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Multi-user Touch Surfaces to Promote Social Participation and Self-efficacy in Upper-limb Stroke Rehabilitation

DOCTORAL THESIS

Fábio Dinis Silva Pereira
DOCTOR DEGREE IN INFORMATICS ENGINEERING
SPECIALIZATION: HUMAN-COMPUTER INTERACTION

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SUPERVISION
Mónica da Silva Cameirão

Abstract

This thesis addresses the growing incidence of stroke and its impact on long-term disability, emphasizing the importance of post-stroke rehabilitation. Predicting a 34% increase in stroke cases by 2025, this work focuses on factors affecting post-stroke motor rehabilitation, such as depressive symptoms, while recognizing the role of social participation and self-efficacy in modulating these outcomes.

To tackle these challenges, we propose the use of a multi-user interactive table for upper limb rehabilitation. This innovative approach involves detecting objects of various sizes and shapes as interfaces for serious games, fostering collective therapeutic activities targeting motor rehabilitation, depressive symptoms, social participation, and self-efficacy.

Four exploratory studies informed the development of the interactive table. The studies determined game mechanics, object types, and game features. Three game modes (competitive, co-active, and collaborative) were explored, with the collaborative mode showing higher social engagement and more positive outcomes. Subsequent studies involving stroke survivors confirmed the effectiveness of collaborative gameplay. Feasibility, engagement, and usability were tested using objects of different sizes and shapes, revealing insights into task performance, grasping, and task complexity adjustments.

The developed interactive table accommodates up to four participants, using top-down object shape tracking and a multi-touch panel. Four serious games were designed to target specific upper limb skills, played in collaborative mode with incorporated features to enhance the overall experience. A pilot study with 12 stroke survivors over four weeks demonstrated significant improvements in motor outcomes, including range of motion, dexterity, strength, and coordination. The participants reported high enjoyment and interest in the system, with good usability scores. The study suggests that a group-based holistic motor rehabilitation approach, as presented, holds potential for enhancing motor outcomes by promoting social interaction and self-efficacy. These results indicate the viability of the proposed system as a promising solution for stroke rehabilitation.

Keywords: stroke motor rehabilitation; interactive table; tangible interfaces; self-efficacy; social interaction; depressive symptoms.

Resumo

Esta tese aborda a crescente incidência do AVC e o seu impacto na funcionalidade a longo prazo, realçando a importância da reabilitação pós-AVC. Prevendo-se um aumento de 34% nos casos de AVC até 2025, este trabalho foca-se em fatores que afetam a reabilitação motora pós-AVC, como os sintomas depressivos, reconhecendo o papel da participação social e do sentimento de auto-eficácia na nestes sintomas.

Para enfrentar esses desafios, propomos o uso de uma mesa interativa multi-utilizador para reabilitação dos membros superiores. Esta abordagem inovadora envolve a deteção de objetos de vários tamanhos e formas como interfaces para os jogos sérios, permitindo atividades terapêuticas em grupo direcionadas à reabilitação motora, sintomas depressivos, participação social e autoeficácia.

Quatro estudos exploratórios suportaram o desenvolvimento da mesa interativa, determinando mecânicas de jogo, tipos de objetos e recursos do jogo. Três modos de jogo (competitivo, co-ativo e colaborativo) foram investigados, com o modo colaborativo mostrando maior envolvimento social e resultados mais positivos. Estudos subsequentes envolvendo sobreviventes de AVC confirmaram a eficácia do jogo colaborativo. Viabilidade, envolvimento e usabilidade foram testados usando objetos de diferentes tamanhos e formas, revelando insights importantes relativos ao desempenho nas tarefas, preensões e ajustes de complexidade da tarefa.

A mesa interativa desenvolvida acomoda até quatro participantes, e permite a deteção de objectos para serem usados como interfaces e um painel multi-toque. Quatro jogos sérios foram projetados para reabilitar competências específicas dos membros superiores, desenhados para serem jogados em modo colaborativo e com recursos incorporados para potenciar o processo de reabilitação e a experiência do utilizador. Um estudo piloto com 12 sobreviventes de AVC ao longo de quatro semanas, demonstrou melhorias significativas nos resultados motores, nomeadamente amplitude de movimento, destreza, força e coordenação. Os participantes reportaram níveis altos de prazer e interesse no sistema, e pontuações de usabilidade promissoras. Este trabalho sugere que uma abordagem de reabilitação motora holística e em grupo, como apresentada, tem potencial para melhorar os resultados motores promovendo a interação

social e o sentimento de auto-eficácia. Estes resultados sugerem a viabilidade do sistema proposto como uma solução promissora para a reabilitação motora no AVC.

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During the past six years, I faced numerous challenges both professionally and personally. This period also witnessed some of the most significant moments in my life story. I started the Ph.D. when my first daughter was 1 year old and will complete it by the time my second daughter is 1 year old. Meanwhile, my professional focus shifted to a new employer, which significantly increased my workload and simultaneously I lived a personal nightmare with the government expropriating my home. The task of completing the Ph.D. became more challenging over time, and I experienced occupational imbalance and relied heavily on my family's support. However, my determination to finish as initially planned remained constant.

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List of Acronyms

9HPT	Nine-Hole Peg Test
ADL	Activities of Daily Living
ARAT	Action Research Arm Test
BDI-II	Beck Depression Inventory - II
BLObs	Binary Large Objects
BBT	Box&Blocks Test
CBF	Cerebral Blood Flow
FLP	Functional Limitations Profile
FMA	Fugl-Meyer Assessment
GEQ	Game Experience Questionnaire
H MoCAs	Higher MoCAs Scores
IADL	Instrumental Activities of Daily Living
ICD	International Classification Disorder
ICF	International Classification of Function
IMI	Intrinsic Motivations Inventory
IQR	Inter-Quartile Range
L MoCAs	Lower MoCAs Scores
mAS	Modified Ashworth Scale
MAL	Motor Activity Log
Mdn	Median
MINI-IPIP	Short version of International Personality Item Pool
MoCA	Montréal Cognitive Assessment
NIBS	Non-Invasive Brain Stimulation
NSA	Nottingham Sensory Assessment
PNF	Proprioceptive Neuromuscular Facilitation
PSD	Post-Stroke Depression
RGB	Red, Green, and Blue
ROM	Range of Movement
RPSS	Reaching Performance Scale for Stroke

rTMS	Repeated Transcranial Magnetic Stimulation
SD	Standard Deviation
SESARAM	Serviço de Saúde da Região Autónoma da Madeira (Madeira Health Service)
SSEQ	Stroke Self-Efficacy Questionnaire
SULCS	Stroke Upper Limb Capacity Scale
SUS	System Usability Scale
TCAs	Tryciclic Antidepressants
tDCS	Transcranial Direct Current Stimulation
ULF	Upper Limb Function
ULI	Upper Limb Impairment
VR	Virtual Reality

Chapter 1. Motivation

1.1. Introduction to the Context of Research and its Relevance

Stroke is the leading cause of acquired physical disability in Europe and the second leading cause of death worldwide [1]. According to World Stroke Organization [2], it is estimated that stroke has a global burden of €795 billion. They emphasize a growth of 70% increase in incident strokes in the past three decades, resulting in approximately 1 in every 3 seconds around the world [3]. Together with the aging of the world population [4], projections point to an increase of 20.5% in the prevalence of stroke between 2012 and 2030 [5]. This increase in incidence and the emergence of more developed techniques for providing life support that enhance the provision of urgent medical services [6], [7] increase survival rates after stroke. According to Owolabi *et al.* [3], there are currently approximately 101 million individuals worldwide who are living with stroke. This number has been steadily increasing and has even doubled within the last three decades [3]. This means there will be more people with long-term impairments who will need rehabilitation [6], and despite medical advances, about 50% of stroke survivors remain permanently reliant on others for daily living tasks [8]. On the other hand, these advancements in the medical management of acute stroke have diminished upper limb affectation from around 70%-80% in 2001 [6], [7] to 48%-57% in 2019 [8]. A more recent study from 2021 reports 57% of upper limb weakness on admission and 49% after 24 hours post-admission [9]. This highlights that despite the progress in the medical techniques for managing stroke, a substantial subset of patients still experiences a high percentage of limb impairment. Up to 50% of survivors will display persistent deficits five years after stroke [10].

Upper limb deficits can have a significant functional impact that severely affects the performance of basic activities of daily living ADL. It is estimated that 80% of those with upper limb affectation require hand therapy [11]. The loss of hand function is an apparent reason for impairment in neuromuscular disorders [12] as it negatively interferes with effective occupational performance and independent participation[13], [14]. The most common impairments are muscle weakness, diminution of range of motion, shoulder subluxation, muscle shortening, sensory alterations, pain, and spasticity [15], [16]. In addition, these physical impairments are frequently linked to post-stroke depression (PSD) [17], as functional impairment has a fivefold increased risk of causing depression [18]. According to meta-analyses, the cross-sectional prevalence of

PSD is between 18 and 33% [19]. PSD has a multifactorial basis, with functional status, cognitive impairments, and lesion size as its primary causes of incidence [17], [18], [20]. Besides causing social role changes and social isolation, PSD makes the rehabilitation process more challenging, with reports showing a decline in effectiveness [21]–[23].

Stroke can impact social dimensions extensively, affecting family dynamics, altering roles and daily routines, and changing how stroke survivors engage in family activities and social life [21]. After a stroke, it is common to notice a decline in social networks, leading to diminished social support and closely related to the emergence of depressive symptoms [24]. Social participation is one of the most crucial elements for a full recovery from a stroke and is also closely related to post-stroke depression [25]. Physical impairment and increasing depressiveness are, in turn, associated with a low sense of self-efficacy. There is growing evidence that self-efficacy is relevant for stroke management [26], [27], as it is associated with mobility, balance, and health-related quality of life [28]. It is defined by Bandura [29] as "people's beliefs about their capabilities to produce designated levels of performance that exercise influence over events that affect their lives''.

Hence, the effects of stroke are multifaceted, and its severity and consequences are very heterogeneous. Thus, current rehabilitation health guidelines point towards a person-centered approach, where rehabilitation shall be addressed as a whole [30]. This means that while not discounting the unique characteristics of each person, such as their interests, values, and roles, we should consider all stroke-affected dimensions, such as social participation, mood (emotional), motor, and cognitive.

Post-stroke care continues to have its foundations mainly on rehabilitation services, predominating standard methods such as bilateral arm training, constraint-induced movement therapy, various electrical stimulation techniques, mirror therapy or repetitive task training [31]–[33]. However, many new technologies have emerged to create novel paradigms to support stroke rehabilitation [34]–[36]. Technologies such as robotic arms, body and hand trackers, interactive tables, Virtual Reality (VR) or data gloves allow new forms to address rehabilitation, with several benefits compared to conventional therapy [34], [37]. Some of these benefits are [38]–[42]: 1) Increased number of movement repetitions; 2) Increased motivation and engagement; 3) Replication of functional activities in specific virtual environments; 4) Automatic user ability adjustment; 5) High level of personalization; 6) Real-time feedback; and 7) Performance analysis over time. Therefore, integrating these systems into rehabilitation can potentially improve stroke recovery results.

This thesis focuses on upper limb motor rehabilitation while approaching depressive symptoms, social impact, and self-efficacy, as these are interconnected and significantly influence the rehabilitation process. We address these four domains using a multi-user interactive table with various serious games. This approach allows stroke survivors to participate in collective therapeutic gamified activities focused on hand rehabilitation. Games are designed to potentiate a sense of positive self-efficacy and social interaction. A variety of objects are used for the interaction. These objects can be adjusted to the individual motor profile of each user, encouraging progressive training of fine and gross motor skills. We expect this approach to impact reducing depressive symptomatology through increasing social participation and self-efficacy, thus potentiating upper limb rehabilitation.

1.2. Thesis Organization

The thesis is organized into seven chapters. The first chapter aims to give the reader an understanding of the research's context and why it is important. Chapter 2 provides a comprehensive overview of the current state of the art, and finishes with the main research questions and the respective research contributions. In the third chapter, we explore the effect of game modes on motivation and social interaction. We report a preliminary study with elderly participants and a second study with stroke patients using different setups. Chapter 4 discusses the design of objects and serious games for upper limb motor rehabilitation with stroke survivors. This chapter is divided into two parts. The first part explores game mechanics and object properties in a tangible interactive upper limb motor rehabilitation system. The second part discusses the impact of distance and object size on reach and grasp in stroke patients. Chapter 5 details the creation and challenges faced during the development of the interactive table and its associated serious games. The process is thoroughly described. Chapter 6 describes a pilot study where we analyzed the impact of our proposed approach on upper limb motor skills, depressive symptoms, social interaction, and the sense of self-efficacy. Finally, Chapter 7 is dedicated to the main conclusions of the thesis, the implications for future practice in the field of rehabilitation, limitations, and future work.

Chapter 2. State of the Art and Research Questions

2.1. Stroke

Stroke is defined in the International Classification Disorder – 11 (ICD-11) by the World Health Organization (WHO) [46] as "acute symptoms of focal brain injury that have lasted 24 hours or more (or led to death before 24 hours)"[46]. There are two subtypes of stroke, ischemic and hemorrhagic [46]. The first is defined in ICD-11 as an "*acute focal neurological dysfunction caused by focal infarction at single or multiple sites of the brain"* [46]. The second is defined as an "*acute neurological dysfunction caused by hemorrhage within the brain parenchyma or in the ventricular system"* [46]. Until 2018 stroke was classified as a disease of the blood vessels under ICD-10 [47]. Since the reclassification of stroke as a neurological disorder in ICD-11, researchers have been able to get increased funding to produce more accurate data and statistical analysis. This has led to advancements in acute stroke healthcare[47].

Whether it is ischemic or hemorrhagic, stroke is characterized by a sudden onset of neurological symptoms caused by inadequate blood flow to the brain, leading to a lack of oxygen supply and consequent cell death (necrosis) and brain damage. According to the World Stroke Organization, ischemic occlusions account for most strokes, with 62% occurring worldwide [2]. Whether the cause is ischemic stroke or intracerebral hemorrhage, a common pathway triggers brain inflammation [48]. This plays a critical role in developing brain edema and other pathophysiological consequences. Inflammation responses in the brain can occur beyond the injury site and persist long-term. These responses can significantly impact the pathophysiology of brain injury following a stroke and contribute to the decline of overall brain function [48].

Stroke can be cortical or subcortical. The cerebral cortex, a significant part of the brain, consists of four lobes: the frontal, parietal, occipital, and temporal lobes. A stroke in one of these lobes is called a cortical stroke [49]. Apart from the cerebrum, subcortical structures are located deep inside the brain, such cerebellum, brain stem, internal capsule, thalamus and basal ganglia. When a stroke occurs in these areas, it is referred to as a subcortical stroke. The blood vessels that provide nourishment to the subcortical regions are smaller and fragile, making them prone to rupture and causing a hemorrhagic subcortical stroke. If a blockage occurs, it can lead to an ischemic stroke, commonly referred to as a lacunar stroke [49].

The brain receives blood from various arteries, with the middle cerebral artery being the most prevalent. It provides blood to a wide region of the lateral surface of the brain, part of the basal ganglia, and the internal capsule through four different segments. Each of these segments supplies blood to different areas of the brain [50]. The anterior cerebral artery supplies blood to the frontal, prefrontal, primary motor and sensory, and supplemental motor cortices. Pure anterior cerebral artery infarctions are rare due to the significant collateral blood supply provided by the anterior circulating artery [50]. The superficial posterior cerebral artery supplies the occipital lobe and the lower part of the temporal lobe. The deep posterior cerebral artery provides blood supply to the thalamus, the posterior limb of the internal capsule, and other deep structures of the brain [50]. Finally, the vertebrobasilar region of the brain is nourished by the vertebral and basilar arteries, which start in the spinal column and end at the Circle of Willis. These areas provide blood flow to the cerebellum and brainstem [50].

When the cerebral blood flow to brain decreases more than 50%, independently of the cause, there is a risk of progression of cerebral tissue towards irreversible infarction [51]. When the flow is quickly restored, the neurons resume their function without any infarction. This is known as a transient ischemic attack in the patient. If the flow is not restored, it can result in irreversible damage to the tissue if it lasts for a significant amount of time, leading to deficits corresponding to the location of the lesion [51]. Figure 2-1 shows how the onset of irreversible tissue injury depends on the magnitude and duration of the drop in blood flow to the brain.

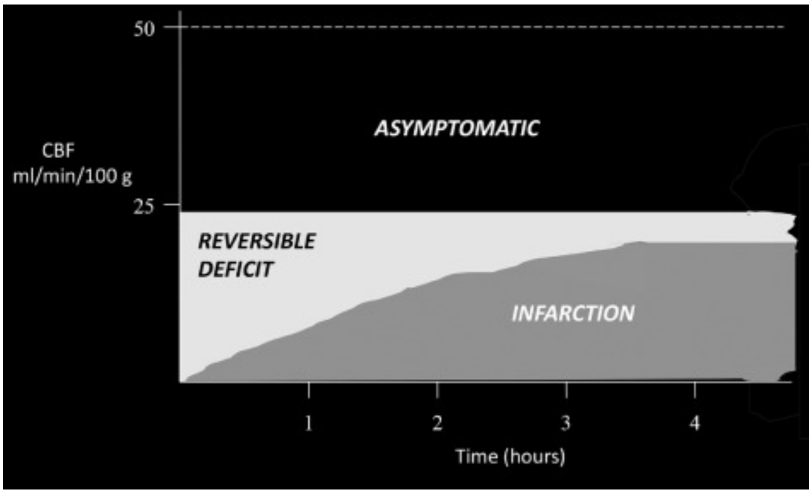


Figure 2-1 - Time course of cerebral ischemia. CBF means Cerebral Blood Flow. This figure was extracted from Feske, 2021.

This is why a rapid response to the onset of first symptoms is crucial. It is strongly advised to have a well-structured stroke protocol in place to speed up the assessment process. For patients who meet the criteria for thrombolytics, a door-to-needle time of 60 minutes is recommended for acute ischemic strokes [50]. In addition to assessing and stabilizing vital signs, quick evaluations should be conducted to eliminate the possibility of alternative diagnoses, such as neurological issues caused by hypoglycemia. Patients should undergo a plain Computed Tomography head or brain Magnetic Ressonance Imaging within 20 minutes of arrival to rule out hemorrhagy [50]. When it is available, vascular imaging is typically considered for potential scenarios such as endovascular intervention; however, this procedure should not delay the administration of thrombolytics. Some patients are candidates for early intravenous thrombolysis to revert the neurological deficit if exams suggest the stroke has less than 6 hours [50].

Stroke survivors experience a wide range of severity of deficits and consequences due to variations in the affected brain area, the extent of the lesion, and the recovery progress. This leads to significant heterogeneity in the outcomes of stroke [52]. The effects of stroke are far-reaching and can affect multiple aspects of a person's life. These can include physical issues such as difficulty with movement, neurological changes, pain, fatigue, and functional challenges like mobility and daily care. Mental health can also be impacted, including changes in mood, self-perception, and cognition [53]. Social interactions such as work, social networks, and social roles can also be affected. The complex interplay between these factors is not fully understood, which can impact rehabilitation efforts [54]. Hence, stroke has a multidimensional impact that severely impairs quality of life and often leads to lifelong consequences [55].

2.2. Stroke & Person-Centered Approach

When addressing stroke rehabilitation, it is important to adopt a comprehensive person-centered approach, which has been shown to have benefits such as increased patient satisfaction with care, improved adherence to care plans, and better quality of life for patients and their families [56]. This approach contrasts with more limited biomedical approaches that mainly address physical, cognitive, and mental symptoms [57].

A person-centered approach acknowledges that every stroke survivor is a person that has unique values, roles, habits, social circle, family, and interests that define them beyond their physical and cognitive traits [58]. One relevant theoretical model that puts the person at its center is the Model of Human Occupation. The study of human occupation is centered around ‘the why’ and ‘the how’ we engage in different occupations such as work, self-care, leisure, or even sleep. All occupations serve a purpose and are important for our overall well-being and health. The Model of Human Occupation provides insight into various components that impact our health and helps us understand human occupation more thoroughly. The model identifies three main components: Volition, Habituation and Performance Capacity. Volition "*refers to the motivation for occupation*'' [58] and is based on personal causation (one's sense of capacity and effectiveness), values (what we find important and meaningful to do) and interests (what we find enjoyable and satisfying to do), being these three interwoven [58]. Another component is habituation, which "*refers to the process by which occupation is organized into patterns and routines*'' [58], being guided by habits and roles. Finally, performance capacity "*refers to the physical and mental abilities that underlie skilled occupational performance, comprehending body factors, as musculoskeletal, neurologic, mental or cognitive and corresponding subjective experience*" [58]. This drives us to another concept which is the lived body. This concept derives from the work of philosophers that argue that the body is a site of experience, which offers new ways of understanding how we can perform and how impairment is experienced and affects performance [58]. This model also considers how the environment affects a person's motivation and performance patterns. Therefore, to enable a more comprehensive approach to rehabilitation, it is important to consider multimodal interventions for rehabilitation that address various areas, including social, physical, cognitive, and emotional aspects [59].

According to the literature, factors such as Post-Stroke Depression (PSD), self-efficacy, and social background can affect motor recovery following a stroke [19], [60]. Moreover, these elements are interdependent and affect each other dynamically [60]. In the next sections, we will individually explore PSD, self-efficacy, and social background to understand their specific impact on motor rehabilitation.

2.3. Post-Stroke Depression

PSD is defined on DSM-5 as a "*mood disorder due to stroke with depressive features, major depressive-like episode, or mixed-mood features*'' [61]. PSD symptoms can occur anytime, but studies show they are most common between 3-6 months after the stroke [62]. However, symptoms tend to decrease in frequency after the first year [63], [64]. It affects approximately 33-40% of all stroke survivors [65], [66]. A recent study with 192 stroke survivors showed that 40% of the sample experienced depressive symptoms at ten years follow-up [66]. Hence, it is important to understand how wider mood alterations/PSD impact people's life and its role in the recovery potential [26], [59]. The mechanism of PSD is not completely clear [63]. It has been suggested that PSD is mainly associated with the consequences and the experience of stroke [67] and has a multifactorial basis [68]. Several factors, including genetic factors, age, sex, history of depression, stroke severity, lesion location, and other factors such as social support, marriage, and years of education, can all contribute to the onset of PSD [63]. Another factor is the need for assistance in the occupations of stroke survivors, negatively affecting their psycho-social well-being [69].

Besides the fact that PSD hinders satisfactory recovery from stroke [70], studies have confirmed that PSD significantly impacts social and family life. For instance, one prospective cohort study, found that PSD led to social isolation during a three-month observation period with 242 patients assessed when completed 3 months after stroke onset [22]. Also, in their systematic review, Northcott *et al*. found that 13 in 14 studies associated depression with poor functional social support [21]. These authors suggest that PSD can potentially disrupt family relationships and produce changes or even loss of roles/routines. In another study conducted by Volz *et al*., 88 patients were studied to determine the impact of early depressive symptoms, social support, and decreasing self-efficacy on post-stroke intervention over a period of 6 months [26]. The study revealed that a lower perception of social support was predictive of PSD, while increasing depressiveness was associated with declining self-efficacy. Importantly, poor rehabilitation outcomes are often linked to PSD [71], [72].

When it comes to treating PSD, there are four main methods: psychosocial, pharmacological, non-invasive brain stimulation (NIBS), and stroke-focused interventions [19], [73]. Psychosocial interventions can include cognitive behavioral therapy, care management, psychoeducation, behavioral activation, and family support, which can be delivered alone or combined [19]. Medeiros *et al.* [19] identify several strengths regarding psychosocial interventions, such as having reliable and standardized proof of effectiveness, the potential of achieving symptomatic relief and the development of coping skills, the possibility of having lower relapse rates and fewer side effects than pharmacotherapy several studies suggest the benefits of using antidepressant medication. As weaknesses, they identify the difficulty of delivering such interventions to patients with cognitive or speech impairment and those severely depressed. Additionally, it requires more time commitment, and access may be more limited. A study by Minshall *et al*. tested a personalized psychosocial intervention on 137 participants, including 73 stroke survivors and 64 carers, over one year through a randomized controlled trial [27]. The variables examined included factors such as quality of life, self-efficacy, symptoms of anxiety and depression, coping mechanisms, perception of illness, work and social adjustments, carer strain, and carer satisfaction. There were no significant differences in outcomes, except for carer satisfaction in the intervention group after 6 months. The effectiveness of the intervention was hindered by the lack of available services and barriers to social engagement, as identified by them [27].

Another modality of intervention is pharmacological. Medeiros *et al.* identify selective serotonin reuptake inhibitors and serotonin-norepinephrine reuptake inhibitors as having sufficient evidence for both effectiveness and tolerability in treating PSD [19]. Nortriptyline and imipramine, which are types of Tricyclic antidepressants (TCAs), have been proven to be more effective than placebo. However, TCAs may cause more side effects. The authors found that the strengths include fair and consistent evidence of efficacy, enabling treatment of other common comorbid conditions such as anxiety disorders. This widely available option can potentially enhance rehabilitation and recovery. Limitations identified are the relatively small samples of clinical trials, drug-drug interactions, a slight increase in the absolute risk of central nervous system hemorrhage, and the higher vulnerability of PSD patients to cardiotoxicity by TCAs [19]. According to a review by Cochrane, 6 trials showed a reduction in the number of people who did not respond well to treatment compared to those who received a placebo [74]. Additionally, in all 8 trials, there was a decrease in the number of people who met the criteria for depression. Adverse events related to the central nervous and gastrointestinal systems were noted in the pharmacological intervention than in the placebo group [74].

When it comes to treating PSD with NIBS, the literature points to two methods: repeated transcranial magnetic stimulation (rTMS) and transcranial direct current stimulation (tDCS) [75]. rTMS is a commonly researched type of NIBS with minimal severe side effects. By modulating specific areas of the brain, it can greatly enhance PSD. Some meta-analyses have confirmed its efficacy [76], [77]. Studies using tDCS with PSD are still preliminary [73], [75]. However, Valiengo *et al.* performed a controlled study with 48 antidepressant-free patients with PSD in a rehabilitation program that consisted of 12 sessions of 30 minutes with transcranial direct current stimulation [78] with effective results in improving depressive symptoms. Bornheim *et al.* conducted a randomized, triple-blind sham-controlled study with 50 stroke patients [79]. Results indicate statistically and clinically significant improvements in anxiety and depression. Transcutaneous vagus nerve stimulation is a technique used to treat depression, but there are no clinical trials regarding PSD treatment [75].

The stroke-focused interventions do not specifically target the symptoms of PSD. Rather, they involve exploring the root cause of the stroke, promoting independence and a higher quality of life, preventing future strokes, and providing rehabilitation. According to Medeiros *et al*. [19], this study area involves large-scale clinical trials, recent advancements in rehabilitation, promising new interventions, and the potential for home-based delivery. However, rehabilitation can be lengthy, lasting months or even years and involving multiple professionals and devices. This can be quite expensive. Additionally, prevention often requires the use of multiple medications and difficult lifestyle changes.

