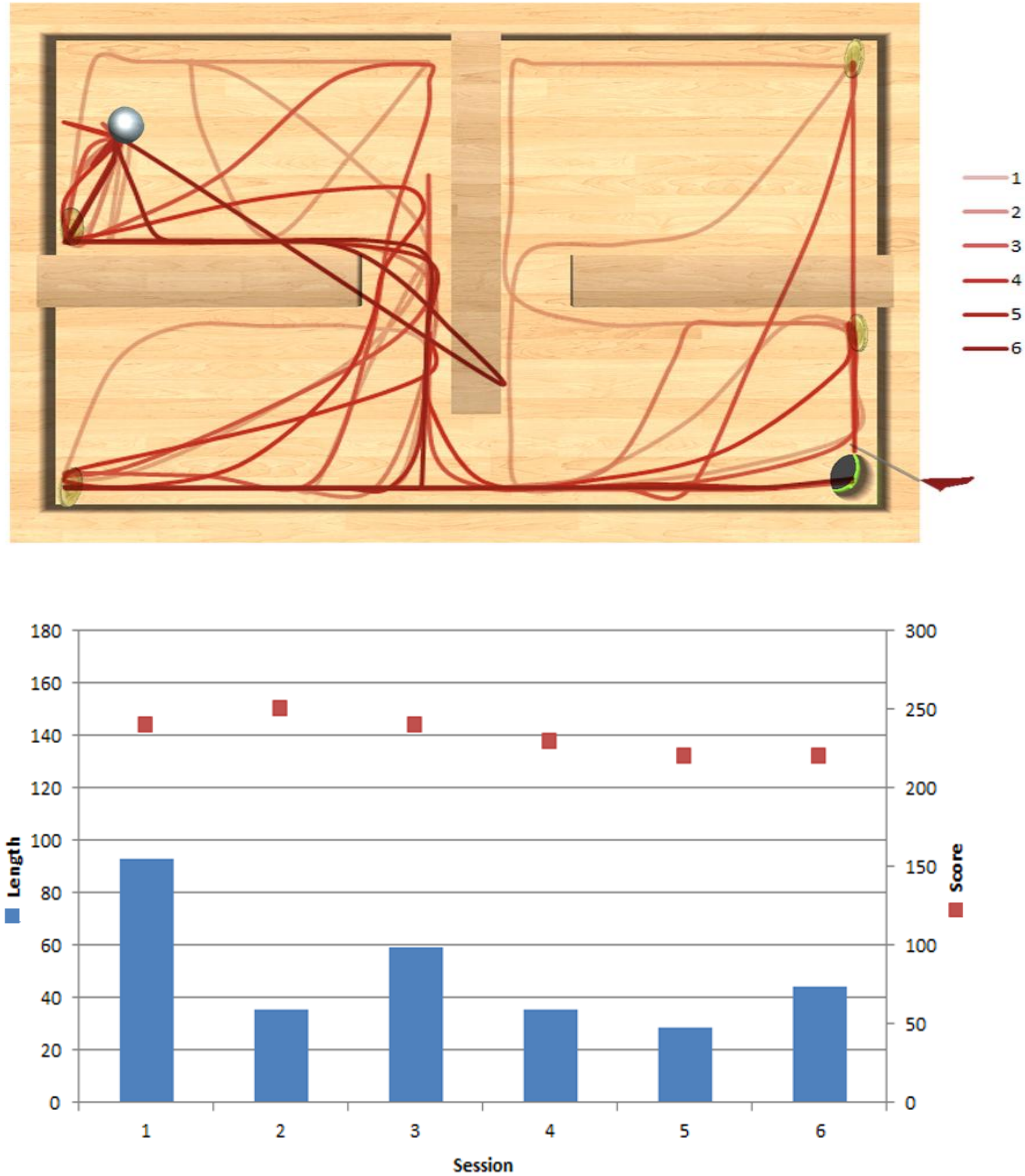
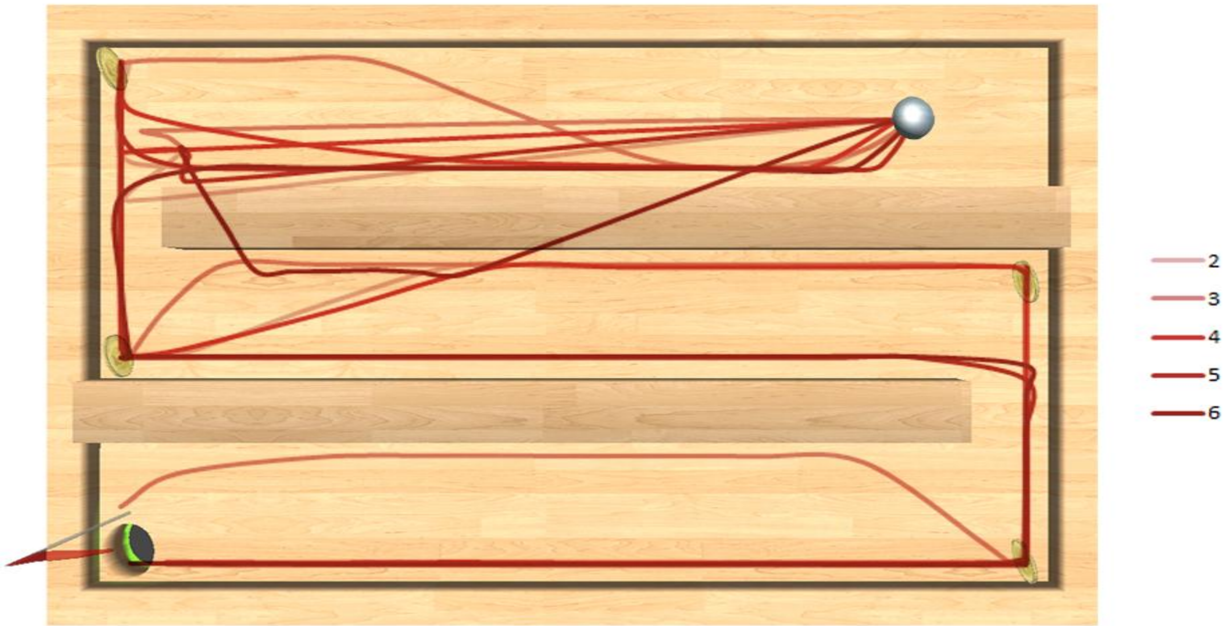