2.4. Self-efficacy

Bandura describes self-efficacy as a person's expectation of their ability to take a particular action and achieve a specific outcome [80]. Regardless of the type, patients with chronic diseases require a particular set of skills to manage their condition, with self-efficacy being one of them [81]. Self-efficacy is not a personality trait but rather a set of beliefs. People must believe their actions can produce specific effects to persevere through challenging situations. Believing in one's ability to achieve a goal directly impacts achieving it [82]. To effectively manage disease processes, patients must increase their self-efficacy and believe in their ability to manage their condition [83]. It is one psychological construct used in managing various chronic diseases, with growing evidence about its importance in treating long-term illnesses [84].

Based on the Self-efficacy Theory [80], the main sources of efficacy expectations are, in order of impact: performance accomplishment (mastery), vicarious experience, verbal persuasion and biofeedback (emotional arousal) [28]. Performance accomplishment or mastery experience is about having positive experiences during a task; vicarious is based on the use of another person as a model through comparison; verbal persuasion is related to increasing own beliefs about the personal level of skills persuaded by another person; biofeedback relates to when efficacy beliefs are a consequence of the feedback produced by individuals' physiological state.

Some authors argue clinicians should consider adaptive psychological factors, such as self-efficacy, during long-term care [85]. However, Szczepańska-Gieracha *et al*. state that therapists do not consider it in their rehabilitation procedures [86]. The impact of self-efficacy in stroke management is shown by Dixon *et al*. in a qualitative study with 24 patients to explore constructs relevant to self-efficacy in neurological rehabilitation [87]. The authors refer to 11 themes that emerged as a reflection of self-efficacy beliefs regarding rehabilitation, with *self-reliance, independence* and *determination* considered the most important. The data collected by these authors helped to understand the perspectives of people with disabilities and how self-efficacy contributes to the rehabilitation process. Additionally, it recognizes the impact of self-efficacy on one's drive to engage in activities, the level of determination required to accomplish goals, and the ability to bounce back from challenges [87].

Self-efficacy is also linked with depression and is strongly modulated by the level of motor impairment. Specifically, self-efficacy is negatively associated with PSD [26] and significantly positively associated with motor impairment, mobility, balance, and health-related quality of life [28]. A study with 96 ischemic stroke patients approximately 6-7 weeks after stroke concluded that high self-efficacy, no antecedents of depression and high levels of perceived social support are protective elements for depression symptomatology and should be considered during the rehabilitation process [88]. It is recommended that interventions aimed at improving patients' confidence in their ability to participate in their own rehabilitation process should be the priority. This is because there is a strong likelihood that improving their functional abilities will reduce depressive symptoms [89]. This approach is preferable from a psychological standpoint, as it relies on the patient's own efforts rather than medication [86]. According to research, self-efficacy and rehabilitation outcomes can affect mood, but not the other way around [60].

Self-efficacy is usually delivered through self-management programs, and a positive impact is reported [90]. These programs are intended to educate people about stroke, encourage them to participate actively in its management and focus on training skills. This training can embrace problem-solving, goal-setting, decision-making and coping skills [90]. However, according to some authors, the transfer of self-efficacy gains across different situations involves a dynamic cognitive process [27]. This process may pose a challenge for stroke patients since there is a correlation between their overall cognitive function and general self-efficacy [88].

2.5. Social Support

According to the literature, stroke has an impact on various social aspects such as family relationships, social networks, and social support [21], [24], [26], [91]. In a systematic review by Northcott *et al.*, the impact of stroke on family relationships was discussed as a possible cause of disruption in family life [21]. This is because stroke can affect a person's role, daily routines, and participation in family activities. Also, aphasia can cause stress, as communication is crucial in relationships [21]. The social network is often mentioned in the literature as being at risk after a stroke episode [92]. Studies have shown that individuals who have experienced a stroke often struggle with maintaining relationships with their pre-stroke friends, as well as a decrease in social participation [92]. Loneliness is also a common experience among stroke survivors.

Actually, social support tends to decline over time [24], and is associated with depressive symptoms [19]. The emotional response to a stroke event and the duration of depressive mood can be influenced by social support from friends, neighbors, and acquaintances. This support plays a vital role in mediating the impact of a stroke on a person's emotional well-being [93]. In fact, reduced social network was found to be significantly associated with depression in 7 of 8 studies and with disability in 2 of 2 studies [25]. In line with these results, Cruice *et al*. also identified a decline in the involvement in social activities after a stroke and stress the importance of reversing withdrawal from social interaction [94]. One strategy relies on reinforcing the sense of achievement, confidence, enjoyment, and a feeling of being valued and useful for the community [21]. Additionally, Kammeyer, *et al*. argue that positive social interactions can contribute to prevent or attenuate initial PSD severity [95].

Regarding therapeutic interventions that focus on social participation outcomes, Obembe & Eng elaborated a systematic review where they analyzed 21 studies involving 2042 stroke survivors [96]. Interventions such as exercise, horseback riding, yoga and support services were related to improvements in social participation when they were a component of the rehabilitation program. According to Gingrich *et al*., healthcare professionals can assist stroke survivors in enhancing their social participation by utilizing techniques that enhance their motivation and accessibility to their surroundings [97]. However, further research is required to identify the best rehabilitation approach to enhance social involvement [98]. According to Foley *et al*., social support plays a significant role in predicting social participation [93]. As a result, post-stroke rehabilitation programs that emphasize social support may help increase involvement in social activities. However, most interventions intended to provide social support following stroke are home-based care management programs, which provide infrequent and irregular contact with a consequent weak impact [99]. According to a systematic review by Northcott *et al*. [21], support can only be considered helpful if the person receiving it finds it to be truly beneficial. This support can come from family, community, or health providers who become part of the individual's social network. In this systematic review, the most valued social support functions following stroke and their feasibility were identified, namely: Feeling valued; Encouragement (can be related to self-efficacy principles); Acceptance (through group therapy); Help to promote independence, sense of control and social participation; Social companionship (group therapy); Maintain roles; Meet other stroke survivors (group therapy).

2.6. Stroke Motor Rehabilitation

Upper limb impairment is prevalent after stroke, affecting around 50-80% of patients in the acute phase and 40-50% in the sub-acute phase [100]. Following a stroke, people may have difficulty with their motor skills, which can hinder their participation in activities that give their life purpose. These activities may include helping others, achieving personal goals, performing well at work, engaging in social activities, or building interpersonal relationships [101]. Avoiding or having fewer opportunities for social interaction can prevent getting the social support needed, meaning worse physical recovery is associated with poor social support [21]. Frequently, these motor impairments affect the performance of ADL, mostly activities that require coordination between upper limbs and/or fine finger movements such as feeding, dressing, and grooming [16], [102]. Shi *et al*. found a strong correlation between PSD and motor impairments [103]. In addition, an analysis of the relationship between deficits in ADLs and PSD in a sample of 40 stroke patients, concluded that there is a strong relationship between these two dimensions [102]. For these reasons, recovering upper limb impairments is important for maximizing recovery.

Upper limb rehabilitation is complex [104], not only due to the complex integration and recruitment of muscle activity from shoulder to fingers [105] but also because of the allocation of cortical resources in several cortical and subcortical structures for hand management of motor and sensory issues [106], [107]. Interventions used by health professionals are mainly based on the information gathered with motor/functional/cognitive assessment and patients' goals [31]. The brain's ability to reorganize itself, known as neuroplasticity, is the key factor behind the success of most neuro-motor therapies [108]. Therefore, benchmarks for these therapies are based on biomarkers that measure neuroplasticity [44]. Evaluating the physiological and structural changes at the cortical level, the principles of motor therapy, including its intensity, repetitiveness, and specificity, have been firmly established [44]. A wide range of rehabilitation interventions can be delivered depending on what healthcare professionals consider the most suitable approach, as described in Table 2-1. However, many therapists choose to use an "eclectic mix model" approach, which means they base their therapy on both their clinical experience and the available neurophysiological evidence [44].

Table 2-1 - Brief description of different upper limb rehabilitation approaches (Pollock *et al*., 2014).

Rehabilitation Approaches	***Description***
Proprioceptive Neuromuscular Facilitation (PNF)	Stretching technique used to increase ROM and flexibility
Brunnstrom Movement Therapy	Emphasizes the ability to recover normal movement by facilitating reflexes, basic muscle synergies and sensory stimulation
Bilateral Arm Training	Perform activities with both sides of the body simultaneously
Biofeedback	Adapt performance within an activity according to physiological activity
Neurodevelopmental Treatment (Bobath approach)	Uses guided or facilitated movements as a treatment strategy to ensure correlation of different sensory inputs
Transcranial Direct Current Stimulation	Technique that delivers low electric current to the scalp
Constraint-Induced Movement Therapy	Involves constraining movements of the less-affected arm
Electrical Stimulation	Elicitation of muscle contraction through electric impulses
Manual Therapy Technique	Use of hands to restore mobility
Mental Practice (Imaginary)	Movement imagination
Mirror Therapy	Use of a mirror to simulate movement on the affected limb
Music Therapy	Use of music for rehabilitation purposes
Pharmacological Interventions	Use of drugs for rehabilitation purposes
Repetitive Task Training	Rehabilitation through repetition of exercises
Robotics	Use of robotics as a mediator of rehabilitation
Sensory Interventions	Involves sensory stimulation/desensitization
Strength Training	Use of isometric and isotonic exercises
Stretching and Orthosis	Involves musculoskeletal stretching and positioning (orthoses) to restore movement/function
Surgical Interventions	Motor Surgeries to restore function/movement
Task-specific training	Goal directed practice of functional tasks
Virtual Reality	Use of virtual scenarios for rehabilitation

From these, the most common interventions are Neurodevelopmental Treatment (Bobath), Bilateral Arm Training, Biofeedback, Brunnstrom Movement Therapy, Constraint-Induced Movement Therapy, Musculoskeletal strengthening, mobilization and stretching, Sensory interventions, Mirror Therapy, Electrical stimulation, and the use of assistive devices such Orthoses. As can be seen in Table 2-2, the only interventions with evidence of benefit (moderate) are Constraint-Induced Movement Therapy, Repetitive Task Training and Sensory Intervention.

Table 2-2 - Level of evidence of neuromuscular interventions concerning upper limb function, impairment and ADL (Adapted from Pollock *et al.*, (Pollock *et al.*, 2014)

Key:

- Low or very low evidence
- Lack of evidence
- 0 Moderate evidence of no benefit or harm
- + Moderate evidence of benefit
- - Moderate evidence of harm

Rehabilitation approaches	Upper Limb Function (ULF)	Upper Limb Impairment (ULI)	ADL	Notes
Bilateral arm training vs other				Low quality for comparison of bilateral arm training with usual care or other interventions.
Bilateral arm training vs unilateral arm training	-	0	-	Moderate quality evidence that unilateral arm training is more effective than bilateral arm training at improving upper limb function.
Neurodevelopmental Treatment (Bobath approach)				Up-to-date high-quality review required.
Constraint Induced Movement Therapy	+			High quality systematic review of impairment and ADL outcomes required.
''Hands-on'' therapy				High quality trial evidence required.
Repetitive task training (> 20 hours dose)	+			Subgroup with a dose of > 20 hours, provides moderate quality evidence of beneficial effect.
Task-specific training				Up-to-date high-quality review required.
Strength training				Low quality evidence due to poor reporting on information within review. High quality up-to-date review and RCTs required.
Stretching & Positioning		0	0	Moderate quality evidence from review pooling data from trials with a wide range of populations, interventions and comparison groups. High quality subgroup analyses are required.
Sensory interventions	+	+		Moderate quality evidence from one trial (n=29) of thermal stimulation as compared to no treatment. Low quality evidence for comparison with placebo or control. High quality trial evidence required.

According to Friedman *et al.*, 80% of all stroke survivors require hand therapy [11], being the loss of hand function the most significant source of impairment among neuromuscular disorders, which inhibits effective occupational performance and independent participation [13]. Therefore, the ability to make functional progress relies more on the movements of the hand and wrist rather than on the mobility of the shoulder and elbow [109]. However, to have reasonable control over hand movements, the shoulder needs to have sufficient stability to support those movements. The functioning of the hand is complex, as it involves 29 major joints and 29 muscles. This allows for a wide variety of movements, and it is well-equipped with several types of sensory receptors from the muscles to the skin, particularly on the palmar side [110].

Motor impairments can arise from difficulties executing movements or planning and learning motor skills. Execution problems may stem from weak wrist/finger muscles, co-contraction, and difficulty coordinating finger movements or grasping. Planning/learning deficits are often caused by changes in sensorimotor associations and the inability to plan actions internally. Different approaches are needed for each problem. When the issue is motor execution, therapy should address movement difficulties, strengthen weak muscles, and regulate tone and spasticity. On the other hand, when it is related to motor planning/learning, intensive task-oriented training, bimanual training, action observation, or motor imagery are more appropriate [70].

2.7. Technology-based Approaches for Upper Limb Rehabilitation

In the last 20 years, the health industry has seen significant growth in computer-based technologies and robotics. Using these newer technologies in stroke rehabilitation can provide numerous benefits, including improved body function assessment, increased engagement, biofeedback, and more efficient data collection [59], [111]. Throughout the upcoming sections, we will delve into various technologies, including robotics, data gloves and hand trackers, interactive tables, and virtual reality. We will examine their specificities, advantages and disadvantages, and effectiveness for rehabilitation purposes.

2.7.1. Robotics

Over the past few decades, there has been a significant increase in the development of robot-mediated therapy systems for stroke patients with upper limb impairments. This trend has been particularly noticeable in the last 20 years, as stroke remains one of the most extensively studied diseases in robotics rehabilitation [112], [113]. Using robotic-assisted therapy that focuses on high intensity, numerous repetitions, and task-oriented movements can help to apply motor relearning theories and restore functionality in both the upper and lower limbs [114].

Though there is no globally recognized system for categorizing rehabilitation robotics [35], it is commonly divided into end-effector and exoskeleton [115]. The first is defined as a "*system with a single distal attachment point to apply mechanical forces to* *the distal segment of a limb"* [116], intended to create dynamic environments corresponding to ADL. The second one follows the anatomy of the upper limb and is typically attached and aligned to the corresponding body segments. According to Zuccon *et al*. wearable devices are distinct from the previous two types of devices and are gaining more attention [112]. They are designed to be lightweight, comfortable, and easy to carry, making them ideal for patient rehabilitation at home.

Robotic devices can be used according to different training modalities: assistive (assists a voluntary movement), active (robot used as a measurement device), passive (robot performs movement), passive-mirrored (bimanual robots, being the impaired limb moved using the control of unimpaired), active-assistive (aids when the patient cannot do part of the movement actively, experiencing this stage passively), corrective (robot stops subject when detects errors), path guidance (robot guides when patient deviates from pre-defined trajectory), and resistive (robot provides resistance to the movement) [117].

A systematic review and meta-analysis about the effects of robot-assisted therapy for upper limbs after stroke included 44 randomized control trials from 1362 patients [35]. They concluded that this approach allows patients to increase repetitions and, consequently, the training intensity. Effects on motor control were found to be small and specific to the targeted joints. The same authors summarized the evidence for joints targeted by the robot therapy, the type of robot therapy, and other relevant aspects [35]. We should emphasize particularly the evidence of benefits that exists of using end-effector robots compared to exoskeletons. A transfer from robotics rehabilitation to ADL was not verified, and the benefits compared to dose-matched interventions are unclear [117]. Maciejasz *et al*. reviewed 120 systems and concluded that the effectiveness of robotic over conventional therapy is arguable [113], contrary to results shown by Veerbeek *et al*., which showed that dose-matched interventions are beneficial or likely to be beneficial, at least in shoulder/elbow joints [35].

Outcome		Synergy-independent motor control			Muscle strength	Muscle tone	Upper limb capacity	Basic ADL
		Upper limb	Shoulder/elbow	Wrist/hand				
	All RT-UL	✓	✓	x	x	⊖	x	x
Joints targeted by RT-UL	Shoulder/elbow	✓	✓	x	✓	x	x	x
	Whole arm	x	?	?	?	?	x	?
	Shoulder/elbow/wrist	x	?	?	x	x	?	?
	Elbow/wrist/hand	?	?	?	?	?	?	?
	Elbow/wrist	✓	✓	x	x	?	?	?
	Elbow	?	?	?	?	?	?	?
	Wrist	?	?	?	?	?	?	?
	Wrist/hand	?	x	x	?	?	?	?
	Hand	?	?	?	?	?	x	?
Subgroups	Exoskeleton	x	?	x	x	x	x	?
	End-effector	✓	✓	✓	x	x	x	x
	< 3 months	x	✓	✓	x	x	x	x
	≥ 3 months	x	✓	x	x	x	x	x
	Dose-matched	✓	✓	x	x	⊖	x	x
	Non dose-matched	x	✓	✓	x	?	?	✓

Figure 2-2 - Summary of evidence for the joints targeted by robot therapy for the upper limb (RT-UL), and for type (i.e., exoskeleton or end-effector), timing post-stroke (ie, <3 or ≥3 months), and treatment contrast in trials of time spent in RT-UL (i.e., dose-matched or non–dose-matched trials). (✓) Beneficial or likely to be beneficial; (×) uncertain benefit; (?) unknown effect; (ϴ), negative effect. This figure was extracted from Veerbeek *et al*., 2017.

Khalid *et al.* [115] conducted a systematic review of robotic devices designed for upper limb rehabilitation. They categorized these devices into two groups: assistive and rehabilitation devices. Robotic rehabilitation devices are commonly utilized in clinical settings under the supervision of therapists. These devices are typically paired with specialized therapeutic software to enhance motor skills. Robotic assistive devices also referred to as rehabilitative assistive devices, aim to aid individuals in performing ADL independently or with minimal assistance from others [115]. These devices shall be portable, low-cost, and easy to carry to be used at home. Demofonti *et al.* elaborated a systematic review to identify affordable robotics for upper limb stroke rehabilitation [118]. Most robotics have high costs making the process of acquisition harder. They identified more affordable robotic systems (5 end-effector robots and 4 exoskeleton robots) and techniques that can reduce production costs, such as different materials and reducing the number of degrees of freedom, defending that a robot with just one degree of freedom is still a viable option with satisfactory results [118]. Other authors also recognize that certain devices may be too costly, and therefore steps should be taken to ensure their cost-effectiveness [115].

Some examples of robotic exoskeleton devices are MAHI-II [119], Bi-Manu Track [120], Armeo Spring [121], Armeo Power [122], and Leap Motion Controller [123]. Regarding their impact on rehabilitation, in an experimental study, MAHI-II was tested and significantly improved arm and hand functions with intensive training, with significant differences on Action Research Arm Test (ARAT), Jebsen Taylor hand Function test, American Spinal Injury Association upper limb motor score, grip, and pinch strength [119]. The Bi-Manu Track device underwent a 4-week trial and showed improved outcomes in chronic patients as compared to the control group [120]. The Armeo Spring device underwent testing on children between the ages of 4 and 17 who have cerebral palsy. All of the participants displayed noteworthy enhancements in their hand functions and movement patterns [121]. The Armeo Power was tested on tetraplegic patients, but only a few minor improvements were observed and no significant differences were seen [122]. In a randomized clinical trial involving individuals with multiple sclerosis, the LMC was utilized [123]. The experimental group received conventional therapy as well as game sessions. It was observed that there were improvements in upper limb dexterity and coordination [123].

However, Khalid *et al*. [115] have pointed out some potential downsides of using robotic devices for therapy. One of these is that without the presence of a therapist, the patient may become disengaged and not push themselves to improve. Also, the robot can conduct the entire training with minimal involvement from the patient. Additionally, if the device is too heavy, it could cause strain on the patient's limb during exercise.

2.7.2. Data Gloves and Hand Trackers

Advances in mechanical and mechatronics devices allowed robotic hands to be largely developed, with varying degrees of freedom, size, weight, and manipulation facilities [124]. This development is being culminated through soft robotic gloves, which seem to be the best solution for stroke hand rehabilitation because of their lightweight and ease of use. Some examples of robotic systems used for hand rehabilitation are HandSOME II [125], HEXOSYS II [126], Gloreha [127], Amadeo Hand System [128], or CyberGrasp [129]. These exoskeletons are actuated through different systems such as electric motors, pneumatic actuators or shape memory alloys actuators. To assess their impact, several studies were done [125]. Casas *et al.* [130] developed a passive wearable exoskeleton named HandSOME II. A longitudinal study was conducted on 10 patients suffering from chronic stroke. The patients were requested to use the device for 90 minutes per weekday for a duration of 8 weeks. Following the completion of training, there was a significant improvement in functional ability, as measured by the ARAT, and a decrease in flexor tone, as measured by the modified Ashworth Scale (mAS). Additionally, there was an improvement in the use of the impaired limb, as measured by the Motor Activity Log (MAL). These improvements were maintained at the 3-month follow-up, including gains in finger range of movement and hand displacement during a reaching task. Milia *et al.* [127] explored the efficacy of a robotic glove named Gloreha with 12 stroke patients. Significant differences were found Functional Independence measure and Nine-Hole Peg Test. Amadeo Hand System was tested additionally to standard rehabilitation in sessions of 40 minutes for 20 consecutive sessions, and results showed improvements in all patients' motor assessments [128]. Currently, data gloves are less commonly used for rehabilitation and are mainly utilized for gesture recognition [131]. This shift can be attributed to the advancements in hand trackers.

Technological improvements made hand tracking possible through hardware such as the *Leap Motion Controller* or the *Intel Realsense*. These devices enable very accurate readings without the hardware attached to the body [132], [133]. However, one challenge is finding a balance between hand/finger tracking versus force feedback/resistance. These two aspects are essential for rehabilitation, as the first allows the rehabilitation of dexterity and fine movements, and the second allows to increase strength. Another difficult challenge is to overcome detection problems due to overlaps. Regarding the impact of these devices in motor rehabilitation, Khademi *et al*. used the *Leap Motion* controller and a modified version of the Fruit Ninja game with positive results, demonstrating significant correlations between scores generated from the Fruit Ninja game and clinical outcome measures [132]. In a pilot study conducted by Iosa *et al*., the feasibility of using the Leap Motion in neurorehabilitation was explored with four elderly patients with subacute stroke [133]. The elderly patients with subacute stroke underwent six 30-minute sessions in addition to conventional therapy. The outcome indicated that this approach was effective, with high levels of participation, and resulted in improved hand abilities. A group of researchers, Liu *et al*., created an online interactive system for hand rehabilitation that also uses the Leap Motion technology [81]. The system was evaluated by four rehabilitation doctors and eight patients, who found it to have the potential to be effective in rehabilitation based on a preliminary prototype [134].

More recently, hand tracking has become an integrated feature of head-mounted displays for immersive VR. This brings new opportunities but also some challenges.

There are various opportunities available, such as utilizing hand-tracking technology in conjunction with immersive VR, resulting in a more immersive experience and a greater sense of presence [135]. Interaction can be more effective since it allows for fine motor movements, and hands can be used to enrich communication, which opens possibilities for social interaction [135]. On the other hand, interacting with objects can be a challenge due to the possible imprecise and difficult-to-use nature of hand tracking. Recent research indicates that hands tracked with a Leap Motion tracker tend to score lower on the System Usability Scale when performing a block-moving task compared to a hand-held controller [136]. This can be due to the lack of tactile and haptic cues [135].

2.7.3. Interactive Tables

During the last decade, we have observed considerable growth in the development of interactive surfaces and multi-touch tabletops due to the new available technologies and their decreasing cost. Different technologies can be used to mount an interactive table: projectors combined with infrared or touch films. These technologies have different strengths and weaknesses, depending on the setup, population skills and purpose. Multi-touch tabletops can enhance patient motivation and compliance through interactive and immersive rehabilitation activities [137]. Another benefit is the ability to directly interact through touch or object manipulation, which avoids potential issues like mapping between a proxy object and the target. Direct interaction has a stronger correlation with clinical scores and is more closely related to ADL regarding hand-eye coordination [138]. Additionally, the large screen size allows patients to expand their arm movements, helping in the restoration of gross motor function [139].

Some studies have assessed the impact of interactive surfaces. A study by Al Mahmud *et al*. assessed the impact of two different setups, a conventional board game and a digital tabletop version of the same game [140]. Conclusions were that senior citizens found the tabletop version more absorbing and immersive. Annett *et al*. developed a multi-touch table named AIR Touch for upper extremity motor rehabilitation, using projectors and infrared to detect finger touch on an acrylic panel [88]. It was built with the expertise of occupational therapists, which gave positive feedback about its potential. Unfortunately, we did not find any published results on the efficacy of this system with patients. Tsai *et al*. [141] developed a system called Sharetouch, to enrich social network experiences with the elderly. Both hardware and software were designed carefully to create a user-friendly interface system with three subsystems: a community pound, a waterfall interactive game and multimedia sharing. Validity was measured using the Technology Acceptance Model Questionnaire to measure all hypotheses proposed, namely, the intention to use, perceived usefulness, perceived ease, enjoyment, output quality and if the result demonstrability positively impacted the intention of older people to use Sharetouch. Findings indicated that all these factors had a positive and significant impact [141]. A different system, InTouchFun, was designed by Meza-Kubo *et al*. [142] to ease interaction and enable social family network members to interact with elders during cognitive stimulation activities independently of their location. The system was evaluated in a simulated session using a general perception of standard questionnaires' ease of use and usefulness. Results reported low anxiety levels and high perceived ease of use, usefulness, and enjoyment. Another study where authors developed a low-cost mixed reality tabletop system for upper limb rehabilitation was tested with 30 stroke patients and showed significant improvements in arm function and hand dexterity [143]. Also, the system was reported as highly usable, enjoyable, and motivating. A more recent study discovered that using multitouch technology, specifically the Snowflake MultiTeach® system, helped improve the executive and cooperation skills of children with acquired brain injury who were undergoing socio-cognitive deficit training [144]. Additionally, the study found that the Diamond Touch Table® system helped improve communication and language skills, metacognitive skills, and coping abilities in difficult social situations [144].

2.7.4. Virtual Reality

The meaning of VR has been the subject of many discussions and viewpoints. The terms "virtual" and the expression "virtual reality" can have varying interpretations and relate to various kinds of uses [145]. Indeed, there is a lack of clarity and agreement on terminology and concepts in academic literature [146]. One of the particularities that define the impact of virtual environments is their immersion degree (the extent to which a user perceives he is in a virtual environment rather than the real world), classified accordingly: Immersive, semi-immersive or non-immersive. Semi-immersive and non-immersive VR systems are the most used to manage the motor deficits of stroke patients [147]. VR systems that are non-immersive typically rely on a computer or video game console, a flat screen, or a monitor, along with input devices like keyboards, mice, and controllers [111]. VR often involves fully immersive experiences presented through 3D displays such as head-mounted displays or 3D glasses [148]. Additionally, virtual environments can be delivered through projection systems or flat screens [149]. One of the most accepted definitions for VR is the definition by Tong [150]: "*immersive multimedia or computer–simulated realities, replicates an environment that simulates* *physical presence in places in the real world or imagined worlds and lets the user interact in that world*".

A systematic review to determine the efficacy of VR on upper limb function compared with alternative interventions or no intervention with 72 trials found evidence of significant differences when VR was used in addition to conventional therapy but not when compared to conventional therapy [151]. Another systematic review concluded that solid scientific evidence supports VR's beneficial effects on upper limb recovery [147]. Along the same line, Palma *et al*. analyzed the effects of VR on stroke individuals based on the International Classification of Functioning (ICF), which are positive in body structure and body function but inconclusive in the domains of activity and participation [152]. ICF powered an approach change from an exclusive focus on neurophysiological findings into a psycho-social perspective [153]. Hence, it focuses more on the importance of environmental influence and personal factors on health, turning rehabilitation into a patient-centered process.

Despite its potential benefits, VR is not often utilized for hand rehabilitation in stroke recovery [154]. A review of six trials involving 266 participants determined that the effects of VR on hand function were not significantly different from those of conventional therapy [151]. However, a trial with 47 participants found that a virtual rehabilitation intervention using video games was more effective in improving grip strength than conventional therapy [155]. Other researchers have focused on different approaches to improve hand rehabilitation with stroke survivors using VR systems. For example, by comparing the integrated training of all joints with isolated training; however, no significant differences were found [156]. On the other side, a recent study evaluated the clinical potential and neuroplastic effect of VR intervention for post-stroke rehabilitation of the distal upper limb [157]. The study concluded that patients who underwent VR training showed improved motor outcomes and increased cortical excitability. Moreover, it has been noted that VR is becoming increasingly useful as a supplementary method in post-stroke rehabilitation. However, further research is still required to determine how VR can be customized to meet the varying clinical needs of patients [157]. Chen *et al*. suggest that using certain input mechanisms, such as Leap Motion or gloves with sensors, can be helpful for improving fine motor movements [158]. Furthermore, their review concluded that VR-supported therapy did not have a positive impact on fine motor function, as measured by the ARAT.

2.8. Serious Games

Serious games have education or rehabilitation as their primary goal [159] and are designed to assist people in learning practical concepts through training [160]. Nonetheless, a wider definition is given by Bergeron: “an interactive computer application, with or without significant hardware component, that has a challenging goal, is fun to play with, incorporates scoring concept and imparts the user a skill, knowledge and attitude which can be applied to real world” [161]. The incorporation of serious games in rehabilitation is primarily achieved using VR systems and/or robot-assisted therapy [159], performing as a mediator for playful interventions [162]. In addition to the unique benefits that each hardware technology provides for rehabilitation, serious games offers entertainment, problem-solving and attentional engagement to challenge function and performance [163], [164]. Furthermore, they adhere to various principles of motor learning that serve as the foundation for successful interventions in neurorehabilitation [164], [165], which is why certain authors believe that VR systems have a greater impact than commercial video games [159]. In a recent study, Maier *et al.* [164] identified several principles of neurorehabilitation based on motor learning from the meta-analysis as follows: massed practice/repetitive practice, spaced practice, dosage/duration, task-specific practice, variable practice, increasing difficulty, multisensory stimulation, explicit and implicit feedback/knowledge of performance, modulate effector selection, action observation/embodied practice, goal-oriented practice, rhythmic cueing, motor imagery/mental practice, and social interaction.

There are characteristics of serious games that increase their efficacy, such as the ability to adjust the game difficulty to encourage recovery and sustain motivation [163], through the incorporation of functional tasks that simulate ADL in virtual environments or even through feedback on performance during or after task completion [166]. The characteristics of serious games vary according to their intended rehabilitation purposes and the system's technical specifications. Studies have shown that VR interventions, specifically serious games, can improve upper limb recovery in stroke patients [165], [167], [168] Particularly, a superior effect of VR-based stroke interventions for the upper limb compared to conventional treatment is referred, especially those specifically designed for rehabilitation [165], [168], [169]. One reason for this is the numerous features emerging technologies have, which can help overcome the limitations of traditional rehabilitation methods [170]. Studies have demonstrated that serious games can enhance patient motivation and engagement because they incorporate elements of fun and competitiveness [171]. In addition, serious games technology enables therapists to provide objective feedback on a patient's progress and fine-tune the intensity of their treatment with accuracy [172]. The software's flexibility also allows for rehabilitation to be tailored to the individual needs of each patient, resulting in more personalized treatment plans [173].

When developing games for rehabilitation purposes, various game specificities are considered. Alankus *et al.* [174], as a result of brainstorming sessions with therapists, identify in their work three attributes about the use of games for rehabilitation: social context (multiplayer or single player), which in this thesis we approach as game mode (discussed in sub-chapter 2.9 and chapter 3), motion type (single or multiple muscle motion) and cognitive challenge (easy or difficult). The importance of social context was highlighted due to the challenges stroke patients face in maintaining their network of friends. Additionally, multiplayer games provide extra motivation compared to single-player games. When it comes to motion, you can choose to focus on a single muscle's movement or synergistic movements. This decision may be influenced by both the hardware and the game design. When designing games, it is important to consider the level of cognitive challenge they provide. Games should be easy to understand but can also be designed to help improve cognitive skills [174].

2.9. Game Modes

As mentioned in the previous sections, VR systems and robot-assisted therapy have numerous benefits. serious games are usually part of a VR system [175], and being software, have the advantage of being totally designed to influence user’s experience, actions, and decisions according to specific rehabilitation objectives. Nevertheless, playing single-player or multi-player games results in distinct experiences [43]. Baur *et al.* [43] found that in most of the reviewed studies engaging in social interaction through multiplayer games can enhance both the game experience and performance compared to playing alone as a single player (Figure 2-3). Research on multiplayer modes and serious games highlights their positive impact on performance and motivation [176]. Playing games with the opportunity to be socially involved can bring several benefits for rehabilitation [43], [177]–[180].

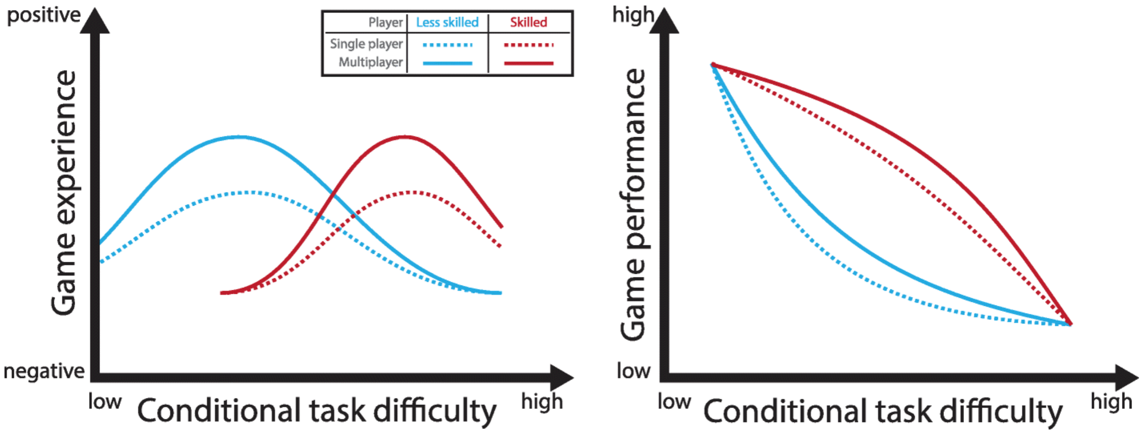


Figure 2-3 - Comparison between single-player and multiplayer with less skilled and skilled participants for game experience and game performance according to conditional task difficulty (image extracted from Baur *et al*. 2018).

There are various types of game modes in multiplayer mode, each providing a unique gaming experience [43]. This gaming experience also depends on the player's cognitive and motor skills [43], [181], [182], and the previous level of relationship they have with the opponent [183]–[185]. Baur *et al.* [43] state in their review that game modes are commonly named competitive, cooperative, and collaborative. However, various authors use the same terminology for different game modes. To clarify, certain modes should be referred to as co-active instead of cooperative [43]. Coactivity implies that a single player can accomplish a task, while cooperation indicates working together as a team with different roles [186]. Even the meaning of cooperative and collaborative, in common sense, is frequently misunderstood and associated with the meaning of just working together. Game mode can be determined by the characteristics of the task, as outlined by Jarrassé *et al.* [186], Konert *et al.* [187], and Mueller *et al*. [188] in their respective taxonomies. The way players behave in the multiplayer mode is determined by the task characteristics and the behavior of the players themselves [43]. Figure 2-4 from Baur *et al.* [43] displays some of the relationships between task characteristics and player behavior, indicating the resulting game mode that arises from this interaction, namely co-activity, coopetition, competition, collaboration, and cooperation.

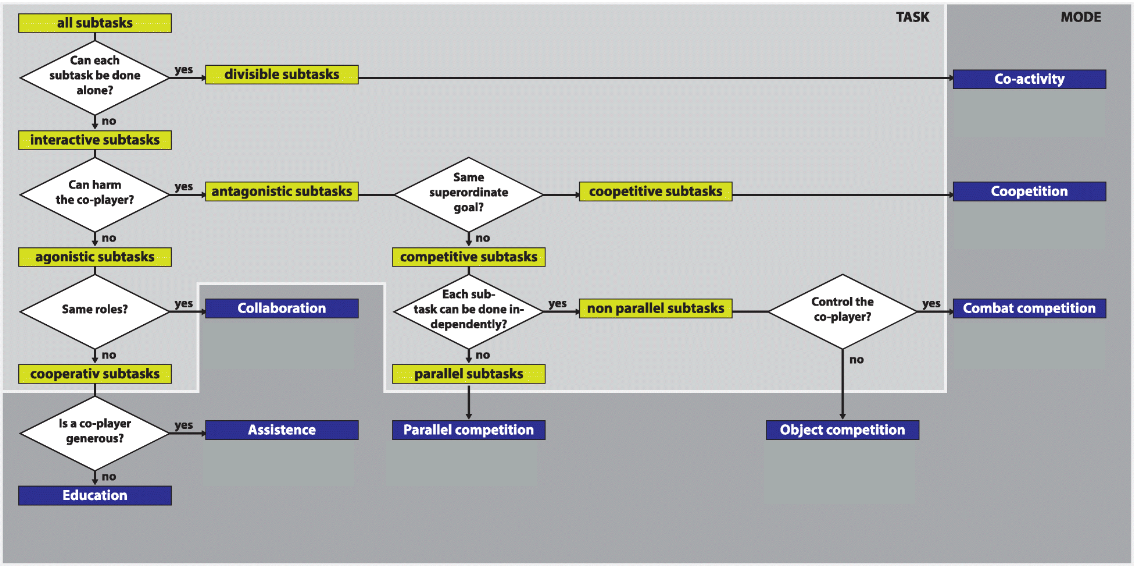


Figure 2-4 - Determination of multiplayer game modes (figure extracted from Baur *et al.* 2018).

As stated earlier, the co-active mode allows a single player to complete the task independently, while the cooperative mode involves playing as a team with different roles. Konert *et al.* [187] have proposed a new game mode called "coopetition" which combines elements of both competition and cooperation. In this game mode, the players work together towards a common goal and rely on each other to succeed. However, there is also the possibility for one player to cause harm to their teammate to take advantage. When it comes to competitive game modes, they can be classified as either parallel or non-parallel competitions [188]. In parallel competition, subtasks cannot be completed independently. However, if they can be done independently, there is a possibility of controlling the co-player (combat competition) or not controlling the co-player (object competition) [188]. Collaborative mode involves depending on your co-player, refraining from causing them any harm, and sharing equal roles [43]. The cooperative mode in a game differs from the collaborative mode based on the assigned roles. The roles can either be support-based, where the player assists others, or education-based, where the player helps others [189].

2.10. Summary

Stroke is a prevalent problem that can have a major negative impact on a person's motor, cognitive, social, and emotional well-being. Therefore, the challenges that follow a stroke can be significant. To ensure successful rehabilitation, it is important to address all affected areas and create a personalized and targeted approach.

Particularly, we strongly believe that the social and emotional impact should be considered during the rehabilitation process.

Serious games and VR have demonstrated the potential to deliver various benefits for rehabilitation, in line with motor learning theories and potentiating neuroplasticity. However, it is not a guarantee of success in rehabilitation without a careful and thoughtful design. If not properly designed, these systems could result in sub-optimal rehabilitation outcomes and abandonment for reasons such as poor difficulty adjustment, lack of personalization to the participant's interests, difficulties with understanding tasks, tasks that are physically demanding, or poor usability. A rehabilitation system needs to have all these aspects into account to produce effective rehabilitation outcomes. Additionally, due to stroke specificities and knowing the consequences depressive symptoms have on motor rehabilitation outcomes, we believe that a system designed for stroke motor rehabilitation needs to account for self-efficacy and the promotion of social interaction, as they strongly relate to post-stroke depression.

Interactive table is the technology more suitable to address this problem, as it allows for group settings, interaction through objects or directly with hands and the use of serious games. To achieve this goal, it is necessary to create objects, serious games, and rehabilitation settings, following a series of steps. First, to determine which game mode promotes more social interaction, motivation, and engagement, we need to analyze the advantages and disadvantages of different multiplayer game modes. Second, to promote the rehabilitation of upper limb motor skills in stroke patients, it is important to consider various game mechanics and create different serious games. These games should improve the patient's self-efficacy and promote effective rehabilitation. And third, the user-tangible interfaces should promote different types of grasps and provide satisfactory levels of usability. We expect that an approach that combines all these elements to results in improved rehabilitation outcomes when compared to more traditional configurations.

2.11. Research Questions

RQ1: Are there significant differences in engagement and social involvement between three game modes: competitive, co-active, and collaborative?

The serious games that will be developed will play an important role in the impact of the proposed approach since it will affect motivation and modulate motor and social behavior. Besides its design, as the proposed approach is group rehabilitation, we must first understand how different multiplayer modes impact the users and what they can apport to rehabilitation. As far as we know, no literature compares competitive, co-active and collaborative game modes. Most studies focus on comparing cooperative and competitive modes. However, many studies have mislabelled modes as "cooperative" when they should be called "co-active." This is because the individual player can complete the sub-task independently without relying on their co-player [43].

RQ2: What types of objects and task mechanics are more adequate to be used for rehabilitation according to patients' levels of impairment?

This research question is necessary to test the feasibility, usability, and engagement of using tangible objects of different sizes and shapes in interactive rehabilitation tasks. Our approach involves using tangible objects as mediators between the user and serious games. These objects play a crucial role in the motor therapeutic aspect of the task. Therefore, it is important to understand which objects are the most adequate for use according to different motor impairment levels. Additionally, this RQ helps answer the task mechanics that can be exploited in serious games and how objects and task mechanics can promote self-efficacy.

RQ3: Does the proposed rehabilitation methodology result in improved motor recovery?

Based on the above findings, a motor rehabilitation protocol that promotes self-efficacy and social participation through interactive technologies will be proposed. Towards that, we constructed an interactive table to accommodate up to four people and developed four serious games. Additionally, we designed interfaces that encourage various ways to grasp and interact with the games. With this protocol, we want to understand its feasibility and how it impacts upper limb rehabilitation with stroke patients.

2.12. Research Contributions

Our thesis aims to improve upper limb motor rehabilitation by incorporating important factors like self-efficacy and social participation. These aspects are often overlooked in traditional therapy methods [44]. Incorporating serious games into the motor learning process has numerous advantages. It enhances motor learning by providing enriched environments, feedback, task specificity, dosing, and adaptability

[45]. It also promotes motivation through goal setting, rewards, challenge, a sense of progress, and socialization [45].

The specific contributions are the following:

A. Collaborative game mode and rehabilitation
    - Evidence of how collaborative, co-active and competitive game modes can impact social involvement and motivation while playing serious games for stroke rehabilitation purposes.
B. Cognitive and motor skills, personality, and rehabilitation
    - Understanding how cognitive skills, motor skills, and personality influence motivation and social involvement while playing games designed for stroke rehabilitation.
C. Reaching and grasping
    - Exploration of how material size and distance affect reaching and grasping with stroke patients.
D. Touch and object interactive setting
    - Development of an interactive setting, where everyone participates in the same activity using their fingers or objects to interact with it, using activities carefully designed to stimulate different motor skills, such as range of movement and hand dexterity, has the potential to promote motivation and social interaction and ultimately leading to increased happiness while undergoing stroke motor rehabilitation.
E. CTPro (Chapter 3)
    - A software that enables users to interact with games directly with objects through color detection.
F. Set of 3D printed objects/interfaces (Chapter 4)
    - Objects that simultaneously allow three different grasps: power grasp, lateral grasp, and tripod. These interfaces are meant to be used on the interactive table through color detection using CTPro or interacting directly with the surface by touching it. The objects are designed to be adaptable to users' skills and to promote a sense of self-efficacy.
G. Design and development of an interactive table

- An interactive table designed to accommodate four people using a wheelchair, with an interactive touch/objects surface and an RGB camera to allow interaction with objects' shape.

H. Set of 4 serious games

- Games developed according to scientific evidence from previous studies to promote self-efficacy, social interaction, and motivation. The games can be customized to match the varying skills of different patients simultaneously.

Chapter 3. Evaluating the Impact of Game Modes on Motivation and Social Involvement

Parts of this chapter have been published in (1) and (2):

(1) F. Pereira, S. Bermúdez i Badia, R. Ornelas, and M. S. Cameirão, "Impact of game mode in multi-user serious games for upper limb rehabilitation: a within-person randomized trial on engagement and social involvement," J Neuroeng Rehabil, vol. 16, no. 1, p. 109, 2019, doi: 10.1186/s12984-019-0578-9.

Contributions: FP, SBB and MSC designed the study. RO developed the software. FP recruited the participants. FP and RO collected the data. FP performed the data analysis. FP, SBB and MSC interpreted the results.

(2) F. Pereira, S. Bermúdez i Badia, C. Jorge, and M. S. Cameirão, "The use of game modes to promote engagement and social involvement in multi-user serious games: a within-person randomized trial with stroke survivors," J Neuroeng Rehabil, vol. 18, no. 1, 2021, doi: 10.1186/s12984-021-00853-z.

Contributions: FP, SBB, and MSC designed the study. Yuri Almeida developed the software. CJ recruited the participants. FP and CJ collected the data. FP performed the data analysis. FP, SBB, and MSC interpreted the results.

This chapter delves into the effects on motivation and social participation of playing a serious multi-player game in different modes, specifically, involving competition, co-action, or collaboration. This is a relevant aspect to be considered for group rehabilitation because it can affect participants' communication and interactions, as well as their motivation to engage in the activity. In section 3.1, we present a study that compares the effects of three game modes (competitive, co-active, and collaborative) on social involvement and engagement in a group of healthy participants playing a game on a desktop computer. In section 3.2, we present a second study that had the same research goal, but this time with stroke survivors playing the games with tangible objects on a large-screen interactive table. Besides analyzing the impact on social involvement and engagement, we also examined how these results are modulated by personality, and cognitive and motor function.

3.1. Impact of Game Modes with Multi-user Serious Upper Limb Rehabilitation with the Elderly

3.1.1. Introduction

Serious games have been widely studied concerning their impact on improving physical and social skills with the elderly [190], mostly because of their potential to increase motivation levels compared to conventional therapies [16], [191]. Moreover, the therapeutic potential of games for the elderly is well documented, with results showing a positive impact on their health and well-being [190]. However, while one of the most critical elements of successful aging is to conserve social relationships [21], research on how to appropriately address social experiences with serious games is still scarce [190]. Also, social interaction through multiplayer games has been underlined as an essential aspect of motor rehabilitation because it supports enhanced enjoyment during interaction and an increased sense of self-efficacy [192]. In fact, stroke survivors with low levels of social support have a greater risk of developing depression [193]. A longitudinal study examined the impact of social support on 5643 participants that had experienced a heart attack or stroke, with results indicating that the risk of developing depression is very contingent on the level of social support [193]. Moreover, social support is a modifiable factor that can mitigate the impact of illness on depression, and higher social support could improve the outcomes [193]. In another study, Janssen *et al.,* investigated how social activity of stroke patients undergoing rehabilitation changes over time [194]. After analyzing data from a sample of 14 participants, the authors concluded that the levels of social activity were low even after improvements in the levels of independence and mood. These data highlight the need to explore alternative ways of social stimulation within rehabilitation environments [194].

One way to foster social interaction is through multiplayer modalities, which typically promote more socialization than their single-player counterparts[195]. For rehabilitation purposes, the design and specific characteristics of these games should be carefully analyzed to identify the features that influence motivation and engagement levels, which in turn could impact recovery. One feature that can potentially have an impact is the playing mode, i.e., inter-player relationships can be one of the following four kinds of interaction: competitive, co-active, cooperative, or collaborative [186], [189]. However, the literature typically addresses competitive, collaborative, and cooperative modes only [43]. In addition, most of the studies that addressed game modes focused on competitive vs. cooperative or competitive vs. collaborative, not establishing a difference between cooperative and collaborative modes [180], [195]–[199]. When it comes to working together, cooperation and collaboration are two concepts that may seem similar, but they actually have distinct differences. Cooperation involves individuals coming together to achieve a common goal, but each person has a unique role to play. On the other hand, collaboration involves individuals working together in the same role to achieve a shared objective [186], [200]. Moreover, there is no consistency in nomenclature. Previous studies have suggested that certain game modes should be referred to as co-active instead of cooperative. This is because these game modes involve players working towards a common goal and task, but they do not necessarily depend on each other to complete it [186], [189]. Considering these different definitions, research on collaborative games is lacking. To our best knowledge, only a minority of studies differentiated the three above-mentioned game modes [201], and according to a systematic review of multi-player games, there is no research comparing them [43].

Multiplayer rehabilitation games show good potential for producing greater enjoyment and more intense exercise compared to single-player modalities [195]. A study with 12 pairs of unimpaired participants concluded that participants prefer to cooperate than to exercise alone, feeling less pressure in this mode [202]. Another study that linked patients with their spouses in rehabilitation through haptic interaction found that multiplayer modes were more motivating when compared to single-player modes [20]. Nevertheless, the best game mode for an individual is dependent on their skill level and personality, as well as finding a suitable teammate, when comparing competitive and collaborative modes [8]. A study with 158 healthy adults found that a co-active mode caused higher levels of motivation and effort in comparison with a competitive mode, but motor performance was similar in both [21]. An interesting result of this study was that the level of relationship (friends vs. strangers) also influenced players' motivation, goal commitment, and performance. Those who played with friends showed greater goal commitment than those who played with strangers [21]. In contrast, several studies indicate that competitive modes motivate players more, resulting in more intense performance, and are associated with more movement repetitions [12], [15], [22], [23].

Here, we aim to understand the impact on engagement and social involvement of different multiplayer settings, specifically aiming to distinguish collaboration and cooperation. For this purpose, we deployed a game in three different modes (Competitive, Co-active and Collaborative) and tested these in a sample of healthy older adults (> 55 years). We decided for a sample of older adults without motor deficits to avoid potential confounds brought by stroke, which is known to impact cognitive, motor, emotional or social domains. We believe that a sample where these domains remain relatively intact represents a good baseline to assess the impact of these game modes on engagement and social involvement. Next, with a stroke population it will be possible to better understand how these results are modulated by the deficits brought by stroke. Our first hypothesis is that engagement will be significantly higher in the Competitive mode when compared to Co-active and Collaborative modes. Our second hypothesis is that social involvement will be significantly higher in the Collaborative game mode compared to Competitive and Co-active modes. Additionally, we want to understand how the results are modulated by the cognitive profile, personality, and previous relationship between co-players.

3.1.2. Methods

3.1.2.1. Pilot Testing

Before the final experiment, three pilot tests were conducted to address game interaction and mechanics, and understandability issues of the setup and assessment questionnaires. Four participants (4 female), with a mean age of 79 years (range 60-86 years), and 3-7 years of schooling participated in these pilots. As a result, changes were made in the interaction form, starting with a joystick and ending with a handle (interface) that worked similarly to a mouse (Figure 3-1). Also, the Collaborative mode was changed to simplify mechanics. Regarding the assessment questionnaires, some points were reformulated to become more understandable.

Figure 3-1 - Setup with a camera, camera support, computer, handles with tracking pattern, and wood card for delimiting the working space.

3.1.2.2. Experimental Setup

The setup consisted of a PC (OS: Windows 7, CPU: Intel core 2 duo E8235 at 2.80GHzz, RAM: 4Gb, Graphics: ATI Mobility Radeon HD 2600 XT) with a 24” screen, a PlayStation Eye camera (Sony Computer Entertainment Inc., Tokyo, Japan) and two customized handles with a tracking pattern (Figure 3-1). For tracking, we used Analysis and Tracking System (AnTS) [24], which uses computer vision to detect specific patterns on the camera’s field of view. For that, we printed two patterns and attached them to handles and used them as controllers, as the pattern positions are mapped on the screen space. Users were seated side-by-side and facing the screen. To interact with the game, users had to grasp the handle and move it over the surface of the table. A 3mm wood card with two cut down rectangles (50cm by 30cm) was used to delimit the space where the camera was tracking the handles. These rectangles made the calibration process easier and reliable, guaranteeing an equal calibration for all the participants. The calibration was done using the Reh@Panel Unity3D client (https://neurorehablab.arditi.pt/tools/rehpanel-unity3d-client/) and consisted of mapping the X and Y limits where the handle could move to the whole screen area.

3.1.2.3. Task

The task was a two-player game with the primary objective of catching balls that are falling from the top of the screen. For that purpose, each user controlled a virtual ring on the screen by moving the handle on the table. There were three different versions of the task, which corresponded to three game modes: Competitive, Co-active, and Collaborative (Figure 3-2). Differences between the game modes relied on the objectives, but the task mechanics were the same. In the Competitive mode, participants had to catch the maximum number of balls. The participant who scored more points (each ball resulted in 1 point) won the round. In the Co-active game mode, participants had to play as a team and catch balls for a combined score. In the Collaborative game mode, they also played as a team; nevertheless, for participants to score in this mode, both had to catch a ball of the same color. If one of the participants caught a ball of a specific color (eg. green), then the other player could only catch a ball of the same color (green). As a consequence of scoring, a line between the two rings was formed to give feedback that players succeeded. There was no in-game adaptation according to the participants performance. The game settings were chosen to make sure that the task was doable by all our participants.

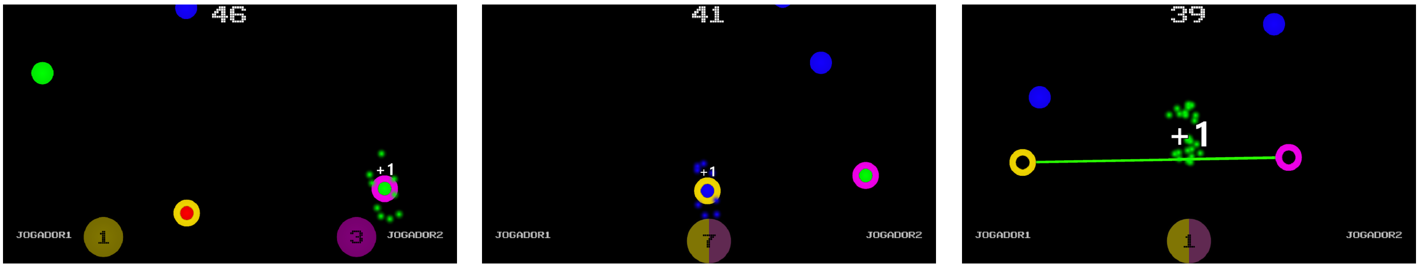


Figure 3-2 - Competitive, Co-active and Collaborative game modes, from left to right. Each player controls a ring (yellow or pink) to catch balls of different colors (the center of the ring shows the color of the last ball caught). The screen displays on the top the remaining time and on the bottom the name of the player and its respective score (matching the color attributed to the player). In the Competitive mode, players compete for the balls, in the Co-active mode players can catch any ball for a combined score, and in the Collaborative mode, when one of the participants catches a ball of a given color (eg. green), then the other player can only catch a ball of the same color (green). For this mode, when scoring, a line between the two rings is formed to give feedback that players succeeded.