Figure 13-25 (a) Paths of the marble in Level 3 during different training sessions

(b) Lengths of the paths and score achieved in Level 3, during different sessions



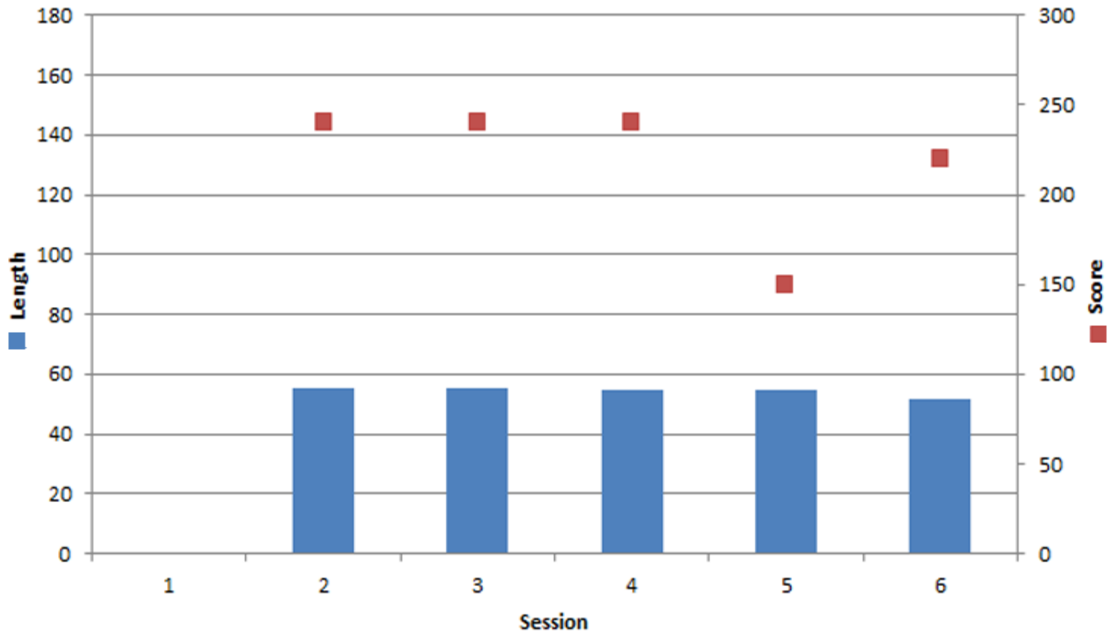


Figure 13-26 (a) Paths of the marble in Level 4 during different training sessions
(b) Lengths of the paths and score achieved in Level 4, during different sessions

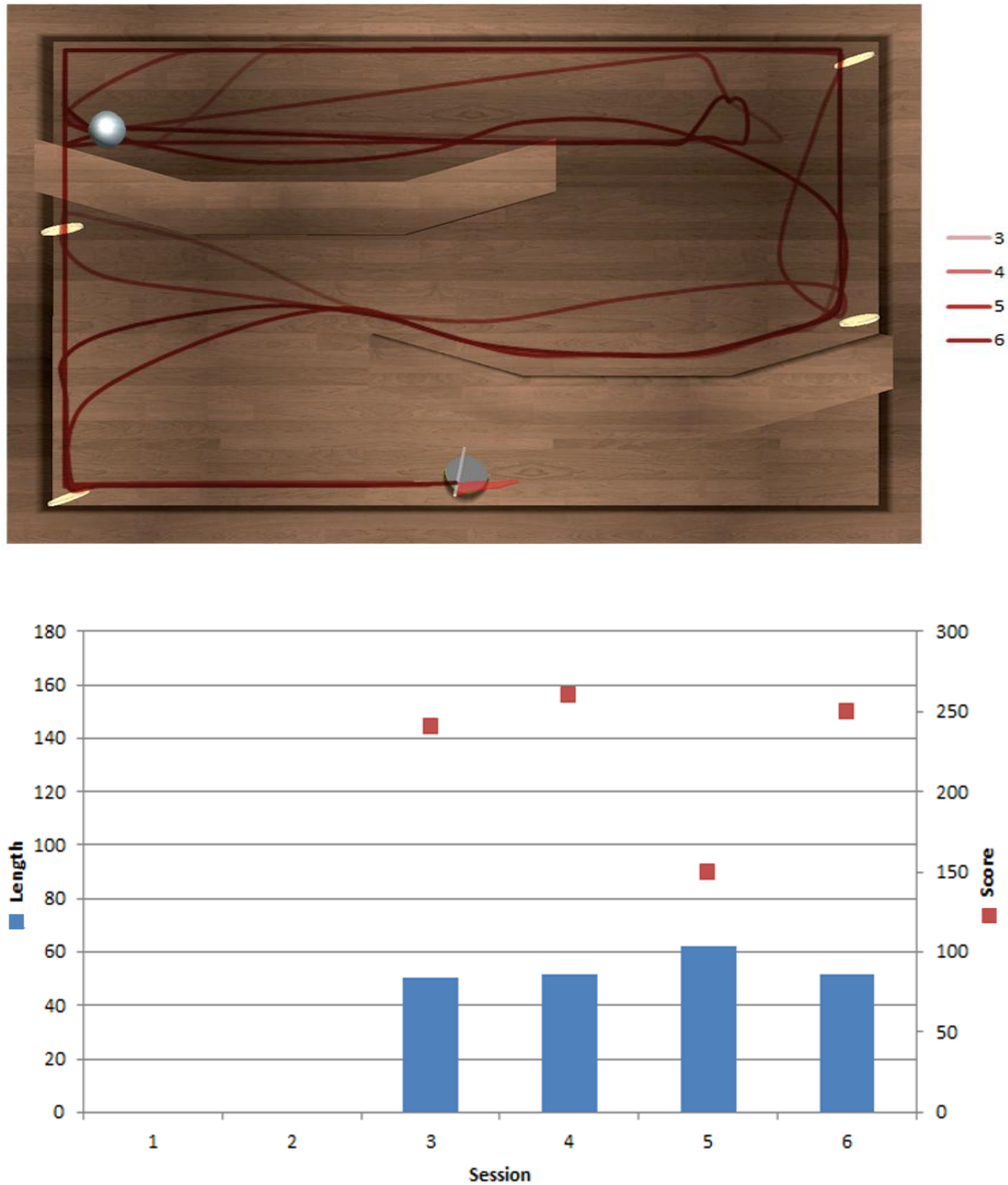
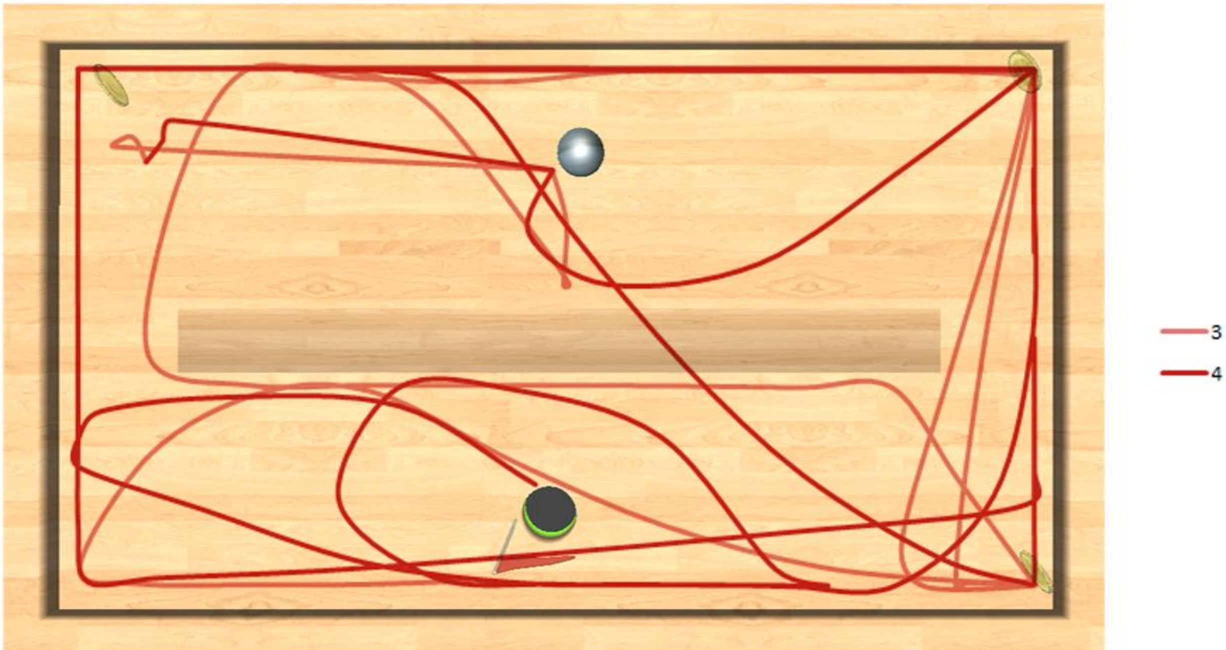