3.1.2.4. Experimental Procedure

The study followed a within-person design with three independent variables (Competitive, Co-active, and Collaborative) to assess the impact on engagement and social involvement. The order of the conditions was previously randomized using random.org, and sample allocation was according to the availability of participants. Data collection was conducted in two sessions of approximately one hour each and ran in different days or morning-and-afternoon sessions, according to the availability of the participants. In average, the time between the two sessions was 79 hours (3 days). The sessions were conducted by two researchers trained on the system and the assessment questionnaires. In the first session, participants were organized in pairs, introduced to the study, got familiarized with the game, signed the informed consent, and performed the first condition. In the second session, participants performed the remaining two conditions. Each condition consisted of 8 consecutive rounds of 1-minute duration with a 5-15 seconds interval between rounds to allow participants to interact spontaneously. Between each round, the score was reset. At the end of each condition, participants answered the Game Experience Questionnaire (GEQ) – Core Module and GEQ – Social Presence Module [25]. The total time of the experiment was about 90-150 minutes, depending on the participant, because of the variable times to apply the questionnaires.

After a brief explanation of the system, participants underwent two training phases. The first one was to learn how to use the interface and how to control the virtual ring (end effector). This training phase did not have a time limit, ending when participants felt comfortable controlling the virtual ring (as assessed by the researcher). In a second training phase, participants tried each game mode mechanics until they felt they had understood it, also aiming to reduce the novelty bias. Here, we also decided not to restrict the time, as each participant needed different times and feedback to understand and get used to what was expected from him/her.

3.1.2.5. Sample and Recruitment

The sample was recruited at a community center that provides social support to the population. It was a convenience sample, and the single inclusion criterium was to be more than 55 years old. The exclusion criteria were the following: 1) Motor limitations in the dominant upper limb; 2) no literacy; and 3) not able to understand the game according to the therapist's assessment [26]. Fifty-five potential participants were approached. Seven refused to participate, and eight were excluded due to exclusion criteria. Forty participants (20 pairs) took part in the study. Out of these, the data of 1 participant were not considered because of lack of compliance during the assessment questionnaires, leaving a final sample of 39 participants for analysis. Twenty-four were females and 15 were males, with a mean age of 71.5±8.7 years (range: 56-91 years) and 6.2±4.2 (range: 2-16) years of schooling (Table 3-1).

To get a profile of the participants, we used: 1) a brief questionnaire for demographic information; 2) a Likert scale (from 1= distant relationship to 10= very close relationship) for a self-reported characterization of the previous relationship between pairs; 3) the Montreal Cognitive Assessment (MoCA) for cognitive screening (26); and 4) the Mini-International Personality Item Pool (Mini-IPIP) validated for Portuguese population [27] to characterize the participants with respect to their personality. Although Mini-IPIP measures the Big Five factors of personality (Openness/Intellect or Imagination, Conscientiousness, Extraversion, Agreeableness, and neuroticism, only the extraversion factor was analyzed since to our understanding it is the one that relates clearly to engagement and social involvement. The mean value for MoCA was 21.3±4.9 (range: 12-30). Additionally, regarding previous experience with digital games, 38.5% of the sample had previous experience with video games. From these, 44% played once or twice per year, 25% every week, and 31% daily. The computer was the most used interface (55%), followed by smartphones, tablets, and video game consoles.

Table 3-1 - Participants' profile

PARTICIPANT	GENDER (M/F)	AGE	SCHOOLING (YEARS)	MOCA (0-30)
1	M	56	7	28
2	F	62	12	25
3	F	81	7	16
4	F	71	7	14
5	F	63	7	16
6	F	72	4	12
7	M	70	7	16
8	F	76	16	25
9	M	64	16	28
10	M	75	7	23
11	M	66	7	17
12	M	77	7	16
13	M	73	6	20
14	F	83	15	23
15	F	61	7	25
16	F	69	16	21
17	M	58	7	24
18	F	71	7	17
19	F	63	16	28
20	F	70	16	24
21	F	80	7	16
22	M	65	7	30
23	F	62	7	26
24	M	91	16	19
25	F	73	6	18
26	M	85	7	24
27	F	62	16	26
28	M	68	7	23
29	F	63	16	26
30	F	75	6	15
31	M	72	7	14
32	F	72	16	24
33	M	77	12	22
34	M	86	16	26
35	F	63	7	21
36	F	77	7	27
37	F	66	7	22
38	F	87	12	17
39	F	85	7	15

3.1.2.6. Outcome Measures

The GEQ – Core Module [25] and the GEQ – Social Presence Module [28] were chosen to measure engagement and social involvement, respectively. The Core Module measures the players' thoughts and feelings through 7 components (Competence, Sensory and Imaginative Immersion, Flow, Tension/Annoyance, Challenge, Negative affect, and Positive affect) in a total of 33 items [25]. The Social Presence Module has three components (Psychological Involvement – Empathy, Psychological Involvement – Negative Feelings and Behavioral Involvement), and a total of 17 items. In both questionnaires, the items are rated from "0" (Not at all) to "4" (Extremely). These questionnaires are typically filled-in by the user, but because of the characteristics of the sample, the answers' scale was provided on an A4 sheet, always visible to the participants, and the questions were made verbally. The scale was translated from English to Portuguese by two experts in English-Portuguese translation.

3.1.2.7. Data Analysis

Because of the ordinal nature of the measures, non-parametric statistical tests were used for data analysis. Hence, the median was used as a measure of central tendency and the interquartile range (IQR) for dispersion. To test for differences across conditions, we used Friedman's test for each of the components of both modules from the GEQ. We tested for significant differences across game modes in the three groups. For pairwise comparisons, the Wilcoxon signed-rank test was used with a Bonferroni correction to account for the number of comparisons. To analyze how cognitive skills and personality impacts engagement and social involvement in the three game modes, data were split into subgroups. For cognitive level, we divided the sample into two subgroups using the mean of MoCA scores (21.26±4.86): 'Higher MoCAs' (score above 21) (n=21) and 'Lower MoCAs' (score lower or equal to 21) (n=18). For personality, we computed the mean of extraversion component of Mini-IPIP (11.54±3.64) and then summed and subtracted half of the standard deviation as suggested by the official website for the IPIP [29]. This way, we got a range (9.72 – 13.36) where average people fall in (n=16). Below that range, people are considered more introvert (n=11) and above the range, more extrovert (n=12) than the average. Finally, to analyze the effect of co-player relationship, we divided the sample into two subgroups, according to the score attributed by each participant to their level of relationship (1 (no relationship) -10 (close relationship)) with the correspondent pair. The first subgroup (n=22) was composed of participants that considered having a distant relationship, attributing a score lower or equal to 5. The second subgroup (n=17), was composed of participants that attributed a score higher than 5, indicating a closer relationship. For between-group comparisons, we used the Mann-Whitney U Test or the Kruskal-Wallis Test, for pairwise or more than two conditions, respectively. Data were analyzed using IBM Statistics for Mac, Version 25.0 (Armonk, NY: IBM Corp).

3.1.3. Results

3.1.3.1. Social Involvement

Regarding the GEQ Social Presence module, Empathy was relatively high on all conditions (Mdn=[2.33-2.83]), but with a lower median and higher dispersion in the Competitive mode (Figure 3-3, Table 3-2). The difference across conditions for this component was significant (Fr(2)=6.587, *p*=0.037), with the Collaborative mode having a significantly higher rating when compared to Co-active (Z=-3.723, *p*=0.006) and Competitive (Z=-2.885, *p*=0.004) modes (Table 3-3). For Behavioral Involvement, ratings

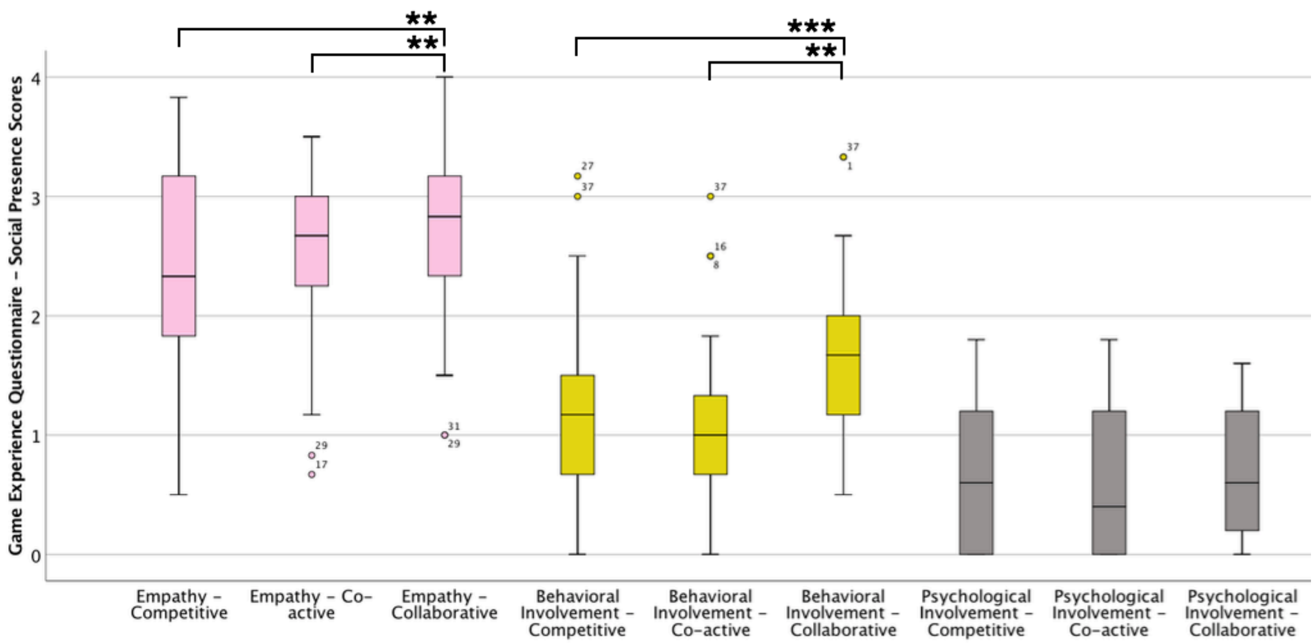


*Figure 3-3 - Boxplots of the GEQ – Social Presence Module components per game mode. ** p<0.01, and ***p<0.001.*

tended to be low (Mdn=[1.00-1.67]), and there was a significant effect across conditions (Fr(2) =18.440, *p* < 0.001). Also, for this component, the Collaborative mode showed a significantly higher rating when compared to Co-active (Z=-4.068, *p*=0.000) and Competitive (Z=-3.273, *p*=0.001) modes. Finally, ratings were low for Negative Feelings (Mdn=[0.40-0.60]), with no significant differences across conditions (Table 3-3).

Table 3-2 - Medians (IQR) in the components of the Game Experience Questionnaire – Social Presence Module per condition, and Friedman's statistics across conditions.

Component	***Competitive***	***Co-active***	***Collaborative***	***Friedman's statistic*** **(Chi-Square)**	***p* value**
Empathy	2.33 (1.34)	2.67 (0.83)	2.83 (1.00)	6.587	**0.037**
Behavioral Involvement	1.17 (0.83)	1.00 (0.66)	1.67 (0.83)	18.440	**<0.001**
Negative Feelings	0.60 (1.20)	0.40 (1.20)	0.60 (1.00)	0.271	0.873

Table 3-3 - Pairwise comparisons for Empathy and Behavioral Involvement components

Component		***Competitive Vs Co-active***	***Competitive Vs Collaborative***	***Collaborative Vs Co-active***
Empathy	Z	*-0.941*	*-2.885*	*-2.723*
	p value	0.347	**0.004**	**0.006**
Behavioral Involvement	Z	-1.030	*-3.273*	*-4.068*
	p value	0.303	**0.001**	**<0.001**

3.1.3.2. Engagement

Concerning the components of the GEQ - Core Module, Flow was high for all the conditions (Mdn=2.80-3.00) and so was Positive Affect (Mdn=3.00) (Table 3-4). However, the task was not considered challenging enough (Challenge, Mdn=0.60-0.80). Although the sense of Competence was in general not very high (Mdn=2.20-2.40), feelings of Tension/Annoyance were very low (Mdn=0.00). No significant differences were found when comparing conditions in these domains (Table 3-4).

Table 3-4 - Medians (IQR) in the components of the GEQ – Core Module per condition, and Friedman's statistics across conditions.

Component	***Competitive***	***Co-active***	***Collaborative***	***Friedman's statistic***	
				(Chi-Square)	***p* value**
Competence	2.40 (1.40)	2.60 (1.20)	2.20 (1.20)	0.557	0.757
Sensory and Imaginative Immersion	2.33 (1.17)	2.50 (1.00)	2.33 (1.00)	0.529	0.768
Flow	2.80 (1.20)	2.80 (1.20)	3.00 (1.00)	3.418	0.181
Tension/Annoyance	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	1.182	0.554
Challenge	0.80 (0.60)	0.60 (1.00)	0.80 (1.00)	4.211	0.122
Negative Affect	0.00 (0.19)	0.00 (0.00)	0.00 (0.00)	5.688	0.058
Positive Affect	3.00 (1.20)	3.00 (0.80)	3.00 (0.80)	0.803	0.669

3.1.3.3. Effect of Cognitive Profile

For the Higher MoCAs subgroup, significant differences across conditions were found for the Behavioral Involvement component (Fr(2)=13.468, *p*=0.001) of the Social Presence Module (Table 3-5). Further pairwise comparisons showed that the Collaborative mode had significantly higher ratings (Mdn=1.83 (0.91)) than the Competitive mode (Mdn=1.33 (1.00)) (Z=-2.567, *p*=0.010) and the *Co-active* mode (Mdn=1.00 (0.58)) (Z=-3.515, *p*<0.001). There were no significant differences across conditions for the different components of the Core Module (Table 3-5).

Concerning the Lower MoCAs subgroup, there were no significant differences across conditions for the different components of the Core and the Social Presence Modules (Table 3-5).

When comparing the two MoCA subgroups for each game mode, ratings were typically higher for the higher MoCAs subgroup (Table 3-5). There were between-group significant differences in the Collaborative mode for the sense of Competence (U=118.500, *p*=0.046), Sensory and Imaginative Immersion (U=115.500, *p*=0.038), and Flow (U=100.00, *p*=0.011). For the Competitive mode, the higher MoCAs subgroup had significantly higher ratings in Flow (U=116.500, *p*=0.040).

Table 3-5 – Medians (Mdn) and Interquartile Range (IQR) for higher (H MoCAs) and lower MoCAs (L MoCAs) for each condition (game mode), between-groups comparison (Mann-Whitney U Test), and Friedman's statistics for higher and lower MoCAs according to each component of the Game Experience Questionnaire's Core Module and Social Presence Module

		Competitive			***Co-active***			***Collaborative***			***Between conditions comparison***	
	Component	***H MoCAs*** ***Mdn (IQR)***	***L MoCAs*** ***Mdn (IQR)***	**Between-groups comp.** ***Mann-Whitney U, p Value***	***H MoCAs*** ***Mdn (IQR)***	***L MoCAs*** ***Mdn (IQR)***	**Between-groups comp.** ***Mann-Whitney U, p Value***	***H MoCAs*** ***Mdn (IQR)***	***L MoCAs*** ***Mdn (IQR)***	**Between-groups comp.** ***Mann-Whitney U, p Value***	**H MoCAs** **Chi-Square, *p* Value**	**L MoCAs** **Chi-Square, *p* Value**
Core module	*Competence*	2.40 (2.00)	2.40 (1.10)	162.5, 0.454	2.80 (1.10)	2.20 (0.95)	154.5, 0.329	**3.00 (1.40)**	**2.20 (0.75)**	**118.5, 0.046**	0.444, 0.801	1.971, 0.373
	Sensory and Imaginative Immersion	2.50 (1.00)	2.09 (1.21)	304.5, 0.117	2.50 (1.17)	2.33 (0.88)	322.0, 0.283	**2.67 (1.09)**	**2.09 (0.88)**	**286.5, 0.038**	2.111, 0.348	0.206, 0.902
	Flow	**3.20 (1.10)**	**2.40 (1.30)**	**116.5, 0.040**	3.00 (1.20)	2.80 (1.30)	147.5, 0.240	**3.20 (1.10)**	**2.50 (0.85)**	**100.0, 0.012**	3.909, 0.142	0.471, 0.790
	Tension/Annoyance	0.00 (0.00)	0.00 (0.00)	185.0, 0.830	0.00 (0.00)	0.00 (0.00)	167.5, 0.250	0.00 (0.00)	0.00 (0.00)	187.0, 0.883	0.800, 0.670	0.500, 0.779
	Challenge	0.80 (0.60)	0.70 (1.10)	162.5, 0.451	0.60 (1.00)	0.40 (1.25)	161.0, 0.426	1.00 (0.90)	0.60 (0.85)	154.5, 0.328	2.413, 0.299	3.033, 0.219
	Negative Affect	0.00 (0.13)	0.00 (0.06)	186.0, 0.909	0.00 (0.00)	0.00 (0.00)	186.5, 0.894	0.00 (0.00)	0.00 (0.00)	175.5, 0.512	4.769, 0.092	2.632, 0.268
	Positive Affect	3.40 (1.10)	3.00 (0.65)	136.0, 0.131	3.20 (0.70)	3.00 (0.60)	125.0, 0.068	3.40 (1.00)	3.00 (0.50)	122.0, 0.057	0.488, 0.799	0.375, 0.829
Social Presence Module	*Empathy*	2.50 (1.16)	2.17 (1.54)	150.5, 0.277	2.67 (0.50)	2.42 (1.00)	138.5, 0.151	2.83 (0.75)	2.92 (1.12)	167.0, 0.533	2.960, 0.228	5.559, 0.062
	Negative Feelings	0.60 (1.20)	0.60 (0.70)	181.0, 0.819	0.40 (1.20)	0.50 (1.05)	188.0, 0.977	0.40 (1.00)	0.80 (1.20)	180.0, 0.796	0.500, 0.779	0.030, 0.985
	Behavioral Involvement	**1.33 (1.00)**	1.09 (0.91)	159.5, 0.404	**1.00 (0.58)**	0.67 (1.34)	165.5, 0.505	**1.83 (0.91)**	1.42 (1.08)	127.0, 0.079	**13.468, 0.001**	5.548, 0.062

3.1.3.4. Effect of Personality

The ‘extrovert’ group showed significant differences across conditions in the Behavioral Involvement component of the GEQ – Social Presence Module ($Fr(2)=12.049$, $p=0.002$) (Table 3-6). Further pairwise comparisons showed that the Collaborative mode (Mdn=1.67 (0.81)) promotes significant more Behavioral Involvement than the Competitive (Mdn=0.83 (0.99)) ($Z=-2.496$, $p=0.013$) and Co-active (Mdn=1.08 (0.83)) ($Z=-2.938$, $p=0.003$) modes. Also, the Collaborative mode (Mdn=3.09 (0.612)) promotes significantly more empathy than the Competitive (Mdn=2.17 (0.89)) ($Z=-2.502$, $p=0.012$) and Co-active (Mdn= 2.67 (0.61)) ($Z=-2.858$, $p=0.004$) modes.

The ‘introvert’ group showed significant differences across conditions in the Flow component of the GEQ – Core Module ($Fr(2)=6.545$, $p=0.038$). Further pairwise comparisons showed no significant differences after Bonferroni correction. On what concerns the ‘average’ group, significant differences across conditions were found in the Behavioral Involvement component ($Fr(2)=7.311$, $p=0.026$), however, again after the Bonferroni corrections, pairwise statistics were not significant.

When comparing the three types of personalities for each game mode, no significant differences were found.

Table 3-6 - Medians (Mdn) and Interquartile Range (IQR) for Introvert, Average and Extrovert personalities for each condition (game mode), between conditions comparison (Friedman's) for the three personalities , according to each component of the GEQ Core Module and Social Presence Module

		Competitive			***Co-active***			***Collaborative***			***Between conditions comparison***		
	Component	**Introvert**	**Average**	**Extrovert**	**Introvert**	**Average**	**Extrovert**	**Introvert**	**Average**	**Extrovert**	**Introvert**	**Average**	**Extrovert**
		Mdn (IQR)	***Mdn (IQR)***	***Mdn (IQR)***	***Mdn (IQR)***	***Mdn (IQR)***	***Mdn (IQR)***	***Mdn (IQR)***	***Mdn (IQR)***	***Mdn (IQR)***	***Chi-Square, p Value***	***Chi-Square, p Value***	***Chi-Square, p Value***
Core module	*Competence*	2.80 (0.89)	2.20 (0.84)	2.50 (1.00)	3.00 (0.79)	2.20 (0.68)	2.40 (0.97)	3.00 (0.73)	2.20 (0.68)	2.40 (0.73)	0.052, 0.974	1.368, 0.504	1.911, 0.385
	Sensory and Imaginative Immersion	2.67 (0.85)	2.17 (0.85)	2.25 (0.77)	2.67 (0.71)	2.17 (0.65)	2.34 (0.72)	2.50 (0.75)	2.17 (0.60)	2.42 (0.71)	0.195, 0.907	1.750, 0.417	1.302, 0.521
	Flow	2.60 (1.03)	2.80 (0.59)	3.20 (0.70)	2.80 (0.89)	2.80 (0.76)	3.30 (0.91)	3.20 (0.71)	2.60 (0.70)	3.00 (0.71)	**6.545, 0.038**	1.793, 0.408	0.884, 0.643
	Tension/Annoyance	0.00 (0.00)	0.00 (0.42)	0.00 (0.95)	0.00 (0.00)	0.00 (0.26)	0.00 (0.30)	0.00 (0.00)	0.00 (0.42)	0.00 (0.95)	- -	2.000, 0.368	1.400, 0.497
	Challenge	0.60 (0.66)	1.00 (0.57)	0.90 (0.54)	0.20 (0.53)	0.70 (0.70)	0.50 (0.65)	0.40 (0.59)	0.80 (0.53)	0.90 (0.76)	1.400, 0.497	1.077, 0.584	2.780, 0.249
	Negative Affect	0.00 (0.15)	0.00 (0.50)	0.00 (0.25)	0.00 (0.00)	0.00 (0.20)	0.00 (0.29)	0.00 (0.75)	0.00 (0.44)	0.00 (0.14)	1.000, 0.607	3.500, 0.174	3.200, 0.202
	Positive Affect	3.40 (0.46)	3.00 (0.58)	3.00 (0.66)	3.00 (0.46)	3.00 (0.56)	3.30 (0.69)	3.20 (0.59)	2.80 (0.54)	3.00 (0.71)	3.353, 0.187	0.462, 0.794	0.222, 0.895
Social Presence Module	*Empathy*	2.67 (0.41)	2.08 (0.97)	**2.17 (0.89)**	2.67 (0.55)	2.59 (0.83)	**2.67 (0.61)**	3.00 (0.62)	2.83 (0.84)	**3.09 (0.62)**	0.474, 0.789	3.581, 0.167	**7.953, 0.019**
	Negative Feelings	0.80 (0.54)	0.50 (0.53)	0.40 (0.59)	0.60 (0.46)	0.30 (0.60)	1.10 (0.61)	0.40 (0.53)	0.40 (0.51)	1.10 (0.48)	1.471, 0.479	0.154, 0.926	0.437, 0.804
	Behavioral Involvement	1.50 (0.75)	1.17 (0.62)	**0.83 (0.99)**	1.00 (0.61)	1.00 (0.66)	**1.08 (0.83)**	1.50 (0.69)	1.50 (0.61)	**1.67 (0.81)**	2.513, 0.285	**7.311, 0.026**	**12.049, 0.002**

3.1.3.5. Effect of Previous Relationship

Regarding the effect of previous relationship between players, significant differences across game modes were found on the Behavioral Involvement component for distant relationships (Fr(2)=13.835, *p*=0.001) and close relationships (Fr(2)=6.533, *p*=0.038) (Table 3-7). For distant relationships, pairwise comparisons showed that the Collaborative mode (Mdn=1.75 (1.42)) promotes significant more Behavioral Involvement than the Competitive (Mdn=0.92 (1.05)) (Z=-3.265, *p*=0.001), and Co-active (Mdn=1.00 (0.66)) (*Z*=-3.396, *p*=0.001) modes. For the subgroup with a closer relationship, pairwise statistics were not significant after Bonferroni correction.

When comparing both subgroups in the same condition, we found significant differences in Empathy for the Competitive mode (U=113.500, *p*=0.037). Those who reported having a closer relationship (Mdn= 2.83 (1.24)) displayed higher empathy than those that reported having a distant relationship (Mdn=2.25 (1.38)).

Table 3-7 - Medians (Mdn) and Interquartile Range (IQR) for Distant and Close Relationships for each condition (game mode), between-groups comparison (Mann-Whithney U Test), and between conditions (Friedman's) for the three personalities, according to each component of the GEQ Core Module and Social Presence Module

		Competitive			***Co-active***			***Collaborative***				
	Component	**Distant**	**Close**	**Between-groups comparison**	**Distant**	**Close**	**Between-groups comparison**	**Distant**	**Close**	**Between-groups comparison**	**Between conditions**	
		Mdn (IQR)	***Mdn (IQR)***	***Mann-Whitney U, p Value***	***Mdn (IQR)***	***Mdn (IQR)***	***Mann-Whitney U, p Value***	***Mdn (IQR)***	***Mdn (IQR)***	***Mann-Whitney U, p Value***	***Distant (Chi-Square, p Value)***	***Close (Chi-Square, p Value)***
Core module	*Competence*	2.50 (1.40)	2.20 (1.80)	163, 0.495	2.50 (1.05)	2.80 (1.40)	141.5, 0.195	2.20 (1.25)	2.40 (1.10)	171.5, 0.659	1.684, 0.431	0.989, 0.616
	Sensory and Imaginative Immersion	2.25 (0.95)	2.33 (1.42)	171, 0.649	2.33 (0.84)	2.50 (1.26)	155, 0.363	2.42 (1.33)	2.33 (0.83)	178.5, 0.809	1.615, 0.446	0.129, 0.938
	Flow	2.60 (1.05)	3.20 (1.10)	122.5, 0.066	2.80 (1.40)	3.00 (1.10)	142.5, 0.206	3.00 (1.20)	2.80 (1.00)	179, 0.820	5.474, 0.065	2.103, 0.349
	Tension/Annoyance	0.00 (0.00)	0.00 (0.00)	172, 0.419	0.00 (0.00)	0.00 (0.00)	182, 0.788	0.00 (0.00)	0.00 (0.00)	185, 0.882	2.000, 0.368	1.400, 0.497
	Challenge	0.90 (0.75)	0.80 (0.60)	165, 0.529	0.60 (1.25)	0.40 (1.00)	176.5, 0.764	0.60 (0.85)	0.80 (0.90)	164, 0.512	4.554, 0.103	1.276, 0.528
	Negative Affect	0.00 (0.00)	0.00 (0.00)	151.5, 0.173	0.00 (0.00)	0.00 (0.00)	153, 0.067	0.00 (0.00)	0.00 (0.00)	163, 0.242	4.261, 0.119	2.000, 0.368
	Positive Affect	3.00 (0.85)	3.00 (1.30)	154, 0.344	3.00 (1.00)	3.00 (1.00)	175.5, 0.742	3.00 (1.25)	2.83 (1.00)	159, 0.424	0.685, 0.710	0.367, 0.832
Social Presence Module	*Empathy*	**2.25 (1.37)**	**2.83 (1.25)**	**113.5, 0.037**	2.67 (1.25)	2.67 (0.59)	142.5, 0.203	2.75 (1.09)	3.00 (0.67)	135.5, 0.143	4.075, 0.130	3.079, 0.214
	Negative Feelings	0.50 (1.05)	0.80 (1.20)	165.5, 0.536	0.60 (1.20)	0.40 (1.10)	157.5, 0.394	0.40 (1.20)	1.00 (0.80)	139, 0.165	0.400, 0.819	2.151, 0.341
	Behavioral Involvement	**0.92 (1.04)**	**1.33 (0.84)**	125, 0.078	**1.00 (0.66)**	**1.33 (1.17)**	162.5, 0.484	**1.75 (1.42)**	**1.67 (0.59)**	185.5, 0.966	**13.835, 0.001**	**7.429, 0.024**

3.1.4. Discussion

Here we compared three different game modes (Competitive, Co-active and Collaborative) to understand differences in engagement and social involvement, with the purpose of identifying the most adequate multiplayer game strategy for a stroke motor rehabilitation program. However, before addressing the study with stroke survivors, we decided to study healthy elderly participants first because it is important to first assess a population on the same age range as the majority of people with stroke [30], and without significant deficits, besides those related to aging, that could act as confounding factors for the study, such as motor impairments. We acknowledge that for the selected population the main goal or motivation for playing serious games is different from who plays for rehabilitation purposes. However, we believe that the most important is the existence of motivation to engage in an activity. If this engagement is natural and voluntary, levels of motivation will be high whether for entertainment or rehabilitation. Thus, this is a first step towards understanding the impact of game modes on engagement and social interaction with stroke patients.