Figure 13-27 (a) Paths of the marble in Level 5 during different training sessions
(b) Lengths of the paths and score achieved in Level 5, during different sessions



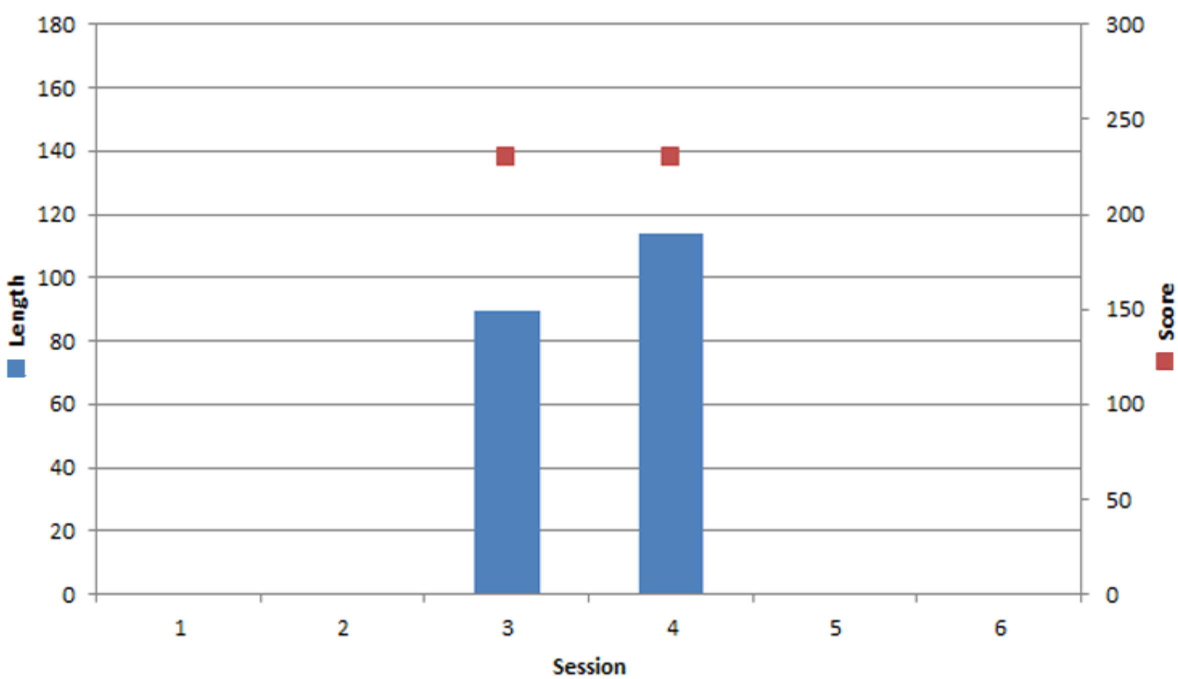


Figure 13-28 (a) Paths of the marble in Level 6 during different training sessions

(b) Lengths of the paths and score achieved in Level 6, during different sessions

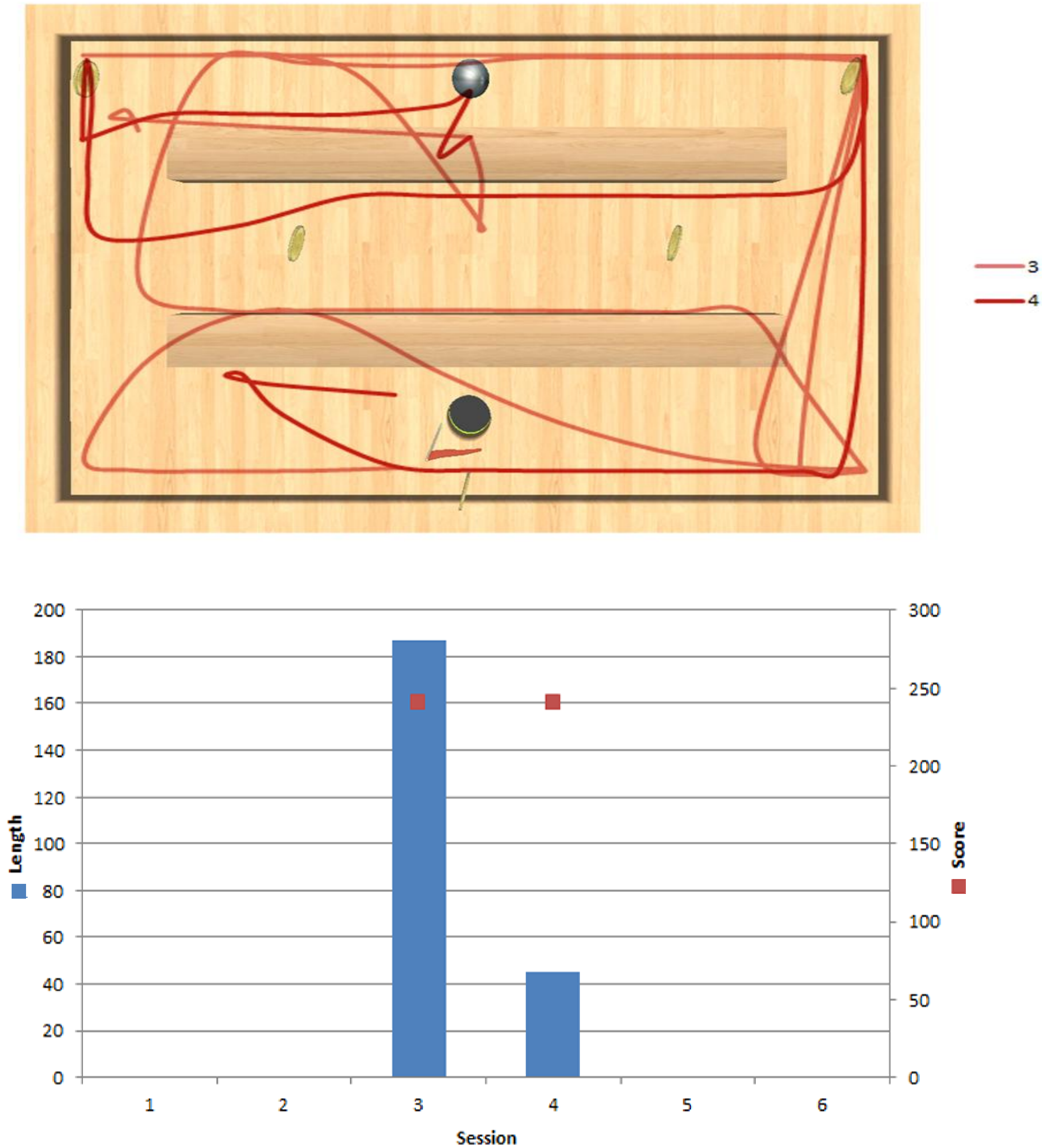
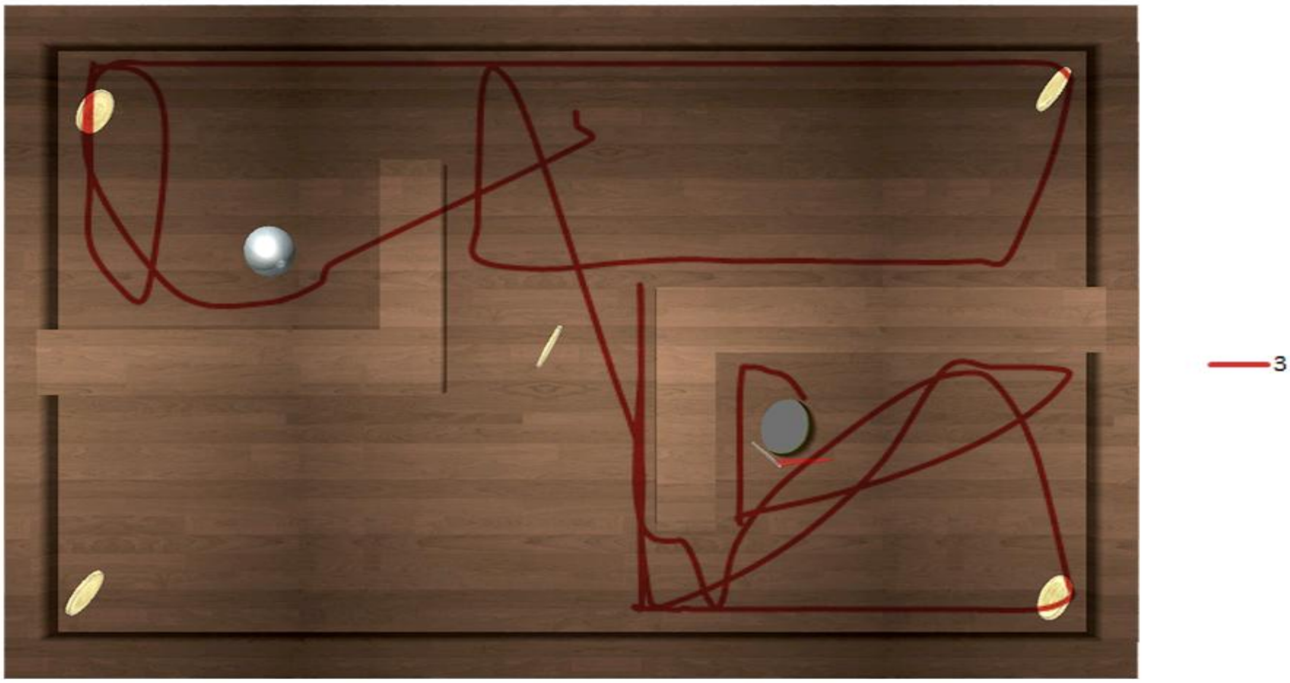