We found evidence that the Collaborative mode promotes significantly more Empathy and Behavioral Involvement when compared to Co-active and Competitive modes. This could mean that collaboration promotes the feeling that one's actions depend on the co-player actions [17], leading to higher levels of attention towards others. In turn, we assume this higher awareness from the other can potentially stimulate social involvement. We hypothesize that the major reason for this result is because in a Collaborative mode a player can not win independently. In this mode, players have to help each other achieving a common goal (e.g., in this specific task, after catching one ball, they could inform which color the co-player should catch to score 1 point). Having both players contributing equally to achieve the goals enhances positive social interaction [17]. This is an important result because of recent evidence that highlights the importance of social engagement on health and well-being of older people [1]. Furthermore, social interaction in the form of multiplayer games has been described as a potentially important element to promote motor rehabilitation [31]. The Collaborative mode also potentiates more empathy, which is very important to facilitate social interaction and as well to affiliate and form social bonds [32]. Hence, multiplayer serious games that require collaboration could be a relevant approach to consider for social rehabilitation.

The observed outcomes in behavioral involvement promoted by the collaborative mode, are expected to increase engagement, as it is predictable that participants with lower skills are going to be assisted by their co-player when presenting difficulties and consequently achieve more success while the participant with higher skills is going to be more challenged and/or required to adopt an altruistic behavior [33]. Gorsic *et al*. [22] studied the impact of Single Player Vs Cooperative Vs Competitive game modes in motivation and exercise intensity, with unimpaired and healthy (familiar or therapist) participants. Their description of the two used variants of Cooperative mode are actually what Mace *et al*. [17] describe as Collaborative (Cooperative with split field) and Co-active (Cooperative with shared field) modes, definitions that we used as guidelines. Their results identified the Collaborative mode as the less preferred and the one where participants felt less competent [22]. Similarly to their study, our results regarding the Collaborative mode also reveal this mode as the one where participants felt less competent. This indicates that serious games for rehabilitation to be played in collaboration must be carefully designed, ensuring compensation mechanisms in order to balance differences of motor and cognitive skills between participants [17].

Globally, ratings of Negative Feelings and Negative Affect were low on every mode, and in line with the high ratings of Positive Affect, which can mean the overall impact of the game modes tested was positive. The sense of Flow was generally reported as high but not significantly different among the three game modes. Also, the tasks were not considered challenging, and the sense of competence was reported as slightly positive. As levels of challenge were low, according to the Flow model [34], it would be expectable that participants would feel bored. We hypothesize that one contribution to the reported high levels of Flow was the inexistence of any kind of negative feedback through the game and constant positive feedback, as positive competence feedback is positively related to subsequent motivation [35]. The only objective informations that participants could use from the game to establish a low performance, were the balls that they could not catch, and the final score of each round with which they could infer if it was lower or higher than the previous. On the other side, constant positive feedback was being given when a ball was caught (visually through green fireworks and a “+1” point that appeared on the screen). Despite this positive feedback was very frequent, the sense of competence was described only as slightly positive.

Cognitive skills are important to have in consideration when using virtual rehabilitation with patients that suffered a stroke, as the capacity to understand and solve tasks have an impact on the experience [36]. Differences in the Behavioral Involvement component regarding the Collaborative mode seem to be explained by participants who had higher cognitive skills. Indeed, a study with persons that suffered a stroke, reported that patients with higher cognitive deficits rated poorly the virtual environment designed for rehabilitation [36] compared to those with lower cognitive deficits. In our opinion, the Collaborative mode is more cognitively demanding when compared to others. That is because participants need to coordinate strategies, requiring thus much more attention from the players. Additionally, since participants with higher cognitive skills may understand this better and may be required to assume a leading role, giving more instructions than receiving, it is understandable that they could feel more behavioral involved than the co-player [36].

Personality is directly linked with our social posture and how we interact with others. For that reason, we characterized our sample in three kinds of personality: average ones, those more extrovert, and those more introvert. Gorsic *et al*. did not find significant differences between personality scores and the game modes studied [22]. However, our results show that the most extrovert participants benefit more from the Collaborative mode compared to Competitive and Co-active modes in Behavioral Involvement. This is in line with findings reported by Novak *et al*. where gameplay in a Competitive and Cooperative settings can be either fun or frustrating according to different personalities [8]. Our results support that these participants felt more comfortable to interact with the co-player in a situation where they had to play as a team. Also, the more extrovert participants felt significantly more empathy with the Collaborative mode when compared to Co-active and Competitive modes. Overall, the Competitive setting was the weakest mode among the three studied to promote this kind of interaction with this specific subgroup.

Regarding participants' previous relationship between co-players, we found that those with a distant relationship preferred to play the Collaborative mode when compared to Competitive and Co-active, which reinforces this mode as particularly suitable to promote social interaction between players. This is an important result because most of the times, in rehabilitation settings, patients do not have any previous relationship, and the use of collaborative tools can be a valid solution to foster their interaction. Moreover, results also show that the Competitive mode can be more suitable for participants that have a previously established relationship, as they feel more empathy. This result is somehow expected, as it is typically easier to deal with victory and defeat when dealing with a person that we already know. This is consistent with literature supporting that the Competitive mode is preferred to Cooperative in persons that have close relationships [192].

As limitations of this study, it would have been valuable to include open-ended questions in our assessment measures to gather additional input from the participants concerning their preferences, which mode they felt more willing to interact with the co-player, which mode they felt more motivated or which mode triggered more frustration. This kind of information could be interesting for the analysis, instead of relying just on the GEQ scores, as it would allow participants to spontaneously comment about specificities of the game and game modes, originating valuable qualitative data. Additionally, the short time duration of each experimental condition could be a limitation, as with longer times the effects could be stronger. Nonetheless, we opted for shorter durations to avoid confounds brought by fatigue or decreasing interest. Another limitation is the possible lack of generalization of results, regarding the sample. While we opted to study a sample of older adults without motor deficits to avoid confounds at this stage, we cannot ascertain that the obtained results are fully generalizable to stroke survivors. Hence, the next step is to validate these results with a sample of stroke survivors. Additionally, the specific design of the game also has potential implications for the generalization of results [40], as different games could lead to different results. Hence, caution should be taken when assuming generalization, especially when game mechanics are based on different sets of motor and/or cognitive skills and different modes of interaction among players to the ones studied here. Finally, it would have been interesting to understand how potentially unbalanced pairs in terms of skills in the games could have affected the results.

3.1.5. Conclusions

This study compared the impact that three different game modes (Competitive, Co-active and Collaborative) can have in engagement and social involvement in multiplayer settings. Data showed that the Collaborative mode can have a significant positive impact on social involvement when compared to Competitive and Co-active modes. This impact seems bigger for some specific profiles, such participants without cognitive deficits and participants that are more extrovert. During collaboration, participants without cognitive deficits feel more Empathy and Flow compared to those with higher cognitive deficits. The more extrovert participants feel more empathy and are behaviorally more involved when playing the Collaborative mode. No significant differences were found regarding engagement. Further studies to extrapolate these conclusions to clinical populations are needed, as these multiplayer games are to be used for rehabilitation purposes.

3.2. The Use of Game Modes with Stroke Survivors to Promote Engagement and Social Interaction through an Interactive Table with Multi-user Serious Games

3.2.1. Introduction

The use of novel technologies for neurorehabilitation has increased during the last years, leading to new rehabilitation methods with multifold benefits [151]. Depending on the technology, we can benefit from personalization to individual patients' specific needs, the ability to measure with objectivity, or provide visual, haptic, or auditory real-time feedback [38]. Despite the many benefits of technology-mediated rehabilitation approaches, other aspects such as the environment, changes in assistive devices, individual preferences, and interaction with peers can modulate the delivered experience and its impact on the users [216], [217]. For instance, multi-user technology-mediated rehabilitation approaches have been shown to influence rehabilitation outcomes, highlighting the potential positive effects of social interaction in rehabilitation settings [43], [183], [218]. However, features like the way players interact between themselves to achieve success in a task or game, i.e., the interaction mode (competitive, cooperative, or collaborative), can influence the social impact and engagement experienced by the users [183], [218]. In fact, Baur *et al.* identified nine studies where different multiplayer modes had a different effect on game experience [43]. In general, competitive games have been shown to lead to higher enjoyment [181], [195], [219]. Specifically, competitive game modes seem to be related to higher physical effort and usually require more skills, at least more than the opponent, to produce performance satisfaction when compared to modalities that require collaboration or cooperation [188], [218], [220], [221]. However, there is no consensus on this matter, as literature suggests that cooperative modes lead to greater efforts than their competitive counterparts [185]. Collaborative modes have been less addressed in the literature, and therefore the evidence on their specific impact is still scarce [43], [200], [222]–[224].

We developed a multi-user interactive table with a custom-made serious game intended to enhance the social impact and improve self-efficacy during motor rehabilitation of stroke survivors. In this study, we aim to understand what the impact on engagement and social involvement of stroke survivors is of having the game presented in three different modes, namely, Competitive, Co-active, and Collaborative. For this purpose, we recruited a sample of stroke survivors who were paired to play a game in those three game modes. We investigated competitive, co-active, and collaborative modes in a previous study with community-dwelling older adults using a different experimental setup (a vertical screen with indirect interaction with VR), identifying some positive effects in collaborative interaction [183]. However, it is not sure to what extent the previously observed results generalize to a stroke population with motor deficits, a different interaction modality (direct interaction with VR), and different technology and interfaces. We hypothesize that engagement will be higher in the Competitive mode than Co-active and Collaborative modes, as the literature suggests that competitive modes are usually more motivating [225]. Also, we expected social involvement to be higher in the Collaborative game mode when compared to Competitive and Co-active modes because this specific mode requires dependence on the co-player to reach the goal. Finally, we want to understand how the results are affected by different levels of motor and cognitive function, spasticity, and personality.

3.2.2. Methods

3.2.2.1. Experimental Setup

The interactive table setup consisted of a PC (OS: Windows 10, CPU: Intel Coffee Lake Core I7-8700K 3.7 GHz 12 MB, RAM: 2x 8GB DDR4 2400 Mhz, Graphics: Gigabyte Nvidia GTX 1070 Ti Gaming 8G GDDR5), a 55" LED TV screen and a 55" infrared multitouch sensitive layer (latency: <15 ms panning, <25 ms touchdown, reporting rate 100 Hz), plus an auxiliary screen for the researcher (Figure *3-4*). Users were seated facing each other, with arms resting on the table and hands on the touch-sensitive screen. Users used a plastic cone (5 cm base diameter, 17.5 cm height, and 3.8 cm top diameter) – later referred to as the handle - mounted on a soft conductive base to interact with the game.

This base reduced friction and facilitated detection over the touchscreen. This object is commonly used for rehabilitation purposes as it eases basic prehension (global prehension) and keeps it uniform through all participants. We used chairs with adjustable height and a structure underneath the table to rest the feet to guarantee a proper posture while seated.

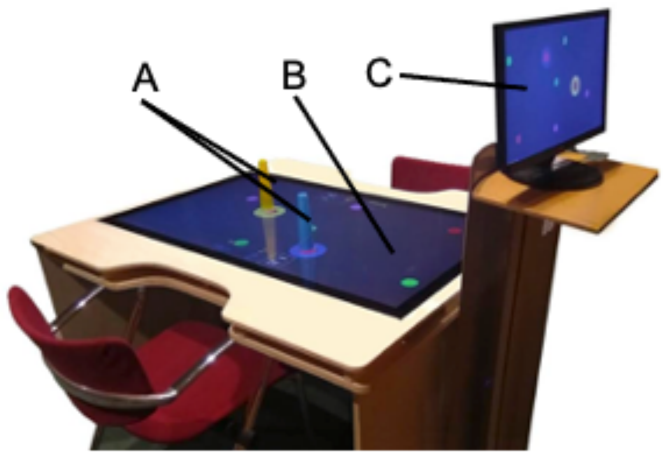


Figure 3-4 - Experimental Setup: Handles (A), infrared touch sensitive layer (B), and auxiliary screen for the researcher (C).

3.2.2.2. Task

The task was a two-player game whose primary objective was to catch balls that appeared in random positions, moving straight to make their movement predictable and easier for users to anticipate. It was designed to have straightforward mechanics to guarantee quick learning. Additionally, its simplicity allowed us to adapt it to the three different game modes with minor game mechanics changes. We opted to have the balls move on a straight line to make their movement predictable and allow easier planning. Each user controlled a virtual ring on the screen by moving the handle over the surface. We implemented three different versions of the task, each corresponding to a different game mode: Competitive, Co-active, and Collaborative (Figure 3-5). The different game modes relied on the same basic mechanics. In the Competitive mode (Figure 3-5 - A), each participant had to catch the maximum number of balls, which accumulated to his/her score. The participant who scored more points (balls caught) would win the round. In the Co-active (Figure 3-5 – B) game mode, participants had to play as a team and catch balls, but points would accumulate to a single combined team score. Finally, in the Collaborative (Figure 3-5 – C) game mode, participants also played as a team but only scored if both players consecutively caught two balls of the same color. These game modes were chosen because Competitive is a game mode that allows participants to engage in a task to be superior to the opponent. In the Collaborative and Co-active modes, the perspective is very different; they have to work as a team. However, in the Collaborative mode, they are dependent on each other to reach the goal, whereas, in the Co-active mode, they do not depend on each other.

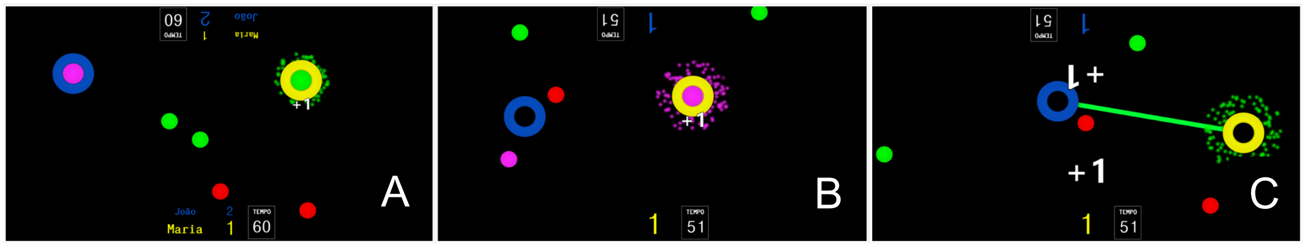


Figure 3-5 - Competitive (A), Co-active (B) and Collaborative (C) game modes, from top to bottom, respectively. The rings (yellow and blue) are used to catch the balls (inside they have the color of the last ball caught) and represent the color of the player. Each mode shows a score and time left to end the round.

3.2.2.3. Sample and Recruitment

A convenience sample of stroke survivors was recruited in health units of the regional health service (SESARAM) in Madeira Island, Portugal. The inclusion criteria were to have suffered a stroke and sustaining upper limb motor deficits. The exclusion criteria were to be unable to hold the handle used for the interaction with the table, to have any type of aphasia diagnosed, not having the ability to read, and hemi-spatial neglect, assessed through Bells Test [226]. Two hundred and seventeen potential participants were approached. Thirteen refused to participate, and 184 were excluded due to exclusion criteria. The reason for this high exclusion percentage was the way of contact, i.e., personally or by a phone call. One hundred and two potential participants were contacted by a phone call, as the local health services gave access to a list of recent stroke survivors and the respective phone number. Sixty-eight of them reported not to have motor deficits. Fifty-three potential participants were excluded after a first approach because they presented minor motor difficulties (18), hemiplegia (18), cognitive deficits (7), aphasia (6), and 4 did not know how to read and write. Additionally, the first exclusion criteria (must be able to hold the handle) also implied the users to hold the handle (cone) with enough control to keep their forearm in a neutral position, allowing them to interact with the touch display.

One participant was excluded after data collection as he could not properly answer questionnaires due to having unreported aphasia. Twenty participants (12 males) with a mean age (with standard deviation) of 60.4±8.2 years (range: 31-71 years) concluded the study and were included in data analysis (Table 3-8). Five participants reported having previous experience with video games. To obtain a profile of the participants, we used: 1) A brief questionnaire for demographic information; 2) The MoCA for cognitive screening [206]; 3) The Fugl-Meyer Assessment for Upper Extremity (FMA-UE) [227]; The mAS [228]; and The Mini-IPIP validated for Portuguese population [207]. Although Mini-IPIP measures the Big Five personality factors (Openness/Intellect or Imagination, Conscientiousness, Extraversion, Agreeableness, and neuroticism), we only considered the extraversion factor as it is the one that we believe clearly relates to engagement and social involvement. The study was approved by the Ethics Commission of SESARAM (number 24/2018), and all participants provided written informed consent.

Table 3-8 - Participants' profile

PAIRS	***PARTICIPANT***	***GENDER (M/F)***	***AGE***	***TIME SINCE STROKE (MONTHS)***	***MOCA (0-30)***	***FMA-UE (0-66)***	***ASHWORTH (0-3)***	***EXTRAVERSION (5-20)***
1	1	M	61	42	22	58	1	14
	2	M	53	23	23	58	0	16
2	3	M	60	74	30	47	1+	14
	4	F	71	44	20	55	0	17
3	5	F	31	54	29	17	2	10
	6	F	67	37	23	33	1+	12
4	7	M	64	8	27	47	1	9
	8	F	64	33	14	52	0	18
5	9	F	63	8	19	54	0	19
	10	F	59	51	25	56	1	11
6	11	F	61	178	28	24	3	11
	12	M	77	13	15	26	3	15
7	13	M	63	16	20	54	1	15
	14	M	65	46	12	53	0	12
8	15	M	62	4	21	31	1	16
	16	M	61	8	25	26	1	12
9	17	F	57	2	22	51	0	12
	18	M	64	1	16	56	0	18
10	19	M	55	5	12	29	1	11
	20	M	57	3	18	29	1	12

3.2.2.4. Outcome Measures

The Game Experience Questionnaire (GEQ) – Core Module [205] and the GEQ – Social Presence Module [208] were chosen to measure engagement and social involvement, respectively. The Core Module measures the players' thoughts and feelings through 7 components (Competence, Sensory and Imaginative Immersion, Flow, Tension/Annoyance, Challenge, Negative affect, and Positive affect) in a total of 33 items [205]. The Social Presence Module has three components (Psychological Involvement – Empathy, Psychological Involvement – Negative Feelings and Behavioral Involvement) and 17 items. In both questionnaires, the items are rated as "0" (Not at all), "1" (Slightly), "2" (Moderately, "3" (Fairly), or "4" (Extremely). These questionnaires are typically filled-in by the user, but because of the sample's characteristics, the answers' scale was provided on an A4 sheet, always visible to the participants, and the questions were made verbally. The scale was translated from English to Portuguese by two experts in English-to-Portuguese translation.

3.2.2.5. Experimental Procedure

The study followed a within-person design with three conditions (Competitive, Co-active, and Collaborative). The order of the conditions was randomized using random.org. Data collection was conducted in two sessions of approximately 90 minutes for each pair of players. In the first session, participants signed the informed consent, were checked against exclusion criteria, and underwent motor and cognitive assessments. An occupational therapist was responsible for the assessments. Sessions were conducted by two researchers trained on the system and the assessment questionnaires. Participants were arranged in pairs (10 in total) according to their motor skill level as assessed by Section A-Shoulder/Elbow/Forearm of FMA-UE, excluding reflex activity. We limited the difference in scores between paired participants to a maximum of 10 out of 30, just considering component A without reflexes activity. The pairs were maintained for all conditions of the study.

In Session 2, we introduced the system to participants through a training phase, allowing them to play each specific game mode before the condition was tested. We ensured that they got familiar with the interface and the game by having participants playing with no time limit, just finishing when researchers considered they had understood the game's purpose and how to play it, reducing the effects of learning and novelty for each game mode. Each condition consisted of 8 consecutive rounds of 1 minute with a 5-15 seconds interval between rounds to allow participants to interact with each other, besides they were allowed to interact during the round. Between each round, the score was reset. At the end of each condition, pairs of participants answered the GEQ – Core Module and GEQ – Social Presence Module in separate rooms.

3.2.2.6. Data Analysis

Because of the ordinal nature of the measures, non-parametric statistical tests were used for data analyses. Hence, the median was used as a measure of central tendency and the interquartile range (IQR) for dispersion. To test for differences across conditions, we used Friedman's test for each of the modules' components from the GEQ, cognitive, motor, and personality impact. The Wilcoxon signed-rank test was used for pairwise comparisons, with significance values adjusted by the Bonferroni correction. Data were analyzed using IBM Statistics for Mac, Version 26.0 (Armonk, NY: IBM Corp).

To understand the impact of the level of motor function, we divided the sample into two subgroups according to the mean of FMA-UE score (42.8±14.00), resulting in a group with a score higher than 42.8 (n=12) and another below or equal to 41 (n=8). For between-group comparisons, we used the Mann-Whitney U Test. The same method was followed to analyze the impact of the level of cognitive function and personality. Regarding the cognitive function, we divided the sample into two subgroups according to the mean of MoCA scores (21.1±5.4), the group with a score higher or equal to 21 (n=11) and below 21 (n=9). For personality, we also divided the sample into two subgroups using the mean of extraversion component of Mini-IPIP (13.7±2.9), the group with a score lower than 13 (n=10) and higher or equal to 13 (n=10). Finally, we analyzed the correlation between spasticity and GEQ ratings in each game mode using Pearson's correlation coefficient.

3.2.3. Results

3.2.3.1. Engagement

Concerning engagement (Table *3-9*), in all conditions (Competitive, Co-active, Collaborative), Flow, Positive Affect, and Competence were reported as high (out of 4 points). The level of Challenge was considered low. Regarding Tension/Annoyance and Negative Affect, these were rated as very low.

We found significant differences across conditions in Flow ($\chi(2)=12.277$, $p=0.002$) and Challenge ($\chi(2)=10.959$, $p=0.004$) (Table *3-9*, Figure 3-6). Pairwise comparisons revealed that Flow ($Z=-2.962$, $p=0.003$) and Challenge ($Z=3.312$, $p=0.002$) were significantly higher in the Competitive mode than the Co-active mode.

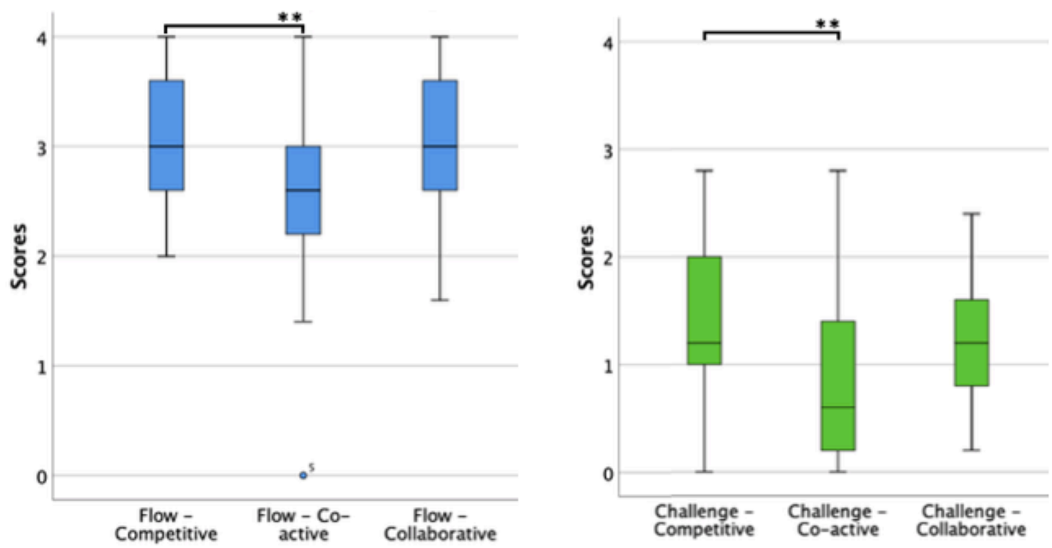


Figure 3-6 - Boxplots of the components Flow and Challenge from the GEQ – Core Module per game mode. ** $p<0.01$.

Table 3-9 - Medians (Interquartile Range) in the Game Experience Questionnaire components – Core Module per condition, and Friedman's statistics across conditions. Bold values represent that significant differences between conditions were found. The asterisk represents significant results after pairwise comparisons.

Component	*Competitive*	*Co-active*	*Collaborative*	*Friedman's statistic* (Chi-Square)	***p* value**
Competence	2.7 (0.8)	2.4 (1.2)	2.6 (0.8)	0.400	0.819
Sensory and Imaginative Immersion	2.3 (1.1)	2.4 (1.2)	2.3 (1.0)	0.194	0.907
Flow	**3.1 (1.2)***	**2.6 (1.0)***	**3.0 (1.3)**	**12.277**	**0.002**
Tension/Annoyance	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.727	0.422
Challenge	**1.2 (1.0)***	**0.6 (1.2)***	**1.2 (1.0)**	**10.959**	**0.004**
Negative Affect	0.1 (0.5)	0.0 (0.5)	0.0 (0.4)	0.167	0.920
Positive Affect	3.0 (1.1)	3.0 (0.7)	3.0 (1.0)	1.794	0.408

3.2.3.2. Social Involvement

Regarding Social Involvement, we found significant differences across conditions in Behavioral Involvement ($\chi(2)=26.694$, $p<0.001$) (Table 3-10, Figure 3-7). Pairwise comparisons revealed that this effect arises from the Collaborative mode being significantly higher when compared to the Competitive ($Z=-3.827$, $p<0.001$) and the Co-active mode ($Z=-3.684$, $p=0.001$). Empathy was similar and positive on the three conditions, contrasting with Negative Feelings that were low across all conditions (Table 3-10).