Figure 13-29 (a) Paths of the marble in Level 7 during different training sessions

(b) Lengths of the paths and score achieved in Level 7, during different sessions



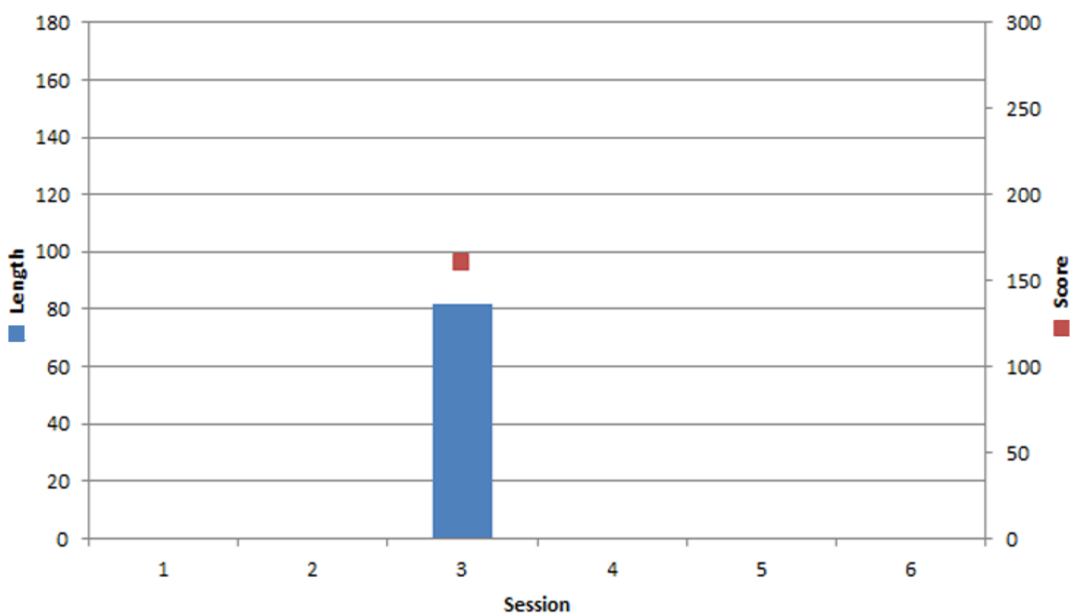
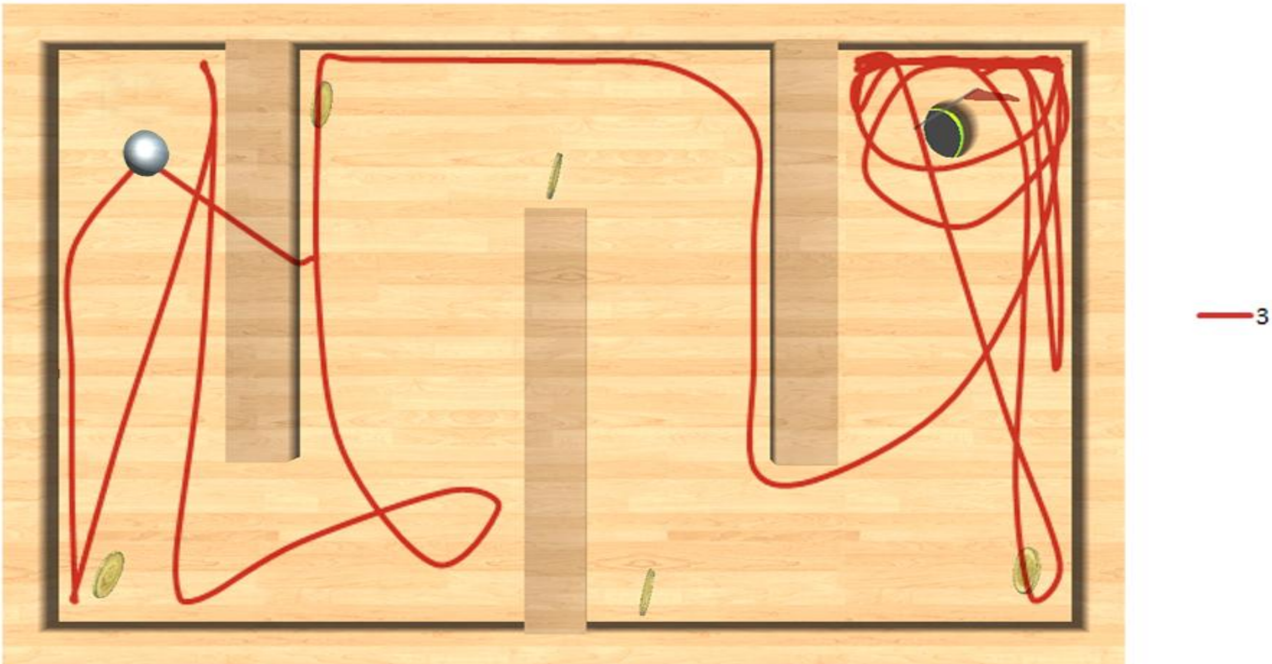


Figure 13-30 (a) Paths of the marble in Level 8 during different training sessions
(b) Lengths of the paths and score achieved in Level 8, during different sessions



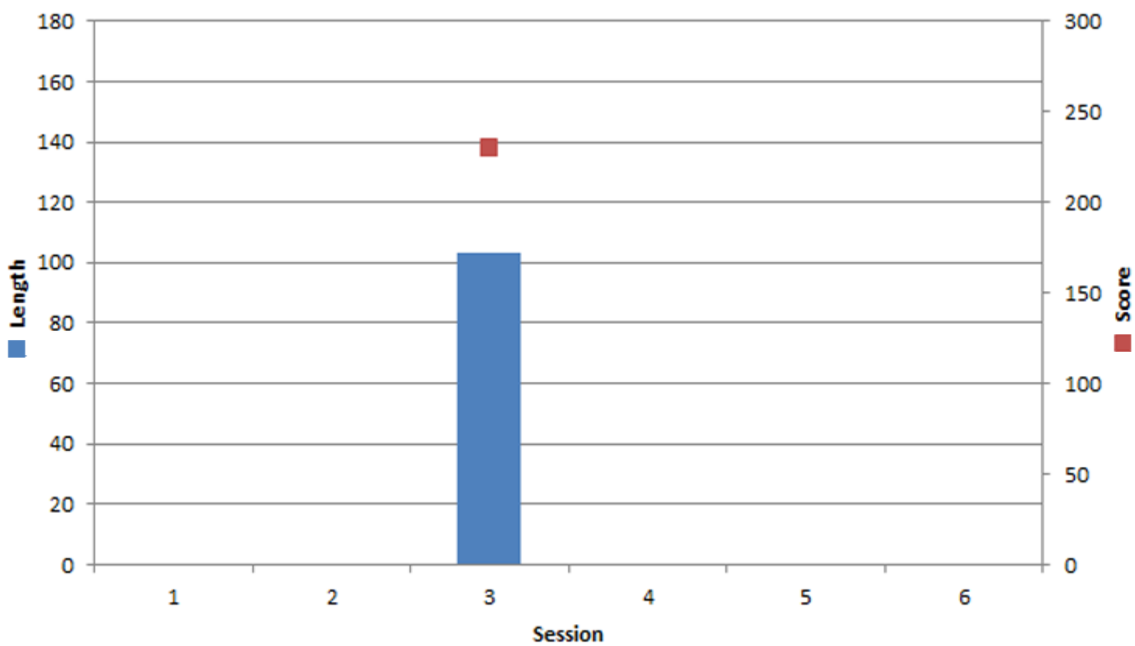
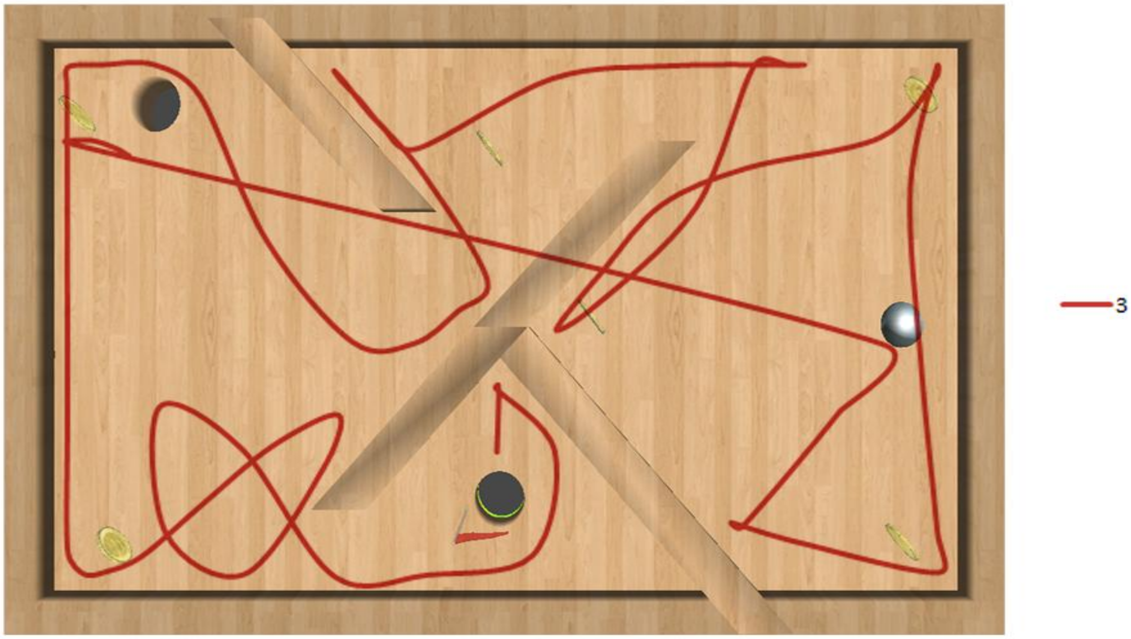


Figure 13-31 (a) Paths of the marble in Level 9 during different training sessions

(b) Lengths of the paths and score achieved in Level 9, during different sessions



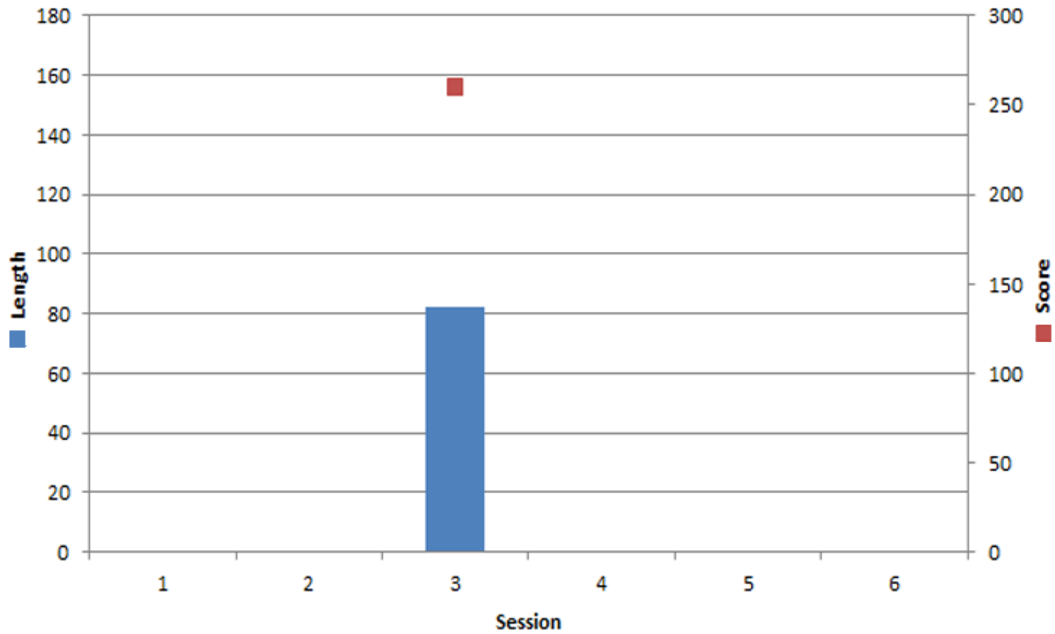


Figure 13-32 (a) Paths of the marble in Level 10 during different training sessions