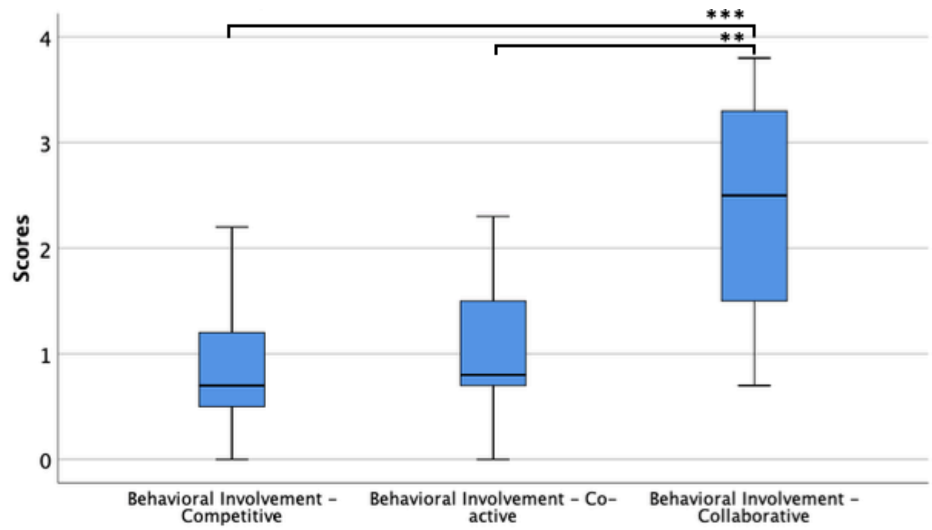


Figure 3-7 - Boxplots of the component Behavioral Involvement from the GEQ – Social Presence Module per game mode, with all sample. **p<0.01, ***p<0.001.

Table 3-10 - Medians (Interquartile Range) in the Game Experience Questionnaire components – Social Presence Module per condition, and Friedman's statistics across conditions. Bold values represent that significant differences between conditions were found. The asterisk represents significant results after pairwise comparisons.

Component	***Competitive***	***Co-active***	***Collaborative***	***Friedman's statistic***	
				(Chi-Square)	***p* value**
Behavioral Involvement	**0.7 (0.9)***	**0.8 (1.1)***	**2.8 (1.8)***	**26.694**	**<0.001**
Empathy	2.3 (1.6)	2.5 (1.2)	2.6 (1.4)	2.795	0.247
Negative Feelings	0.4 (1.0)	0.6 (0.8)	0.6 (1.0)	0.689	0.709

3.2.3.3. Effect of the Cognitive Profile

When dividing the sample into higher and lower score groups according to their MoCA score, we found that there were significant differences across conditions for both groups in Behavioral Involvement (Lower MoCA scores: $\chi(2)=13.937$, $p<0.001$; Higher MoCA scores: $\chi(2)=12.950$, $p=0.002$) (Table 3-11). Pairwise comparisons showed that both groups felt significantly more behavioral involvement with the Collaborative mode when compared to the Competitive mode (Lower MoCA scores: $Z=-2.670$, $p=0.008$; Higher MoCA scores: $Z=-2.803$, $p=0.005$) and the Co-active mode (Lower MoCA scores: $Z=-2.521$, $p=0.012$; Higher MoCA scores: $Z=-2.708$, $p=0.007$) (Table 3-11). We also found significant differences for those with higher MoCA scores in Flow ($\chi(2)=9.722$, $p=0.008$) and Challenge ($\chi(2)=8.537$, $p=0.014$). They considered having felt significantly less Flow ($Z=2.680$, $p=0.007$) and Challenge ($Z=2.499$, $p=0.012$) in the Co-active mode (Mdn=2.6 (0.8)) when compared to Competitive mode.

When making a between-groups comparison, results revealed that those opponents with lower MoCA scores showed a significantly higher sense of Competence in the Co-active mode than those with higher scores ($U=18.500$, $p=0.017$) (Table 3-11). Lower MoCA scores significantly demonstrated more Tension/Annoyance and Negative Affect in the Competitive mode than those with high scores ($U=33.000$, $p=0.044$) and ($U=25.000$, $p=0.045$), respectively. Finally, the Collaborative mode was significantly more challenging for the lower MoCAs than for higher MoCAs, ($U=23.500$, $p=0.047$). ($U=25.000$, $p=0.045$), It also promoted more empathy with the lower MoCAs scores compared with, the higher MoCAs scores ($U=23.500$, $p=0.047$).

Table 3-11 - Medians (Mdn) and Interquartile Range (IQR) for High (H MoCAs) and Low (L MoCAs) Montréal Cognitive Assessment scores (MoCAs) for each condition (game mode), between-groups comparison (Mann-Whitney U Test), and between conditions comparison (Friedman's). Bold values represent that significant differences between conditions were found.

		Competitive			***Co-active***			***Collaborative***			***Between conditions comparison***	
	Component	***H MoCAs*** ***Mdn (IQR)***	***L MoCAs*** ***Mdn (IQR)***	**Between-groups comp.** ***Mann-Whitney U, p-Value***	***H MoCAs*** ***Mdn (IQR)***	***L MoCAs*** ***Mdn (IQR)***	**Between-groups comp.** ***Mann-Whitney U, p-Value***	***H MoCAs*** ***Mdn (IQR)***	***L MoCAs*** ***Mdn (IQR)***	**Between-groups comp.** ***Mann-Whitney U, p-Value***	**H MoCAs** **Chi-Square, *p-Value***	**L MoCAs** **Chi-Square, *p-Value***
Core module	*Competence*	2.2 (0.8)	3.0 (0.8)	29.500, 0.124	**2.4 (0.6)**	**3.4 (1.2)**	**18.500, 0.017**	2.4 (0.8)	2.8 (0.5)	24.000, 0.050	1.167, 0.558	0.483, 0.786
	Sensory and Imaginative Immersion	2.3 (1.0)	2.8 (1.2)	32.000, 0.181	2.2 (1.4)	2.7 (0.9)	24.500, 0.056	2.2 (0.5)	2.8 (0.9)	29.000, 0.117	0.195, 0.907	0.581, 0.748
	Flow	**3.0 (0.8)**	3.6 (1.6)	34.500, 0.252	**2.6 (0.8)**	3.0 (1.1)	31.500, 0.170	3.0 (1.2)	3.0 (1.5)	40.500, 0.492	**9.722, 0.008**	3.379, 0.185
	Tension/Annoyance	**0.0 (0.0)**	**0.0 (0.5)**	**33.000, 0.044**	0.0 (0.0)	0.0 (0.0)	45.000, 0.366	0.0 (0.0)	0.0 (0.5)	45.500, 0.664	2.000, 0.368	3.846, 0.146
	Challenge	**1.2 (1.4)**	1.2 (1.1)	41.500, 0.541	**0.6 (1.0)**	0.6 (1.7)	45.500, 0.760	**0.8 (0.8)**	**1.5 (0.9)**	**23.500, 0.047**	**8.537, 0.014**	4.688, 0.096
	Negative Affect	**0.0 (0.3)**	**0.3 (0.5)**	**25.000, 0.045**	0.0 (0.5)	0.3 (0.5)	44.000, 0.644	0.0 (0.3)	0.0 (0.6)	49.000, 0.966	1.750, 0.417	12.643, 0.267
	Positive Affect	2.8 (0.8)	3.4 (1.2)	30.500, 0.145	2.8 (0.8)	3.0 (1.0)	32.500, 0.193	2.8 (1.4)	3.2 (1.0)	34.000, 0.235	1.514, 0.469	0.581, 0.748
Social Presence Module	*Empathy*	1.7 (1.3)	2.8 (0.9)	24.500, 0.057	2.3 (1.5)	2.7 (1.0)	37.500, 0.359	**2.2 (1.3)**	**2.8 (1.4)**	23.500, 0.047	2.048, 0.359	2.000, 0.368
	Negative Feelings	0.0 (0.4)	0.8 (0.9)	29.000, 0.105	0.6 (0.8)	0.4 (0.8)	45.500, 0.750	0.4 (0.6)	1.0 (1.2)	32.000, 0.180	3.879, 0.144	2.643, 0.267
	Behavioral Involvement	**0.7 (0.7)**	**1.2 (1.1)**	26.000, 0.070	**0.7 (1.2)**	**1.3 (1.4)**	38.000, 0.378	**2.3 (2.0)**	**3.0 (1.8)**	39.000, 0.423	**12.950, 0.002**	**13.937, 0.001**

3.2.3.4. Effect of Motor Profile and Spasticity

When dividing the sample into groups according to their FMA-UE score, we found significant differences across conditions in Behavioral Involvement for both, participants with lower ($\chi(2)=12.452$, $p=0.002$) and higher ($\chi(2)=15.951$, $p<0.001$) FMA-UE scores. Pairwise comparison showed that both groups felt significantly more behaviorally involved with the Collaborative mode than the Competitive mode (Higher FMA-UE: $Z=-2.940$, $p=0.003$; Lower FMA-UE: $Z=-2.521$, $p=0.012$). For the lower FMA-UE group only, behavioral involvement in the Collaborative mode was also significantly higher than in the Co-active mode ($Z=-2.533$, $p=0.011$) (Table 3-12).

Regarding the participants with higher FMA-UE scores, we found significant effects for Flow ($\chi(2)=7.167$, $p=0.028$) and Challenge ($\chi(2)=6.186$, $p=0.045$) (Table 3-12). Pairwise comparisons revealed that higher FMA-UE scores report significantly more Flow ($Z=-2.546$, $p=0.011$) and Challenge ($Z=-2.527$, $p=0.012$) with the Competitive mode than the Co-active mode.

When making a between-groups comparison, results show that in the Co-active mode, lower FMA-UE scores are associated with a lower sense of Flow ($U=22.000$, $p=0.044$) and significantly less behaviorally involved ($U=17.000$, $p=0.016$) when comparing with high FMA-UE scores.

Table 3-12 - Medians (Mdn) and Interquartile Range (IQR) for High Fugl-Meyer Assessment-Upper Extremity (H FMA-UE) and Low Fugl-Meyer Assessment-Upper Extremity (L FMA-UE) for each condition (game mode), and between conditions comparison (Friedman's). Bold values represent that significant differences between conditions were found.

		Competitive			*Co-active*			*Collaborative*			*Between conditions comparison*	
	Component	***H FMA-UE*** ***Mdn (IQR)***	***L FMA-UE*** ***Mdn (IQR)***	**Between-groups comp.** ***Mann-Whitney U, p-Value***	***H FMA-UE*** ***Mdn (IQR)***	***L FMA-UE*** ***Mdn (IQR)***	**Between-groups comp.** ***Mann-Whitney U, p-Value***	***H FMA-UE*** ***Mdn (IQR)***	***L FMA-UE*** ***Mdn (IQR)***	**Between-groups comp.** ***Mann-Whitney U, p-Value***	***H FMA-UE*** **Chi-Square, *p-Value***	***L FMA-UE*** **Chi-Square, *p-Value***
Core module	*Competence*	2.9 (0.7)	2.2 (0.9)	23.500, 0.056	2.5 (1.0)	2.3 (1.8)	37.500, 0.413	2.8 (0.6)	2.4 (0.7)	27.500, 0.110	1.500, 0.472	0.272, 0.871
	Sensory and Imaginative Immersion	2.4 (1.2)	2.3 (1.0)	42.500, 0.669	2.6 (0.8)	2.1 (1.4)	32.500, 0.229	2.3 (0.9)	2.4 (1.1)	44.00, 0.756	0.409, 0.815	0.286, 0.867
	Flow	**3.3 (0.8)**	2.7 (1.6)	35.00, 0.314	**2.9 (1.2)**	**2.4 (1.1)**	**22.000, 0.044**	**3.1 (1.0)**	2.8 (1.6)	35.500, 0.332	**7.167, 0.028**	5.793, 0.055
	Tension/Annoyance	0.0 (0.0)	0.0 (0.3)	41.000, 0.385	0.0 (0.0)	0.0 (0.0)	42.00, 0.221	0.0 (0.6)	0.0 (0.0)	32.000, 0.077	4.769, 0.092	2.000, 0.368
	Challenge	**1.4 (1.8)**	1.1 (0.6)	40.000, 0.534	**0.6 (1.2)**	0.8 (1.0)	42.000, 0.641	**1.2 (1.3)**	1.1 (0.8)	43.000, 0.698	**6.186, 0.045**	4.867, 0.088
	Negative Affect	0.0 (0.4)	0.4 (0.7)	34.000, 0.245	0.0 (0.5)	0.4 (0.7)	34.00, 0.233	0.0 (0.4)	0.0 (0.5)	45.500, 0.827	0.963, 0.618	2,571, 0.276
	Positive Affect	3.0 (1.2)	3.0 (0.8)	43.000, 0.697	3.0 (0.7)	2.9 (0.9)	39.000, 0.484	3.0 (1.3)	3.0 (1.4)	40.500, 0.560	0.650, 0.723	1.357, 0.507
Social Presence Module	*Empathy*	2.4 (0.9)	1.9 (1.5)	41.500, 0.615	2.5 (1.1)	2.5 (1.8)	35.000, 0.313	2.8 (0.9)	2.4 (1.2)	36.000, 0.351	3.872, 0.144	0.194, 0.908
	Negative Feelings	0.4 (1.0)	0.1 (0.7)	34.000, 0.262	0.5 (1.1)	0.7 (0.8)	46.000, 0.871	0.5 (1.1)	0.7 (0.9)	35.500, 0.613	0.250, 0.882	0.897, 0.639
	Behavioral Involvement	**1.0 (1.6)**	**0.7 (0.2)**	35.500, 0.327	**1.4 (1.3)**	**0.6 (0.8)**	**17.000, 0.016**	**2.8 (1.5)**	**2.7 (1.8)**	46.500, 0.907	**15.951, <0.001**	**12.452, 0.002**

To understand the relation between spasticity and ratings in the GEQ components for each game mode, we computed bivariate correlations. We found a negative correlation with Competence in Competitive mode (r(18)=-0.477, p=0.033) and in Flow with Co-active mode (r(18)=-0.529, p=0.016) and Collaborative mode (r(18)=-0.465, p=0.039). At last, Tension/Annoyance was also negatively correlated with Collaborative mode (r(18)=-0.467, p=0.038) (Table 3-13).

Table 3-13 - Correlation Coefficient and p-value between spasticity and all Game Experience Questionnaire components for each condition (game mode). Bold values represent that significant differences between conditions were found.

	Component		*Competitive*	*Co-active*	*Collaborative*
Core Module	Competence	r	**-0.477**	-0.375	-0.288
		p value	**0.033**	0.104	0.219
	Sensory and Imaginative Immersion	r	-0.192	-0.302	-0.227
		p value	0.417	0.196	0.336
	Flow	r	-0.392	**-0.529**	**-0.465**
		p value	0.087	**0.016**	**0.039**
	Tension/Annoyance	r	-0.186	0.229	**-0.467**
		p value	0.431	0.331	**0.038**
	Challenge	r	-0.147	0.192	-0.247
		p value	0.537	0.418	0.295
	Negative Affect	r	0.268	0.147	-0.195
		p value	0.254	0.538	0.409
	Positive Affect	r	-0.012	-0.213	0.043
		p-value	0.959	0.368	0.857
Social Presence Module	*Empathy*	*r*	-0.001	-0.215	-0.097
		p value	0.998	0.363	0.684
	Negative Feelings	*r*	-0.259	-0.242	-0.114
		p value	0.270	0.304	0.633
	Behavioral Involvement	*r*	-0.264	-0.427	-0.040
		p value	0.260	0.061	0.867

3.2.3.5. Effect of Personality

After dividing the sample into groups according to their Extraversion scores, we found that there were significant differences across conditions in Behavioral Involvement for both, participants with higher (χ(2)=11.118, p=0.042) and lower (χ(2)=16.000, p<0.001) scores. Pairwise comparisons showed that groups felt significantly more behaviorally involved with the Collaborative mode when compared to the Competitive mode (More extrovert: Z=-2.668, p=0.008, Less extrovert: Z=-2.807, p=0.005). Additionally, the less extrovert group only felt significantly more behaviorally involved with the Co-active mode (Z=-2.821, p=0.005). We also found significant differences with the less extrovert participants in Flow (χ(2)=10.563, p=0.005) and Challenge (χ(2)=7.000, p=0.030). They considered having felt significantly less Flow (Z=-2.524, p=0.012) and Challenge (Z=2.501, p=0.012) when compared to Competitive mode (Table 3-14).

A between-groups analysis rendered significant differences in Competence in Collaborative mode. In this mode, the more extrovert participants revealed significantly more Competence when compared with those less extrovert.

Table 3-14 - Medians (Mdn) and Interquartile Range (IQR) for High Extraversion and Low Extraversion for each condition (game mode), and between conditions comparison (Friedman's). Bold values represent that significant differences between conditions were found.

		Competitive			***Co-active***			***Collaborative***			***Between conditions comparison***	
	Component	***High Extraversion*** *Mdn (IQR)*	***Low Extraversion*** *Mdn (IQR)*	**Between-groups comp.** *Mann-Whitney U, p-Value*	***High Extraversion*** *Mdn (IQR)*	***Low Extraversion*** *Mdn (IQR)*	**Between-groups comp.** *Mann-Whitney U, p-Value*	***High Extraversion*** *Mdn (IQR)*	***Low Extraversion*** *Mdn (IQR)*	**Between-groups comp.** *Mann-Whitney U, p-Value*	***High Extraversion*** **Chi-Square, *p-Value***	***Low Extraversion*** **Chi-Square, *p-Value***
Core module	*Competence*	3.0 (0.5)	2.2 (0.7)	29.500, 0.117	2.4 (1.1)	2.5 (1.6)	46.500, 0.789	**2.8 (0.7)**	**2.3 (1.9)**	**24.000, 0.047**	1.806, 0.405	2.294, 0.318
	Sensory and Imaginative Immersion	2.3 (1.4)	2.6 (0.6)	39.000, 0.402	2.4 (1.4)	2.5 (1.2)	46.000, 0.761.	2.3 (1.1)	2.4 (0.9)	47.500, 0.849	1.027, 0.598	0.914, 0.633
	Flow	3.0 (1.3)	**3.2 (1.0)**	48.000, 0.879	2.6 (1.5)	**2.7 (0.9)**	43.500, 0.622	2.8 (1.7)	**3.0 (1.0)**	42.500, 0.569	2.970, 0.227	**10.563, 0.005**
	Tension/Annoyance	0.0 (0.1)	0.0 (0.0)	45.000, 0.543	0.0 (0.0)	0.0 (0.0)	45.000, 0.317	0.0 (0.1)	0.0 (0.2)	50.000, 1.000	2.600, 0.273	0.500, 0.779
	Challenge	1.2 (2.0)	**1.5 (0.9)**	38.500, 0.382	0.5 (1.3)	**1.0 (1.1)**	41.000, 0.493	1.3 (1.4)	**1.1 (0.8)**	48.000, 0.879	4.171, 0.124	**7.000, 0.030**
	Negative Affect	0.1 (0.5)	0.1 (0.4)	46.500, 0.776	0.0 (0.5)	0.3 (0.6)	42.000, 0.504	0.0 (0.6)	0.1 (0.3)	45.500, 0.700	0.095, 0.953	0.667, 0.717
	Positive Affect	3.0 (1.3)	3.0 (0.9)	49.000, 0.939	3.0 (1.2)	2.9 (1.7)	45.500, 0.732	3.1 (1.5)	2.9 (1.1)	43.000, 0.594	2.438, 0.296	1.556, 0.459
Social Presence Module	*Empathy*	2.6 (2.0)	1.9 (1.5)	37.500, 0.343	2.5 (1.1)	2.5 (1.6)	37.500, 0.342	2.5 (2.2)	2.6 (1.2)	47.500, 0.849	2.513, 0.285	1.282, 0.527
	Negative Feelings	0.4 (1.0)	0.2 (0.9)	39.000, 0.387	0.7 (1.0)	0.5 (0.8)	44.000, 0.634	0.3 (1.0)	0.7 (0.6)	44.500, 0.675	0.452, 0.798	1.267, 0.531
	Behavioral Involvement	**1.0 (1.0)**	**0.7 (0.5)**	31.000, 0.145	0.9 (1.0)	**0.7 (1.4)**	43.000, 0.593	**2.4 (2.8)**	**3.0 (1.7)**	47.500, 0.849	**11.118, 0.004**	**16.000, <0.001**

3.2.4. Discussion

Here we studied the impact of three game modes (Competitive, Co-active, and Collaborative) in engagement and social involvement during a rehabilitation game for stroke survivors. Our primary purpose was to identify the most adequate multiplayer game approach for a stroke motor rehabilitation program. In a previous study with the same purpose, we analyzed the impact of different game modes in a sample of healthy community-dwelling older adults [183], where participants interacted with the game sitting side-to-side. However, in this study, we prepared the setup to have them front-to-front to enhance the experience's social impact. Also, the interaction with the game is more straightforward, as, in this study, participants interact directly with the virtual objects using a real object on a touch-sensitive horizontal screen. In the previous research, they had to move a real object, being this movement translated into the action of a virtual object on a vertical screen [183]. For the present study, we aimed to understand how motor and cognitive impairments brought by stroke, but personality as well, modulates the experience of multi-user interaction.

3.2.4.1. Social Involvement

Results showed a significant effect of game mode on Behavioral Involvement, a component that measures the extent to which players feel their actions are dependent on their co-players' actions [208]. This dependence is positive as it can foster communication, which is essential to promote social interaction. This is particularly important because of the impact that social engagement can have on health and well-being in senior populations [190] and on high levels of adherence to therapy when a game fosters support and communication between players [229]. Moreover, in a rehabilitation context, it has been shown to contribute to both higher levels of enjoyment during interaction and an increased sense of self-efficacy [192].

Concerning the different game modes, the Collaborative game mode elicited significantly more Behavioral Involvement. This is consistent with the results of our previous study with healthy older adults [183]. Although the setup was different (we used a standard desktop computer instead of an interactive table), the Collaborative mode promoted significantly more Behavioral Involvement than Co-active and Competitive modes. In the present study, we verified the same, significantly higher levels of Behavioral Involvement with the Collaborative mode when compared to the Co-active and

Competitive modes in almost all participants, except the more extrovert participants and those with fewer motor difficulties, which only felt significantly more Behavioral Involvement with the Collaborative mode when compared with the Competitive mode. This suggests that participants with those characteristics (more extrovert or fewer motor difficulties) are more receptive to get involved with players with a different profile from them (i.e., with more cognitive or/and motor deficits) with non-competitive game modes. Additionally, participants with more serious cognitive difficulties report significantly more empathy with the Collaborative mode than participants with less cognitive difficulties. This supports the previous hypothesis, which points to the Collaborative mode as preferable to promote interaction. In the Co-active mode, participants with fewer motor difficulties felt significantly more Behavioral Involvement when compared to those with more serious motor difficulties, besides values of Behavioral Involvement being reported as low. This can be interpreted as these players being more aware of how their dominance could impact their teammate, adapting their performance to motivate and engage their teammate.

It is important and still an open research question to understand how to manipulate game conditions to balance the skill levels to enable multiplayer gaming [43]. Baur *et al*. also acknowledge that players can have very different skills in rehabilitation, and that poses an important challenge in multiplayer games. Our data suggest that, for individuals with fewer motor skills or an extrovert personality, the use of Collaborative or Co-active game modes is preferred to promote positive gaming experiences.

3.2.4.2. Engagement

Data from the different components of the GEQ-Core Module assessed the impact that the game experience had on participants' engagement. Overall, and irrespective of the game mode, participants reported low feelings of Tension/Annoyance and Negative Affect and high levels of Flow, Positive Affect, and Competence. Literature suggests that patients performing exercises with a co-player they already know and have a positive relationship with maximize engagement and motivation within the activity [181]. Although our experiment participants did not know each other, our study revealed that participants felt moderate levels of empathy between them while playing the multi-user game. This result is in accordance with the results by Kort *et al*. that measured empathy through different social settings, such as "playing alone, with virtual others, online with unknown others, online with friends/family, and with co-players physically present (friends)" [208]. They report a value of approximately 2.1 (between 0 – 4) with co-players physically present, similar to our results with Competitive mode (2.2) and Co-active and Collaborative (2.5), being that in our study, participants did not know the partner.

Flow and Challenge were components for which we also found consistent effects. When we analyzed all the sample together, we found that participants felt significantly more Flow and Challenge with the Competitive mode than the Co-active mode. This is coherent with studies that have reported competitive mode as being more motivating [196], [198], [203], [229], [230]. In fact, Flow and Challenge are important cornerstones of Flow Theory [215]. In a recent study that compared a multiplayer co-active mode (according to criteria defined by Baur *et al.*) with a solo mode, results showed no significant differences in motivation as measured by the Intrinsic Motivation Inventory [230]. Comparing this result with what we observed on our study, the Co-active mode was also the one that produced less Flow and Challenge, which can be related to motivation to some extent, as in principle, a person feels flow and challenge at the same time only when being engaged in the task [215].

When dividing the sample into sub-groups, we found that participants with better cognitive performance, the less extrovert, and the ones with higher motor skills were the specific groups that benefit more from Competitive mode in terms of Flow and Challenge. Other studies have also observed that people with low extraversion will prefer game modes where they have to compete instead of interacting as a team [231], as personality can be considered a skill in the context of multiplayer gaming, and therefore interfere with game mode preferences [215]. Thus, less extrovert people will tend to prefer contexts that do not require articulation with other players. However, in group rehabilitation, skills are potentially different between participants, being that the Competitive mode seems to be more limited in accommodating well dissimilarities or participants with potentially low performances as not all players may experience Flow. On the opposite side, Mace *et al.* [200] found that participants with different abilities prefer to engage in collaborative gaming, as this mode enhanced performance proportionally to partnership's mismatch.

Concerning the impact of motor function in Flow, we found significant differences between participants with high and low FMA-UE scores in the Co-active mode. When comparing both groups, participants with higher FMA-UE scores reported higher Flow levels than participants with lower scores. This result is somehow consistent with findings by Alankus *et al*. [174], as impaired players may find competitive modes uncomfortable. Spasticity also seems to be a factor to be considered when choosing the game mode. Our results show that it was negatively correlated with Flow in the Co-active and the Collaborative mode. This correlation suggests that participants with more spasticity felt less Flow with multiplayer modes where they had to engage in teamwork. Overall, the Competitive mode seems to be more suitable to promote Flow, being that participants with more spasticity also reported less Competence in the Co-active mode. Indeed, competitive games have been previously reported as more motivating by people with disabilities within the context of rehabilitation, as they produce more intense performances and are associated with more movement repetition [181], [196], [203]. Interestingly, Tension/Annoyance was negatively correlated with spasticity, which was not expected, as stroke severity is related to cognitive affectation [232].

When comparing participants with higher and lower cognitive deficits, we found that participants with higher cognitive deficits felt Collaborative mode more challenging. This result is in line with what we qualitatively observed during the experiment. Participants typically took more time to understand the goal and mechanics of this game mode. In our previous study, we have also reported collaborative gaming with healthy elderly as being more cognitively demanding because participants need to coordinate strategies, which requires more attention [183]. This is particularly relevant for clinical practice, as participants with lower cognitive deficits reported to feel significantly more Competence in the Co-active mode. This higher sense of Competence can be due to the higher combined team score, as the Co-active mode allows participants to contribute disproportionately for the score, compensating for possible co-players' difficulties. Furthermore, participants with higher cognitive deficits reported significantly more Negative Affect and Tension/Annoyance in the Competitive mode, which suggests that this game mode must be used with caution within-group rehabilitation settings, particularly in multi-user settings. Still, overall ratings of negative affect were very low (0.38 out of 4).

3.2.4.3. Limitations and Future Directions

This study has some limitations that should be acknowledged. For a better comparison with the state-of-the-art, it would have been useful to have added the Intrinsic Motivation Inventory (IMI) as an outcome measure, as it is widely used in this type of research [181], [195], [198], [223]. Another limitation was that we used the same rehabilitation cones as interfaces for everyone, which can have impacted differently participants with different skills. However, the cone was chosen over other objects as its manipulation can be facilitated according to patients' ability and/or preference. We also consider a limitation the impossibility to verify if previous experience with video games impacted engagement and social involvement as only 5 of the participants reported previous experience.

Regarding the data analysis, our sample size is relatively small for some of the statistical analyses performed, and results should be considered with caution. Finally, our game and its different variants were carefully designed to be as similar and generalizable as possible. However, the specific design of the game can potentially influence the generalization of results [40]. Additionally, if each game was specifically designed for each game mode's characteristics, their impact could also be different. Hence, caution assuming generalization should be taken with different game mechanics or modes of interaction than those studied here. As for future work, one possible next step is to explore other variants of game modes, such as combat or object competition, in the Competitive mode. The Cooperative mode also seems very interesting for rehabilitation settings. It allows different roles in the same game, which can be used to balance players with different skills and better fulfill participants' personal interests and motivations. At last, we consider important to understand if these results are similar in the case of the group size increases, but also to better understand the relationship between different settings with familiar and non-familiar pairs and various game modes as there is research and therapeutic interest on home-based technologies for stroke rehabilitation [125].

3.2.5. Conclusions

This study indicates that the Collaborative mode seems to be the more balanced game mode as it promotes significantly more Behavioral Involvement than the Competitive and Co-active modes. Simultaneously, it is not statistically different in terms of Flow and Challenge compared with the Competitive and Co-active modes. Conversely, the Co-active mode promotes significantly less Behavioral Involvement than the other two game modes. Competitive mode elicits significantly more Flow and Challenge than the Co-active mode, being participants with better cognitive performance, the less extrovert, and the ones with higher motor skills that benefit more from it. Participants with higher cognitive deficits tend to feel more competent with the Co-active mode.

To conclude, our results suggest that collaboration is the more suitable gaming strategy to promote social involvement during a multi-user motor rehabilitation setting, with the potential of increasing adherence and the effectiveness of therapy. However, motor and cognitive ability and personality should also be considered when designing personalized tasks.

Chapter 4. Designing Objects and Serious Games for Upper Limb Motor Rehabilitation with Stroke Survivors

Parts of this chapter have been submitted for publication in (1) and (2):

(1) F. Pereira, S. Bermúdez i Badia, R. Ornelas, and M. S. Cameirão, "Feasibility, Usability and Engagement of a Tangible Interface for Upper Limb Rehabilitation after Stroke," submitted.

Contributions: FP, SBB, and MSC designed the study. RO developed the software. FP prepared the hardware and materials. FP recruited the participants. FP and RO collected the data. FP performed the data analysis. FP, SBB, and MSC interpreted the results.

(2) F. Pereira, A. Fernandes, C. Coelho, "Impact of distance and object size on reach and grasp in stroke," submitted.

Contributions: FP, AF, and CC designed the study. FP and CC prepared the material for the setup. CC recruited the participants. CC collected data. AF performed the data analysis. FP and AF interpreted the results.

This chapter describes two studies that address different elements regarding the use of objects and serious games for upper limb rehabilitation with stroke patients, as they are essential for the rehabilitation approach we propose. Objects are going to be used as interfaces and at the same time are expected to have a therapeutic impact. Serious games will be the driving force of our approach, as they will capture the user's attention and at the same time define and motivate their actions and behaviors. In section 4.1 we explore the feasibility, user engagement, and usability of an interactive system that involves the use of tangible objects with various shapes and properties to interact with virtual tasks designed for upper limb rehabilitation following a stroke. In section 4.2 we present a study that correlates compensatory movements and the object's size and distance during reaching movement in three directions (frontal, ipsilateral, and contralateral) with three different grasps (global, lateral, and tripod).

4.1. Feasibility, Usability and Engagement of a Tangible Interface for Upper Limb Rehabilitation after Stroke

4.1.1. Introduction

The need for new motor and cognitive rehabilitation strategies has led to the development of several technology-based rehabilitation systems [175], [233]. According to the literature, these systems are usually associated with Virtual Reality (VR), which adds several benefits to rehabilitation [111]. VR allows structured and individualized rehabilitation programs adaptable to the patient's needs. Additionally, it is possible to implement graded personalized adaptations while providing challenging and meaningful activities that can promote increased engagement and treatment compliance [147], [233]. However, the interface used to interact with a virtual system for rehabilitation plays an important role in its usability, impacting its acceptance as a rehabilitation tool [234]. This is even more relevant with older populations, as larger learning curves and less ability to deal with new technologies are expected compared to younger generations. Despite the age range, the literature suggests that interaction is easier the more direct it is. That is, using the own body to interact and getting immediate feedback right where the interaction occurs, without an extra layer of mechanical devices such as a keyboard or a mouse [235]. This avoids the need to map a specific body movement to a virtual consequence. Furthermore, direct interaction through touch or object manipulation can better resemble real-world object interaction and has been shown to correlate with clinical scores [138]. Particularly promising is the increased ecological validity of task execution by manipulating physical objects in these systems, which can potentially increase learned skills and their transference to the real-world execution of ADL [236], [237].

Hilton *et al.* published one of the first works about using tangible interfaces, exploring their use during a VR task for upper limb rehabilitation [238]. They used a tangible interface to simulate natural and realistic scenarios to replicate iADL in a virtual environment. However, some technical limitations and issues concerning the use of objects, such as feedback issues and undesired activation of sensors, influenced it negatively. A new virtual rehabilitation method called Elements was developed for stroke survivors by Mumford *et al*. [239]. It uses customized surface computing and tangible interfaces to aid motor and cognitive recovery. This approach has shown promising results when applied in a targeted and principled way [240]. In another study, VR and tangible objects were combined to complete various tasks that required participants to manipulate objects [241]. Their setup and technology, *MR-board*, was like the one used in our study. They were also able to track objects through color detection. The researchers found that the *MR-board* could be a valuable tool for self-training in rehabilitation. During the last few years, this type of technology has matured immensely, and the onset of new systems that support the use of multi-touch [242] and tangible objects has facilitated their integration as rehabilitation devices [236], [237]. Most of the literature that studies tangible stroke rehabilitation devices uses fixed-size objects without discussing the impact of their shape [243], [244]. However, some studies acknowledge its importance, allowing participants to choose the preferred object size or their own object [245], [246]. Magnusson *et* al. identified some design guidelines for tangible interaction with stroke patients, which, according to the nature and goal of the tangibles used in this work, we highlight the following ones "Designs need to support different speeds and should be adjustable, customizable and multimodal to allow use by persons with different sensory abilities" and "To support different skill levels, it needs to be possible to adjust a suitable level of challenge" [247].

While these preliminary studies show positive results on using tangible objects, several issues still need to be further explored. Specifically, it is important to understand how objects and materials used on tangible interactive systems can be designed to support effective rehabilitation tasks. For this purpose, we developed a prototype interactive surface that uses camera-based tracking to identify different objects. Through 5 different digital tasks, the user can manipulate different objects and materials (therapy putty and wooden objects) with different shapes, sizes, and resistances. The tasks were designed to train different hand motor skills: strength, dexterity, coordination and grasping. The objects tested were specifically selected to address only three types of grasps (lateral, tripod and global) and strength training. These grasps were chosen because, according to Feix *et al.,* these are the most used in our daily life [248]. Power grasp has stability and security as the primary function [249]. Lateral and tripod precision grasps focus on dexterity and sensitivity, specifically sensing small changes in position and force [249]. Additionally, the literature supports that there is increasing complexity in terms of movement and muscles associated, from power grasp (less complex), lateral grasp (more complex than power grasp, but less than tripod grasp), and tripod grasp (more complex) [249], [250].

Here we present the results of a study with 20 stroke survivors that performed five interactive tasks with different types of tangible objects. With this study, we have three research goals. The first goal is to analyze what types of objects and task mechanics are more feasible for rehabilitating stroke survivors with different levels of impairment. Second, we aim to quantify the usability of our proposed system. Finally, we want to understand how engaging the system is, and if the different objects and tasks modulate engagement.

4.1.2. Methods

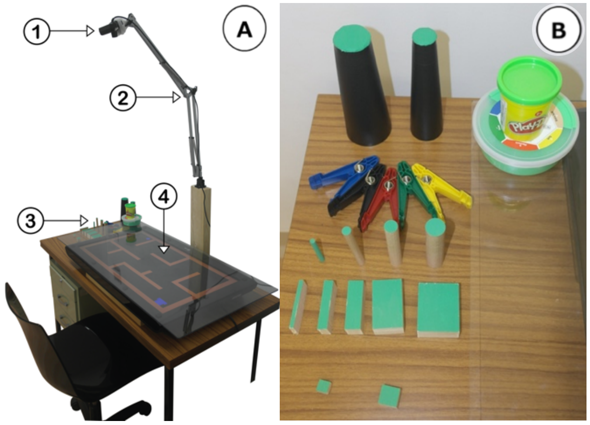
4.1.2.1. Preliminary Testing

Because preliminary testing is essential, particularly for our target population, mainly elderly, which can potentially have difficulties interacting with digital technologies, we performed three sessions of preliminary testing with 3 stroke survivors (2 Males, 1 Female, 64.7±14.6 years old, 30.7±2.3 weeks post-stroke). This iterative process allowed improving the prototype on what concerns its functionality and ease of use, through improved colour detection, tracking calibration, delivery of feedback, and expanding the portfolio of tangible objects to accommodate a broader scope of motor deficits of the upper extremity. Additionally, task instructions and self-report questionnaires were made more clear.

4.1.2.2. Experimental Setup

The setup consisted of a PC (OS: Windows 8.1, CPU: i7-4790 at 3.60GHz, RAM: 8Gb, Graphics: GeForce GTX 1060 6GB), a PlayStation Eye camera (Sony Computer Entertainment Inc., Tokyo, Japan), a 32” TV placed horizontally, and a set of tangible objects (Figure *4-1*– A & B). To compensate for the increased height of the table because of the screen over it, we used a chair with adjustable height, thus guaranteeing a proper posture of the participant during the session.

Figure 4-1 - (A) Experimental setup (1-Camera; 2-Supporting arm 3-Set of tangible objects; 4-TV Screen), (B) Tangible objects used in the interactive tasks, and screenshots of (C) Maze, (D) Paint, (E) Follow the line, (F) Slide, and (G) Fill the figure.



For object tracking, we developed a custom software using the OpenCV Source Computer Vision Library, able to detect an arbitrary number of objects from a previously defined colour list, providing for each object their colour (Hue, Saturation and Value values), centre position relative to the camera, area, perimeter, and a list of coordinates defining their perimeter. All this information is communicated to the task, implemented in Unity3D, through a UDP socket connection. The tracking software requires a calibration process to account for the light conditions, which can significantly change over time and in different environments. The software takes the values from the calibration and then applies them to each frame a thresholding operation to extract Binary Large Objects (BLObs), which refers to a group of connected pixels in a binary image. The term "Large" indicates that only objects of a certain size are of interest since "Small" binary objects are usually noise. Also, since the camera is not always perpendicular to the display, we developed a perspective calibration procedure that corrects the image perspective and crops it by selecting the four corners of the display.

For the interaction, we chose objects with different characteristics (Table 4-1) based on materials used for upper limb rehabilitation in standard occupational therapy [251]. Depending on the skill level of the participant, which was previously assessed, a therapist chose the more appropriate object size for each one of the three grasps (power or global grasp, lateral grasp and tripod grasp) (Figure 4-2). For hand/finger strength training, the rationale was the same; putty resistance was selected according to the strength of the participant's hand. It was ensured that manipulating objects was comfortable but also challenging, as it is intended to simulate a rehabilitation task. We opted to use only one object per competence and task because of the large number of possible objects, but also to avoid exposing the user to very easy or very difficult performances, thus preventing boredom or frustration, respectively.

Table 4-1 - Objects' characteristics.

Cylinders	**Parallelepipeds**	**Cones**	**Pinch Pins**	**Cubes**	**Putty/Plasticine**
Diameter(mm)	Length (mm)	Diameter	Resistance (Kg)	Length (mm)	Resistance
6	5	Small Bottom - 50 Top - 30	Yellow – 0,45	12	Plasticine (Play-doh®)
	10		Red – 0,9		Extra-soft putty
10	15		Green – 1,8		Soft putty
15	30	Large Bottom - 70 Top - 50	Blue – 2,7	18	Medium putty
22	45		Black – 3,6		Firm putty
					Extra-firm putty

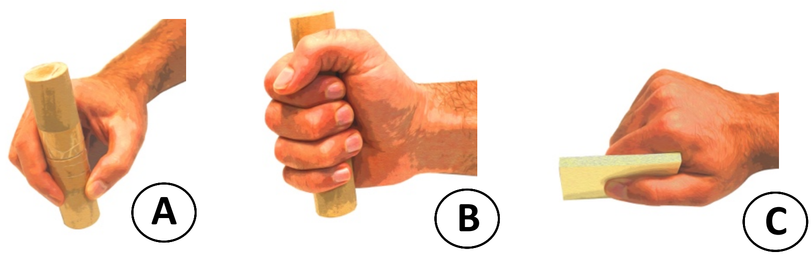


Figure 4-2 - (A) Tripod grasp, (B) Power grasp and (C) Lateral grasp.

4.1.2.3. Tasks

Five tasks described below were developed to exploit different object properties and train specific upper extremity competencies such as range of movement, coordination, and strength (Figure 4-3). All tasks were developed as independent applications using Unity and receiving information from the tracking software through a UDP connection. The tasks are the following:

- Maze - the participant must push a ball through a maze and place it into an exit tube.

- Paint - the participant chose a color between blue, yellow, or red, and painted the inside of a letter in a freestyle. The participant could erase and repaint the letter until he/she was satisfied with the result.

- Follow the line - the participant followed a line with an object, trying to be as precise as possible. When performing the task, a trace was drawn below the object. To avoid occlusion of the line being drawn with the hand, the line had to be drawn from right to left when the left hand was used, and vice-versa.

- Slide - the participant created a path with objects for a ball that falls and bounces on them to guide it towards the exit tube at the bottom of the scenario.

- Fill the figure - the participant overlapped a given shape using objects.

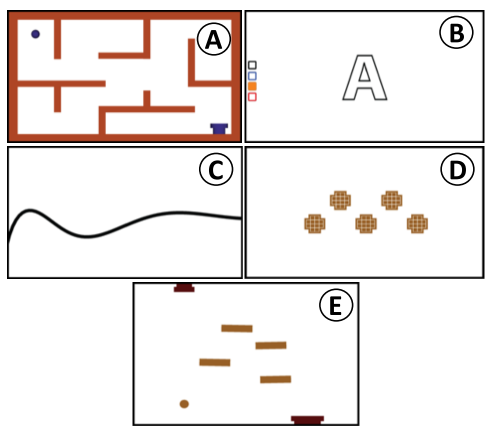


Figure 4-3 - Screenshots of Maze (A), Paint (B), Follow the line (C), Fill the figure (D) and Slide (E).

4.1.2.4. Recruitment and Sample

Participants were a convenience sample recruited from two public hospitals in Funchal, Portugal. The single inclusion criterium was to have suffered a stroke. Exclusion criteria included: having a null (0/57) or a full functionality of the upper extremity score (57/57) in the ARAT [252], [253]; severe cognitive deficit that compromises the understanding of the task, with a score lower than 17 in the Token Test [254]; hemi spatial neglect, assessed through a cancellation test; and no literacy. The study was approved by the Ethics' Commission of SESARAM (number 24/2018) and all participants provided written informed consent.

132 stroke survivors were considered potential participants for this study and 20 were included (95 were excluded because of criteria and 17 refused to participate) (Table 4-2). Our sample was composed of 14 males and 6 females, with a mean age of 65.9±9.3 years (range: 51-80), 17.4±28.4 months post-stroke, 70% ischemic and 30% hemorrhagic, and 5.2±2.9 years of schooling. Only 2 participants had previous experience with computers.

Table 4-2 - Participant's profile - gender (male/female), age, months post-stroke, schooling in years, Montréal Cognitive Assessment (MoCA) scores, Fugl-Meyer upper limb scores, Action Research Arm Test, Box & Blocks (paretic limb – non-paretic limb) scores, and modified Ashworth Scale scores.

PARTICIPANT	**GENDER** *(M/F)*	**AGE**	**MONTHS POST STROKE**	**SCHOOLING** *(YEARS)*	**MOCA** *(0-30)*	**FUGL-MEYER** *(0-66)*	**ARAT** *(0-57)*	**BOX & BLOCKS** *(PARETIC – NON-PARETIC)*	**mAS**
1	F	76	1	4	12	51	56	30 - 36	1+
2	M	51	4	4	14	39	36	19 – 22	1
3	M	76	1	4	16	40	47	19 – 32	1
4	F	67	28	4	25	34	49	24 – 42	1
5	M	80	8	4	21	33	13	0 – 41	1
6	M	54	20	4	22	54	29	3 – 49	1+
7	M	65	4	4	22	62	55	15 – 21	1
8	M	71	3	4	22	48	44	18 – 25	0
9	F	62	112	6	24	15	8	1 – 38	2
10	M	64	1	4	26	55	55	26 – 33	0
11	F	53	11	4	16	44	36	19 – 23	1+
12	M	53	17	4	23	57	42	20 – 29	0
13	M	65	46	9	30	39	28	15 – 35	1+
14	M	65	2	4	23	27	32	17 – 35	1+
15	M	64	5	5	25	41	51	27 – 30	1+
16	M	77	1	4	21	43	29	21 – 27	0
17	F	78	6	7	20	32	24	9 – 22	2
18	F	59	1	16	27	57	46	31 – 37	1
19	M	77	8	4	16	30	26	6 – 27	3
20	M	60	70	4	26	42	37	21 – 27	1+

Participants underwent a motor and cognitive assessment through standard clinical scales for sample characterization. For motor characterization we used the Fugl-Meyer Assessment (FMA) – Upper Extremity for motor function, which score can range between 0-66 [255], and the ARAT for hand function. ARAT final score can range between 0-57; the Box and Blocks Test (BBT) [256], for gross manual dexterity; and the mAS [257] for spasticity. The cognitive characterization was done through the MoCA [206]. The motor and cognitive profile was diverse. In terms of motor function of the upper limb, the sample is varied, with a mean FMA of 42±11.8 (range: 15-62) and an ARAT with a mean of 37.15±13.66 (range: 8-56). Regarding spasticity, 20% of the participants did not show any signs of spasticity, while 65% presented a slight increase in muscle tone. The 15% remaining showed a more marked increase in muscle tone through most of the range of motion. Regarding the cognitive level of the sample, it was also heterogeneous, with an average of 21.55±4.69 (range: 12-30).

4.1.2.5. Outcome Measures of the Study

The measures that were used aimed to quantify the feasibility of the prototype system as a rehabilitation tool, its usability, and the experienced engagement.

- Feasibility measures included the percentage of *success* in each task, *time* to complete the task, need of *assistance* to complete a task, and the *ease* of the task measured through a 7-points Likert-scale ranging from 1 (Very difficult) to 7 (Very easy).

- Usability was measured through the Portuguese version [258] of the System Usability Scale (SUS) [259]. Additionally, we registered the difficulties experienced by the users during the interaction.

- For the experienced engagement, we measured motivation through a Portuguese version of the IMI [260], a shorter 14-item version from which domains of Interest/Enjoyment, Perceived Competence, and Effort/Importance were used, ranging from 1 (totally disagree) to 5 (totally agree). Although IMI scores usually range between 1 and 7, we opted to use the range from the Portuguese version. Additionally, each task was evaluated in terms of enjoyment using a 7-point Likert scale, ranging from 1 (disliked very much) to 7 (liked very much). Participants were asked to rate how much they enjoyed each task by answering the question “How much did you enjoy this task?”

4.1.2.6. Experimental Procedure

Data collection happened in 2 different sessions. The first was dedicated to the motor and cognitive assessment (~60 minutes), and the second was to the tasks and self-report questionnaires (60-90 minutes). In the first session, participants signed the informed consent, followed by the motor and cognitive assessments performed in random order. In the second session, the participants were introduced to the system and informed of the importance of not occluding objects from the camera during the interaction. Subsequently, participants performed each task in a randomized order. For each task, multiple iterations took place to test its feasibility using different objects to train power grasp, lateral grasp, tripod grasp, and strength. To that end, the therapist chose the object size/resistance most appropriate for each specific participant. Before each task, the therapist demonstrated it to ensure that the participant understood it. After each task, participants reported on enjoyment and ease of the task using the 7-point Likert scale. Plasticine and putty were only used with *Slide* and *Fill the figure* tasks. The SUS and the IMI were administered at the end of the session.

4.1.2.7. Data Analysis

For each dependent measure, values of central tendency and dispersion are provided. Interval types of data are presented through their mean and standard deviation (Mean±SD), and ordinal data as the median and interquartile range (Median (IQR)). Because the Shapiro-Wilk test rendered some distributions of interval data as not following a normal distribution, nonparametric tests were used for all analyses. Specifically, we used Friedman's test to check for differences across tasks for each grasp regarding time, ease, and engagement. For pairwise comparisons, the Wilcoxon signed-rank test was used with a Bonferroni correction to account for the number of comparisons. The significance threshold was set at $\alpha=0.05$. Data were analyzed using IBM SPSS Statistics (Version 27).

4.1.3. Results

4.1.3.1. Feasibility

To evaluate feasibility, we used data collected for total task time, ease, and success in completing the task (Table 4-3).

Table 4-3 - Completion time, ease, success rate, and enjoyment data for each interactive task and each trained skill. Bold values represent significant differences between task.

			PAINT	*MAZE*	*FOLLOW THE LINE*	*FILL THE FIGURE*	*SLIDE*	*FRIEDMAN'S (CHI-SQUARE)*	**STATISTIC** *p-VALUE*
POWER GRASP	Cones & Cylinders	Time (s)	83.9±41.6	66.1±38.0	39.0±25.0	59.0±36.6	64.6±60.3	12.340	**0.015**
		Ease	3.00(3.00)	5.00(3.00)	5.00(3.00)	5.00(3.00)	4.00(3.00)	3.633	0.458
		Success (%)	100.0	85.0	100.0	90.0	80.0	-	-
		Enjoyment	5.50(2.75)	5.00(1.25)	5.50(1.00)	5.50(2.25)	6.00(1.50)	0.364	0.985
LATERAL GRASP	Parallelepiped	Time (s)	102.6±73.2	67.9±47.8	31.8±13.2	88.2±63.1	35.6±22.8	40.012	**<0.001**
		Ease	3.00(2.00)	3.00(3.75)	4.50(3.00)	3.50(3.00)	3.50(4.00)	5.061	0.281
		Success (%)	100.0	95.0	100.0	100.0	85.0	-	-
		Enjoyment	5.50(2.00)	5.50(1.00)	5.00(1.75)	6.00(1.00)	5.00(2.25)	2.024	0.731
TRIPOD GRASP	Cylinders	Time (s)	110.7±70.0	72.1±55.7	45.6±19.2	56.8±34.8	66.8±49.6	19.519	**0.001**
		Ease	4.00(2.00)	4.50(3.00)	5.00(3.00)	5.00(3.00)	5.00(2.50)	9.177	0.57
		Success (%)	100.0	85.0	100.0	95.0	80.0	-	-
		Enjoyment	5.50(2.00)	5.00(2.00)	5.00(1.75)	6.00(1.75)	5.00(1.50)	2.081	0.721
STRENGTH	Putty & Plasticine	Time (s)	-	-	-	86.3±30.3	52.9±38.0	-	-
		Ease	-	-	-	5.00(3.00)	4.50(4.00)	-	-
		Success (%)	-	-	-	95.0	85.0	-	-
		Enjoyment	-	-	-	6.00(1.00)	5.00(1.25)	-	-
	Pinch Pins & Cubes	Time (s)	-	-	-	130.4±100.9	70.3±55.6	-	-
		Ease	-	-	-	3.50(3.25)	3.00(4.00)	-	-
		Success (%)	-	-	-	90.0	80.0	-	-
		Enjoyment	-	-	-	6.00(2.00)	5.00(4.00)	-	-

4.1.3.2. Time

Regarding the time needed to complete the tasks, we found significant differences between tasks on all the grasps, namely power grasp ($\chi(2)=12.340$, $p=0.015$), lateral grasp ($\chi(2)=40.012$, $p<0.001$), and tripod grasp ($\chi(2)=19.519$, $p=0.001$) (Table 4-3). Regarding power grasp, pairwise comparisons revealed that the time to finish *Follow the line* and *Paint* were significantly different ($Z=-2.977$, $p=0.029$). Accordingly, *Follow the line* was always the fastest task, while *Paint* was the longest. Concerning lateral grasp, pairwise comparisons show significant differences between *Follow the line* and *Maze* ($Z=-3.200$, $p=0.014$), *Paint* ($Z=-5.044$, $p<0.001$), and *Fill the figure* ($Z=3.742$, $p=0.002$). Also, significant differences were found with pairwise comparison staring Slide and *Maze* ($Z=2.983$, $p=0.029$), *Paint* ($Z=4.827$, $p<0.001$), and *Fill the figure* ($Z=3.525$, $p=0.004$). Furthermore, significant differences were found after conducting pairwise comparisons in tripod grasp between *Paint* and *Fill the figure* ($Z=-4.155$, $p<0.001$), *Follow the line* ($Z=-3.225$, $p=0.013$), and *Maze* ($Z=-2.915$, $p=0.036$). For strength training, *Fill the figure* took more time than *Slide* with both putty & plasticine and pinch pins & cubes.

4.1.3.3. Ease

Lateral grasp was the trained grasp that showed to be more difficult to perform, while pinch pins & cubes were the strength material that was reported as more difficult. *Follow the line* and *Fill the figure* were tasks where higher scores of easiness were reported, especially the first. On the other hand, *Paint* was the task considered more difficult. Overal, no significant statistical differences were found in any grasp between tasks. Tasks using grasp varied their median between 3 and 5.

4.1.3.4. Success

The task itself played an important role in the modulation of the difficulty and consequently in the success rate, with a variation of 80% - 100%. Tasks *Paint* and *Follow the line* achieved 100% of success, while *Slide* achieved the lowest success rate. However, lateral grasp stands with equal or higher levels of success when compared to the other two grasps.