(b) Lengths of the paths and score achieved in Level 10, during different sessions

14. APPENDIX III – FEEDBACK FROM PATIENTS

Game	Patient 1	Patient 2	Patient 3
Burger Hub		▪ Sometimes the plate does not turn green (when there are 3 plates available). The patient has the hand already on top of the plate, but it's not turning green and so not able to grasp the ingredient. ▪ It's quite difficult to move the arm exactly above the plate ▪ Sometimes I can't see the arm on the screen. I'm moving my arm from left to right, but the arm on the screen is not moving. ▪ The patients does not like this game that much, because it seems that the knife is not really doing what the patient is doing with her wrist, it does not react that well. When the patient moves the wrist into flexion, the green marker also moves on the screen, so this makes it difficult to keep the arm on the correct place and cut the vegetable correctly. ▪ The reaction of the system did not seem to work that good. It was very difficult to grasp the ingredients from the 2 plates that are located behind each other. ▪ Moving from left to right do not work that well.	▪ The arm on the screen was really jerky! ▪ When an additional plate is added (so total 3), sometimes one of the plates is not turning green anymore (which means you are able the grasp), although the arm is perfectly above the plate. "If that happens, I don't like the game anymore" ▪ The arm on the screen is very jerky ▪ Cutting the vegetables is really difficult, the patient likes the burger level much more

Game	Patient 1	Patient 2	Patient 3
Flight Game		▪ After calibration we noticed a black screen. Nothing happened anymore, and we had to close the UI and restart the pc. ▪ Sometimes flight does not move correctly up, down, left or right. ▪ Again, it does not react that good to fly up, down, left and right. That's frustrating. ▪ After calibration we saw a black screen, and had to restart the pc. ▪ It looked like the settings for wrist flexion/extension are set a little too sensitive, because the plane moved up really quickly, even without moving the wrist up. ▪ Also when the patient wanted to enlarge the circle to fly through it (hand opening), the plane moved up suddenly. Consequently, she failed that action because she already flew too high then, which was frustrating.	▪ This game is a little boring. ▪ "I don't like this game, it's boring." ▪ The least favorite game

Game	Patient 1	Patient 2	Patient 3
Fruit Picker	▪ In the pause screen, the resume game button did not work. It gave applause again, but did not start the game. The only option was to stop the game and return to the home screen of the UI. ▪ After playing the first level, the game kept staying in the pause screen, the resume game button did not work. It gave applause again, but did not start the game. The only option was to stop the game and return to the home screen of the UI. ▪ The bananas fall just next to the basket, it's annoying and I hate that. ▪ Sometimes, the banana will not release from the hand, when the patient already has his fingers in extension. (--> Explained first to make a grasp again, but this was not logical for the patient).	▪ The grasping does not work that good that week. (--> probably something went wrong during calibration. At next home visit this was solved by repeating the general calibration) ▪ Nice to grasp some new fruits. (when providing category 2 instead of 1)	▪ The marker on the screen was really jerky. ▪ Game got stuck once in the pause screen. The patient wanted to restart, but the system did not react on that (but gave applause again and just stayed in the pause screen. The only option was to stop the game). ▪ The most favorite game, this game works best with me. ▪ The marker on the screen is really jerky, which makes it almost unable to play the fruit picker game ▪ Again, the marker was really jerky. “I’m getting totally crazy if I see that marker blinking all the time. I’m fed up really soon then, because I really don’t like the game anymore because of that.”

Game	Patient 1	Patient 2	Patient 3
Grandpa Lost Glasses		▪ The scores and duration are not saved in the portal. ▪ Sometimes the patient was not able to find the glasses. She tried all the objects, but still couldn't find it. ▪ It's very difficult to search in small objects. When you are grasping, the wrist automatically also moves, so the cursor is not on the object anymore and so you are not able to grasp. ▪ Moving from left to right do not work that well.	▪ I don't get this game, I can't manage to succeed ▪ I really don't like the tune when you lose (can't find the glasses in time)." ▪ The patient cannot succeed in this game, because he is not able to hold the arm still above an object, and then grasp. While grasping, the marker on the screen is already moving again, so the grasp is not successful anymore.

Game	Patient 1	Patient 2	Patient 3
Marble Maze	▪ The patient mentioned that he really liked to play this game. ▪ "Something strange was happening: The ball was just moving through the walls, that stupid thing". It was confusing. But still this game is his favorite.	▪ The game has no "stop game" button in the pause screen, so the patient did not know how the close the game, and closed the pc with the power button (and so data was not stored) ▪ The marble does not move to the left, that doesn't work in this game ▪ She experienced some difficulties in moving the marble to the right in the marble game --> probably because of the amount of (day)light available in the room, and so visibility of the green marker by the camera? ▪ The last ball, when all the coins were already grasped, was often a ghost marble. However, at the end of a level, a ghost marble has no additional function anymore. ▪ Moving from left to right do not work that well.	▪ “This game is quite difficult. I really have to think which gesture means which movement in the game. I really have to think while playing this game. That's why I did not play this game by myself yet." ▪ I really have to think about which gestures to make, to let the marble roll in the correct direction. ▪ The patient mentioned that this is a boring game, he doesn't like it.

Game	Patient 1	Patient 2	Patient 3
Run Jack Run	▪ When he was in calibration, the system hung at the moment the patient needed to keep the green marker in the middle of the screen, so the webcam probably caused the hung. ▪ After playing the game and losing all lives, the patient wanted to restart. Then suddenly, the game was automatically going back to the UI. When playing the next game, we noticed an error in calibration, which needed us to restart the UI again.	▪ The game has no "stop game" button in the pause screen, so the patient did not know how the close the game, and closed the pc with the power button (and so data was not stored) ▪ It's very difficult to see if you turn left/right correctly. The screen changes really sudden, so it's difficult to find the correct moment to turn left/right. And so this goes wrong very often, resulting in losing your lives really soon. ▪ The avatar jumped and or dived on the screen, even when the patient was not actively extending/flexing the wrist. And sometimes when the patient was actually making a wrist extension movement, the avatar did not react on it (--> was explained to first bring wrist into flexion again). ▪ Turning left/right is still very difficult. You have to do this 3 times after each other, and that's not working, and so you keep losing lives.	▪ It's really difficult to turn left and right correctly. ▪ Turning left and right is really difficult, and I don't like that in this game. Therefore, level 2 is way more fun. ▪ After losing all the lives, we automatically returned to the home screen after touching restart game. The next game gives an error in calibration, and consequently we needed to restart the whole UI. ▪ After losing all lives, we wanted to restart, but then again there was the error when clicking restart game: we automatically returned to the home screen, and had to restart the UI to play the next game. ▪ Unfortunately, the game caused an error during calibration. When clicking OK, it skipped the grasp calibration, and then automatically returned to the home page. The next game we wanted to click showed an error in calibration. ▪ Again, the Run Jack2 game caused an error this week when losing all lives. During the visit, contact was made with technical partners to check on this game. Some other software (which was also used during a demo last week without any problems) was installed on the

			patient's pc. But unfortunately this did not help, because after testing again the game returned automatically to the home page after losing all lives, and causing an error in the next game.

Game	Patient 1	Patient 2	Patient 3
Seashell			▪ At first play, he did not understand that he needed to keep his wrist in extension during grasping. (Was explained during home visit). ▪ "I think this is just a boring game." ▪ The game already pauses after 1 minute, is there a reason for this? ▪ The patient mentioned that he does not like the seashell game, so he did not want to play that game during the home visit. ▪ Again the patient mentioned that this is just a boring game

Game	Patient 1	Patient 2	Patient 3
Super Crocco		▪ Wrist flexion and extension seemed not to react always. The patient already has the wrist in extension, but was not able to jump over the rock (--> was explained to first bring wrist into flexion again). ▪ Compared to the other games, left/right does work well in this game.	▪ With crocco level 3 I have to think more about which action to do (because there is wrist flexion, extension, and grasping), which makes it more difficult. ▪ This game works best now, so I like this game most now. “In this game I’m at least able to complete at least 5 minutes." That is the personal goal for this game.

15. APPENDIX IV – GAME GENRES

Table 15-1 - Game genres and description

Genre	Description
Action:	One of the most basic genre of games; action games are fast-paced events and rely on movements which have to be performed timely and reflexively. Games such as Pong and Space Invaders initially defined the genre.
Adventure:	Adventure games are usually based on solving different puzzles to progress through the game and encourage freedom of exploration. Puzzles often involve manipulating and interacting with in-game objects and characters. Monkey Island, Full Throttle, Siberia, and Day of Tentacle are some of the classic examples of adventure games.
Arcade:	Arcade is a fairly broad term genre usually applying to older games. Arcade games usually do not have an expansive storyline and are based on a simple game play where the objective is to finish the game with the most points possible. Bubble Bobble and Metal Slug are good examples of arcade games.
Platform games (also known as platformers):	Platform games in their core form, require the protagonist to move in a 2D or 3D environment between surfaces (the platforms) whilst avoiding or overcoming impeding obstacles. The games usually require dodging the impeding obstacles, but often in some games basic combat in form of squishing or punching is introduced. Super Mario Bros, Sonic the Hedgehog, Prince of Persia are some famous examples of platform games.
Fighting games:	Fighting is a specific genre which involves players to typically fight other players or the computer in a one-on-one combat to a certain outcome. The outcomes are usually based on depletion of health points or being knocked out of a defined arena. The games are based on reflexive movements and put high emphasis on competition. Examples include Street Fighter, Mortal Kombat, King of Fighters and Tekken.

Shooting Games:	Shooting games, as the name suggests involve the player to shoot enemies with arsenal of guns and ranged weapons. Shooting games are often based on first-person view and are also known as First-Person-Shooting (FPS) games, however some games support third-person views, hence are called Third-Person-Shooters (TPS). Shooting games are fast-paced, reflexive games usually based on stealth based and puzzle-solving storylines. Doom 3D, Half Life, Call of Duty and Battlefield are some famous examples of shooting games.
Racing Games:	Racing games involve competing in a race against different opponents and/or time to the finish. There are a variety of racing games from ones like Need for Speed, or Gran Turismo that are based on realism in terms of graphics, physics, and track settings to a more cartoonish style kart-racing games for example the Mario Kart series.
Role-Playing-Game:	A role-playing-game (RPG) is a game in which the player assumes the control of characters in a fictional setting. The game walks the player through a narrative and a process of structured decision-making or character development. Since the genre is based on table-top games, a fantasy theme is often retained. Final Fantasy series, Elder Scrolls Oblivion, and Skyrim are some of the famous examples of RPG games.
Simulation Games:	Simulator games refer to games that realistically recreate an experience allowing the player to interact with various objects and characters and assume different roles. The experiences can be specific like Microsoft Flight Simulator which simulates physical activities like flying an aircraft with as much realism as possible. Other and more general simulation games, like the Sims, allow the player to control a person or number of people developing their characters, relationships, and careers.
Sports Games:	The sport genre, sometimes considered a sub-genre of the simulation genre,

	simulates a sporting experience. Some sports games emphasize on the experience of playing the sport while others focus on the strategy behind the sport. FIFA, Nintendo Wii Sports Series, Champions Manager are notable examples.
Puzzle Games:	Puzzle games present players with mind teasers which they have to solve usually in a rapid pace. Tetris is one of the famous examples of puzzle games. Puzzles genre is also usually incorporated in games of other genres as mini-games which the player must solve to progress in the larger environment of the game.
Traditional Games:	Traditional games represent computerized version of board games, card or word games such as checkers, monopoly, chess, scrabble etc.

The Table 15-1 lists the most common game genres, but there are other ones and sub-genres within these classes. Games within a single genre, often share characteristics but depending on the complexity of the game's interactivity, a single game can belong to multiple genres for example Action-Adventure games.