4.1.3.5. Assistance

When necessary, assistance was given during task completion for three reasons: movement facilitation, problems manipulating an object (due to the object's properties), and interaction issues. Movement facilitation was the most common type of assistance. Assistance was mostly given with shoulder, elbow, and finger extension and positioning, as well as with verbal and tactile cues to facilitate movement and prevent compensatory body positions and undesirable postures.

4.1.3.6. Engagement

The results of the IMI indicate good interest/enjoyment of the system (4.03±0.76), with a slightly lower yet positive sense of competence (3.56±0.66) and increased levels of effort (4.12±0.59). Overall, the total score of the questionnaire was 3.78±0.52 over 5. When analyzing enjoyment, the overall scores are positive, being the median values between 5 and 6 (Table 4-3). Regarding tasks, *Fill the figure* shown to elicit slightly more enjoyment when compared to other tasks. Strength materials had the same enjoyment scores. No significant statistical differences were found in any grasp between tasks.

4.1.3.7. Usability

The reported SUS ranged from 25 to 90, with a mean of 63.3±18.1, corresponding to percentile 35-40 and is considered “ok” [261].

Our observations during the performance of the interactive tasks can be grouped into three domains:

- *Interaction.* Some objects, such as small cylinders, parallelepipeds, and smaller cubes, tend to fall, turn over, or tilt, making them more challenging for the system to detect. In some tasks, such as *Paint* or *Maze*, where participants tried to drag instead of pull, there is also a tendency to use movements related to the affordances of the objects. It would be beneficial to have the option to adjust the position and boundaries of the interactive area for improved accessibility. This is especially important for tasks requiring minimal distance from the user.

- *Software.* The system’s technical implementation, as it stands, relies on a camera with a clear and unobstructed view of the interactive surface. More feedback, direction regarding the next step, and knowledge of performance and results when using objects would be beneficial for some tasks. The occlusion of the interactive objects needs to be discouraged because it interferes with tracking and interactive activities. Slide’s object detection was not entirely stable, which made it challenging to complete the task. Additionally, if the object is very small (with a diameter of less than 1 cm), tracking would be challenging and unstable.

- *Comprehension.* It required multiple explanations before participants with lower MoCA scores could perform to an acceptable level. The task *Slide* was the most cognitively demanding when compared to other tasks.

4.1.4. Discussion

Here, we presented a pilot study exploring a system that uses tangible objects of various shapes and materials to interact with virtual tasks to restore upper limb function following a stroke. Specifically, we analyzed the feasibility, engagement, and usability of this approach in a sample of 20 chronic stroke survivors.

4.1.4.1. Feasibility

To determine if the system is feasible, we gathered information about the percentage of successful outcomes, the amount of time it took to complete a task, how easy it was to use, and some observations during the participants' performance. Overall, in terms of percentage of success, all tasks scored at least 80%, which is encouraging. Additionally, as this score reflects different combinations of materials and tasks, it means that it is feasible to adjust tasks in terms of difficulty and completion time, to address different therapeutic goals. However, during the interaction, the therapist needed to assist participants with greater functional deficits to facilitate movement and muscle activity, promoting new and correct movement patterns [262]. Automated compensatory movements can develop rapidly and become difficult to overcome, limiting long-term clinical results [262].

In the next sub-sections, we will discuss the results of using the system with each type of grasp individually. Specifically, we examine the amount of time it took to complete a given task and how easy it was and contrast these observations with the performance of the participants.

4.1.4.2. Power Grasp

Follow the line took significantly less time to finish when compared to *Paint*. This result was expected, as *Paint,* contrary to the other tasks, did not have a clear 'end of task', i.e., instructions were to paint the image presented until they were satisfied with the result. When we analyzed the time it took to execute each of the three different grasps in *Paint*, we observed it increased based on the level of difficulty of the grasp. The power grasp is the least complex, and the tripod grasp is the most complex in terms of precision as it uses the extremity of two first fingers and the lateral of the third finger to stabilize the tool [250]. Furthermore, this pattern of increasing time according to grasp complexity is also observed in *Maze* and *Follow the Line*. These games demand the use of objects that can be likened to graphic movements as opposed to *Fill the Figure* and *Slide*, which only require object placement.

4.1.4.3. Lateral Grasp

We found that *Follow the line* and *Slide* tasks took significantly less time than the other three tasks. *Follow the line* was a very straightforward task, and for that reason, we already expected it to be one of the fastest tasks. *Slide* was one of the tasks that were more cognitively demanding because it required a trial-and-error process to solve the task. This is why this task had the lowest success rate. The participants that could not finish *Slide* task did not contribute to the results of this task, which is one of the reasons why the time to complete was small. Additionally, the objects used in this task with lateral grasp (parallelepipeds) were more appropriate for the task than the ones used with power and tripod grasp (cylinders). With parallelepipeds, participants could get a wider area to collide with the ball, but also, it was easy to control the direction the ball took after the collision occurred, as it depended on the object's angle. With cylinders, it was much harder to place them in the right place to ensure collision and to control the angle the ball took after the collision, as cylinders are circular. Moreover, some participants placed the material in the right place and with the right angle right on the first try by chance, potentially biasing the results.

4.1.4.4. Tripod Grasp

Paint took significantly longer than *Fill the figure, Maze,* and *Follow the line*. Also, in terms of ease of use, this task was considered slightly harder not only with tripod grasp but also with power and lateral grasps. One hypothesis is that participants tended to use the objects as a regular pen, i.e., the part of the object in contact with the screen would set the painting place. However, object tracking, which controlled the interaction with the screen, was made from the top, which led to inaccuracies when objects were not held vertically with a tripod grasp. With a power grasp, the object was more vertical, but unfortunately, the grasp could obstruct the ability of the user to see the task, negatively impacting performance. The problem with lateral grasp was the material (parallelepipeds). The painting point was in the middle of the edge and not on a vertex, posing a challenge for the participants to paint accurately in the correct areas.

4.1.4.5. Strength Materials

Strength materials were only used in *Fill the Figure* and *Slide.* Performing with pinch pins and cubes appears to be more time-consuming than using putty and plasticine. Regarding the ease of use, it was considered more challenging to use but still provided a similar level of success and enjoyment. Both pinch pins & cubes and putty & plasticine are used for training strength; however, grabbing a cube with a pinch and releasing it to the exact place inside a figure requires some dexterity and coordination. On the other hand, when using putty or plasticine, participants only needed to cut pieces of the material with their hands and fill the figure. This allowed them to use larger pieces of material than the figure itself, making the task easier to complete, as it only was required to fill the figure, independently if the limits of the figure were respected or not. This may be the reason why participants considered this task easier.

4.1.4.6. Engagement

Results from the enjoyment for each task varied between 5 and 6 over 7. This is in line with the results from the interest/enjoyment sub-scale of IMI, where we obtained a mean value of 4.03±0.76 out of 5. Hence, we can consider that overall, the use of the system was positive. The result from the sub-scale level of effort was high (4.12±0.59), which indicates that participants got involved in the tasks. The sub-scale sense of competence results were relatively lower but still positive ((3.56±0.66) over 5). Colomer *et al.* used a system comparable to ours, and similar levels of interest/enjoyment (5.73±0.79) and competence (5.21±0.98) were achieved, having into consideration that they use a Likert scale of 7 points and we used a Likert scale of 5 points [143]. There were no statistical differences between tasks, besides the slight tendency for *Fill the figure* to be more enjoyable, which makes us believe that the tested mechanics are valid to be used for serious games rehabilitation.

4.1.4.7. Usability

In terms of usability, despite receiving a low score, the SUS evaluation is still positive (63.3±18.1) [261]. This score reveals some issues identified across three areas in the experiment: interaction, software, and task comprehension. One of the main usability issues with the user interfaces was the tendency of narrow cylinders to fall over when positioned upright, causing frustration. Another common problem was the unintentional occlusion of objects with hands and arms. We believe these were the two main issues that significantly impacted usability. Also, it is important to note that SUS evaluates all tasks simultaneously, even though each task may have a unique way of interaction and specificities. This can result in unfair outcomes since SUS does not distinguish between different tasks or materials.

Ham *et al.*, developed a system very similar to the one used in this study, involving objects as tangible user interfaces [241]. These were detected through a camera suspended above the interaction area. Besides object tracking, they also do hand-tracking through a depth camera and specific algorithms. They assessed the usability of their system through a self-made questionnaire with eight questions regarding the following areas: specification, weight, manipulation, safety, durability, user-friendliness, comfort, and effectiveness. This questionnaire had an overall score of 4.58±0.54 out of 5. Occlusion was also mentioned as a limitation of this system; however, it seems that the fact of using the HSV (Hue, Saturation, and Value) color model to distinguish between objects and hands somehow alleviated this limitation. Another study where they used tangible user interfaces (but not in all the tasks) to interact with a virtual environment reported good usability scores (79.13±7.54) [143]. However, their sample had an average higher level motor function (FMA=50.2) when compared to our sample (FMA=42.15). Occlusion problems were not reported, possibly because they used one object at a time.

4.1.4.8. Limitations

This study has some limitations that should be referred. First, this was an exploratory study with a relatively small sample of participants. Second, while this study allows us to assess the feasibility of the approach in terms of usability and engagement, it is now necessary to evaluate its impact on rehabilitation outcomes. Third, performance and interaction could have been improved if we had used more sound and visual hints. And fourth, with some participants, the game's requirements restricted users' performance because of their shoulder and elbow range of movement limitations. The possibility of calibrating the playing area could possibly avoid these problems with performance.

4.1.5. Conclusions

This study proposes a new approach to use tangible objects in an interactive setup with top-down object tracking for motor rehabilitation with stroke survivors. The object tracking software developed proved to be reliable and feasible to be used for rehabilitation purposes. High levels of enjoyment across all tasks were reported, with a rate higher than 80% of success, reflecting the appropriateness of the design and the feasibility of this approach. These results are important for the development of future rehabilitation systems, as they allowed us to identify aspects that can interfere with usability, such as the need to calibrate the interaction space, deal with object affordances or diminish the incidence of hand occlusions. These results also show that different grasps affect task performance, specifically in terms of the object position relative to the hand and its relationship to object tracking. Finally, adjustment of the complexity of the task can be achieved by choosing specific objects, as objects naturally lead to a particular grasp. We believe these results should be considered to inform the design of rehabilitation technologies, especially those that involve tangible interaction and top-down object tracking.

4.2. Impact of Distance and Object Size on Reach and Grasp in Stroke

4.2.1. Introduction

Approximately 70% of individuals who have suffered a stroke experience hemiparesis, which affects their ability to use one side of their body. Out of those affected by hemiparesis, 65% cannot regain the ability to reach, grasp or manipulate objects, leading to reduced functionality of the upper limb and diminished independence. These movements are crucial for performing more than 50% of daily activities [263], [264]. Accordingly, this population's typical motor and sensory deficits can limit environmental manipulation, negatively affecting participation and autonomy [16], [265].

Most used grasps in daily life include global, tripod, and lateral grasps [248]. Studies conducted with stroke survivors have indicated that global grasps are generally easier to perform than fine grasps, as stroke survivors often experience difficulties with individual finger movements [266]. The ability to reach and grasp an object results from controlled, precise, simultaneous, and coordinated movements. It is characterized by the hand's reach for the object, the wrist's orientation, and the anticipation of the fingers' position [265], [267]. The movements in question are typically slow and segmented, and the hand's trajectory is often more curved and less fluid. This may be caused by excessive muscle contractions resulting from a change in tone, which reduces selective control, weakens muscles, and leads to the onset of pathological synergy [268].

With healthy individuals, the trunk is only recruited while performing reaching movement when it exceeds 90% of the total arm length; however, in individuals with stroke, trunk compensatory movements are very frequent due to their deficits [269], [270]. Cirstea and Levin [271] found that a decrease in arm extension and shoulder flexion is significantly correlated with increased trunk movement. This makes it difficult to reach and grasp objects, particularly when they are far away, and impairs movement in many directions, particularly forward [266], [272].

We conducted a study to evaluate the correlation between the range of motion and ability to grasp objects of various sizes among stroke survivors using global, tripod, and lateral grasps without evoking compensation patterns.

4.2.2. Methods

4.2.2.1. Recruitment Procedure

The sample was recruited in the community through four different institutions in Portugal: Centro de Reabilitação Profissional de Gaia, Esferasaúde, Climunde, and Centro Social e Paroquial de Raimonda. It was a convenience sample, and the inclusion criteria were to have more than 18 years old and to have suffered a stroke for more than six months. The exclusion criteria were the following: 1) Inability to hold the objects used in the study; 2) To have minimal (0) or maximal (32) score on FMA – upper limb [255]; 3) Visual/Communicative/Comprehensive deficits which compromise the understanding of the task or questionnaires used (assessed through direct observation); 4) Presence of hemispatial neglect assessed with Bell's test [226]; 6) Other associated neurologic, orthopedic or neuromuscular conditions not related to stroke with interference on subject's performance.

4.2.2.2. Sample Characterization

To characterize the sample we used: 1) FMA to assess motor function; 2) the *Stroke Upper Limb Capacity Scale* (SULCS) [273]–[275]to assess functionality over ten different activities of daily living; 3) the dynamometer [276] and pinch meter [276], [277], for measurement of global, lateral and tripod grasps strength. Two attempts were performed for each grasp and kept the maximum score; 4) the mAS [228] to measure shoulder, elbow, and wrist spasticity; 5) goniometry assessment using a 360º goniometer with 20 cm and a fingers goniometer. We measured shoulder (abduction, flexion, internal and external rotation), elbow (flexion and extension), forearm (pronation and supination), wrist (flexion, and extension), metacarpophalangeal (1st, 2nd, and 3rd fingers), and interphalangeal (1st, 2nd, and 3rd fingers).

Twenty-six potential participants were approached in six months, being thirteen excluded due to exclusion criteria. Therefore, thirteen stroke survivors (eight males) with a mean age of 56.5±11.3 years (range: 35-75 years) took part in the study, with an average of 4.1±4.5 years post-stroke (range: 0.5-15.9) (Table 4-4). Half of the participants had their dominant side affected. To what concerns motor skills, participants had an average of 43.5±13.3 in FMA, 6.9±3.3 in SULCS, a strength of 13.5±9.6 at global grasp, 4.5±2.9 at lateral grasp, and 3.8±2.4 at tripod grasp. Regarding spasticity, 84.6% of the participants did not have spasticity in the shoulder. Participants were mainly distributed along the first four spasticity levels regarding elbow and wrist, as shown in Table 4-4.

Table 4-4 - Participants' profile. FMA-UE – Fugl-Meyer Assessment – Upper Extremity; SULCS - Stroke Upper Limb Capacity Scale; mAS – Modified Ashworth Scale.

PARTICIPANT	GENDER (M/F)	AGE	TIME POST-STROKE (YEARS)	FMA-UE (0-66)	SULCS (0-10)	mAS (0-4)		
						Wrist	Elbow	Shoulder
1	M	67	6.3	47	9	1	1	0
2	M	62	0.5	24	10	1+	0	0
3	F	59	2.3	58	8	1	1+	0
4	M	56	0.8	47	10	1+	1	0
5	M	40	1.1	17	2	1+	2	0
6	M	45	1.3	54	1	0	3	1+
7	F	35	3.7	58	5	0	0	0
8	F	65	16	33	10	1+	0	0
9	M	56	1.4	55	10	0	1	0
10	F	58	1.7	24	7	2	2	3
11	M	52	10.6	52	3	0	1	0
12	F	75	3.2	26	5	2	2	0
13	M	65	4	56	9	1	1	0

4.2.2.3. Procedure

The study was approved by the Ethics Commission of Escola Superior de Saúde, Instituto Politécnico do Porto (number 6376-0900). Before data collection, written informed consent was obtained from all participants. The data were collected at the center where each participant was recruited. An occupational therapist with expertise in stroke managed the entire process, including evaluating criteria, characterizing each participant, and collecting data during a 45-minute session.

A wooden rectangle measuring 100cm x 25cm x 0.3cm was used as the setup (Figure 4-4 a)). It had a ruler of 100 cm with 0.5cm graduation printed on it. The six cylinders and five parallelepipeds used for grasp were fabricated using a 3D printer (Figure 4-4 b)). The cylinders had 110mm height and six different diameters: 10mm, 20mm, 30mm, 40mm, 50mm, and 60mm. The parallelepipeds used had 40mm of height, 60 mm of length, and five different widths: 5mm, 10mm, 15mm, 20mm, 25mm, and 30mm.

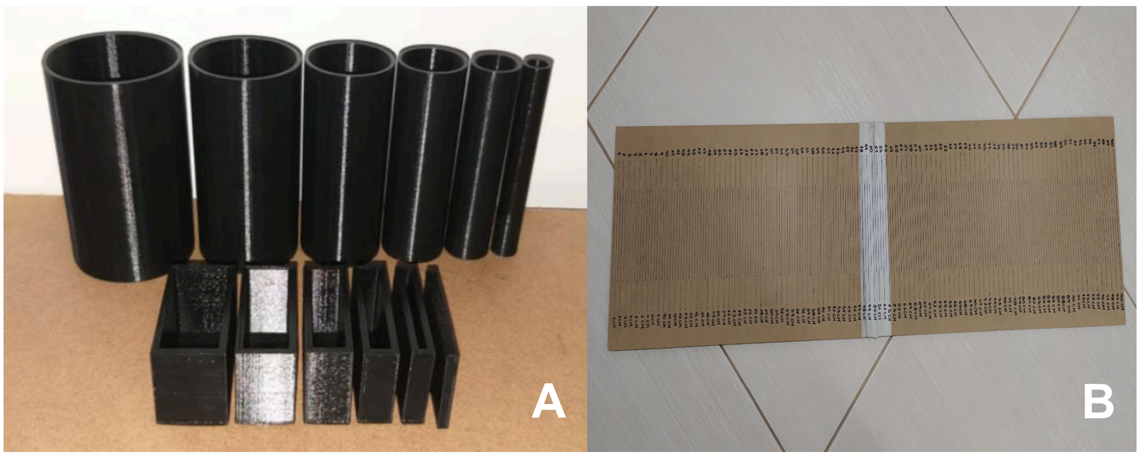


Figure 4-4 - Cylinders and parallelepipeds used for grasps (A) and wooden rectangle ruler (B).

To measure the reach distances, the patient was required to sit upright while leaning against the table. The ruler was consistently aligned with the shoulder of the affected arm, and its direction was adjusted based on the direction in which the reaching movement was made. To determine the object size for each grasp, the object was positioned at 90% of the arm's length to avoid shoulder protraction. The participant was then asked to reach and grasp the object. The object the participant could grasp without any movement compensation was considered the most challenging for the movement being tested. If necessary, the object's size and/or distance were reduced until the participant could make the grasp without any movement compensation. This process was repeated for frontal, ipsilateral, and contralateral reaches, as well as for the three types of grasps (global, lateral, and tripod). As a result, the maximum distance that could be reached without any compensatory movement for the three grasps in the three reach directions was obtained.

4.2.2.4. Data Analysis

The normality of the distribution was assessed using the Shapiro-Wilk test. Due to the ordinal nature of measures, non-parametric statistical tests were used. Therefore, it the median was used as a measure of central tendency and the interquartile range (IQR) for dispersion. Spearman's correlation was used to determine if there was a correlation between the measures used (FMA, SULCS, AS, arm and hand range of movement, grasp strength), size of the object, and reach distance. Friedman's test was used for significant differences across global, tripod, and lateral grasp conditions for each reach direction (frontal, ipsilateral and contralateral). The Wilcoxon signed-rank test was used for pairwise comparisons, with significance values adjusted by the Bonferroni correction. Data were analysed using IBM SPSS Statistics, Version 26.0 (Armonk, NY: IBM Corp).

4.2.3. Results

4.2.3.1. Size of objects Vs. Reach Distance

Bivariate correlations were computed to understand better the relationship between the size of objects and the reach distances in three different directions (Table 4-5). A significant negative correlation was found between global grasp and reach distance in the three different directions (frontal (r(11)= -0.718, p=00.6), ipsilateral (r(10)= -0.616, p=0.033), and contralateral (r(11)=-0.693, p=0.009)). With tripod grasp correlation is negative for frontal direction (r(11)=-0.593, *p*=0.033), and ipsilateral direction (r(10)=-0.637, p=0.026). Lateral grasp is also significant, with a negative correlation (r(11)=-0.717, p=0.006), for frontal (r(11)=0.-593, p=0.001) and ipsilateral (r(11)=-0.717, p=0.006) directions.

Table 4-5 - Correlation coefficient (r) and p-value between the size of objects and frontal, ipsilateral and contralateral reach distances. Bold values represent that significant differences were found.

		SIZE OF OBJECTS		
		Global prehension	Tripod prehension	Lateral prehension
FRONTAL REACH DISTANCE	r	**-0.718**	**-0.593**	**-0.810**
	p-value	**0.006**	**0.033**	**0.001**
IPSILATERAL REACH DISTANCE	r	**-0.616**	**-0.637**	**-0.717**
	p-value	**0.033**	**0.026**	**0.006**
CONTRALATERAL REACH DISTANCE	r	**-0.693**	-0.444	-0.524
	p-value	**0.009**	0.148	0.066

4.2.3.2. Size of objects

Strength is significantly negatively correlated with all directions of reach both using global and lateral grasps (Table 4-6). FMA and SULCS are also significantly negatively correlated with object's size to reach in frontal and ipsilateral directions using global and lateral grasps, and FMA in contralateral reach just using global grasp.

Table 4-6 - Correlation coefficient (r) and *p*-value between the size of objects used at frontal, ipsilateral, contralateral reaches, and motor and functional assessments (FMA, SULCS, and global, tripod, and lateral prehensions' strength). Bold values represent that significant differences were found. G – Global grasp; T – Tripod grasp; L – Lateral grasp; FMA – Fugl-Meyer Assessment – Upper Extremity; SULCS - Stroke Upper Limb Capacity Scale.

		SIZE OF OBJECTS								
		FRONTAL REACH			IPSILATERAL REACH			CONTRALATERAL REACH		
		G	T	L	G	T	L	G	T	L
FMA	r	**-0.699**	-0.431	**-0.806**	**-0.750**	-0.535	**-0.806**	**-0.796**	-0.569	-0.806
	p-value	**0.008**	0.142	**0.001**	**0.005**	0.073	**0.001**	**0.001**	0.053	0.001
SULCS	r	**-0.688**	-0.513	**-0.796**	**-0.697**	-0.555	**-0.796**	-0.730	-0.520	-0.796
	p-value	**0.009**	0.073	**0.001**	**0.012**	0.061	**0.001**	0.005	0.083	0.001
STRENGTH	r	**-0.604**	-0.549	**-0.782**	**-0.583**	-0.493	**-0.782**	**-0.615**	-0.451	**-0.782**
	p-value	**0.029**	0.052	**0.002**	**0.047**	0.103	**0.002**	**0.025**	0.141	**0.002**

Wrist flexion and extension, and II and III metacarpophalangeal extension are significantly negatively correlated with the object's size to reach on all directions using global and lateral grasp (Table 4-7). On the other hand, tripod grasp is significantly negatively correlated with flexion and extension of the I metacarpophalangeal (Table *4*-*7*).

Table 4-7 - Correlation coefficient (r) and p-value between the size of objects used at frontal, ipsilateral, and contralateral reaches, wrist, I metacarpophalangeal (MP), II MP and III MP range of movement. Bold values represent that significant differences were found. G – Global grasp; T – Tripod grasp; L – Lateral grasp; MP – Metacarpophalangeal.

			SIZE OF OBJECTS								
			FRONTAL REACH			**IPSILATERAL REACH**			**CONTRALATERAL REACH**		
			G	T	L	G	T	L	G	T	L
WRIST	Flexion	r	**-0.845**	**-0.692**	**-0.706**	**-0.682**	-0.496	**-0.706**	**-0.701**	-0.321	**-0.706**
		p-value	**<0.001**	**0.009**	**0.007**	**0.015**	0.101	**0.007**	**0.008**	0.309	**0.007**
	Extension	r	**-0.557**	-0.422	**-0.615**	-0.482	-0.478	**-0.615**	**-0.615**	-0.442	**-0.615**
		p-value	**0.048**	0.151	**0.025**	0.113	0.116	**0.025**	**0.025**	0.150	**0.025**
I MP	Flexion	r	-0.341	**-0.572**	-0.362	0.017	-0.399	-0.362	-0.261	-0.101	-0.362
		p-value	0.254	**0.041**	0.223	0.958	0.199	0.224	0.390	0.754	0.224
	Extension	r	-0.453	**-0.625**	-0.452	-0.124	-0.501	-0.452	-0.399	-0.212	-0.452
		p-value	0.120	**0.022**	0.121	0.700	0.097	0.121	0.177	0.509	0.121
II MP	Flexion	r	-0.163	0.108	-0.194	-0.337	-0.044	-0.194	-0.267	0.079	-0.194
		p-value	0.594	0.725	0.526	0.284	0.893	0.526	0.377	0.808	0.526
	Extension	r	**-0.610**	-0.398	**-0.654**	**-0.730**	-0.504	**-0.654**	**-0.715**	-0.444	**-0.654**
		p-value	**0.027**	0.178	**0.015**	**0.007**	0.095	**0.015**	**0.006**	0.148	**0.015**
III MP	Flexion	r	-0.511	-0.299	-0.344	**-0.817**	-0.456	-0.344	-0.552	-0.417	-0.344
		p-value	0.075	0.321	0.249	**0.001**	0.136	0.249	0.051	0.178	0.249
	Extension	r	**-0.615**	-0.461	**-0.700**	**-0.760**	-0.554	**-0.700**	**-0.709**	-0.406	**-0.700**
		p-value	**0.025**	0.113	**0.008**	**0.004**	0.062	**0.008**	**0.007**	0.190	**0.008**

4.2.3.3. Reach Distance

When comparing the three different reach distances with the three grasps tested (Table 4-8), we found that only the tripod grasp varies significantly according to the direction of reach (Fr(11)=6.255, p=0.044).

Table 4-8 - Medians (IQR) for the global, tripod and lateral grasps for the frontal, ipsilateral and contralateral reach distances, and Friedman's statistics across conditions. Bold values represent that significant differences between conditions were found.

	TYPE OF PREHENSION		
	Global prehension Mdn (IQR)	Tripod prehension Mdn (IQR)	Lateral prehension Mdn (IQR)
FRONTAL REACH DISTANCE (CM)	48 (17)	**50 (21)**	50 (18)
IPSILATERAL REACH DISTANCE (CM)	43 (21.5)	**45 (24.75)**	42 (28.75)
CONTRALATERAL REACH DISTANCE (CM)	47 (20.5)	**53 (19.25)**	56 (17.25)
CHI-SQUARE, P-VALUE	1.686, 0.430	**6.255, 0.044**	4.167, 0.125

Pairwise comparisons (Table 4-9) revealed that this effect arises from the ipsilateral reach distance (Mdn=45 (24.75)) being significantly lower when compared to the contralateral reach distance (Mdn=53 (19.25)) (Z=-2.403, *p*=0.016).

Table 4-9 - Pairwise comparisons for frontal, ipsilateral, and contralateral distances with tripod grasp. Bold values represent significant differences after the Bonferroni correction.

REACH DISTANCES	CHI-SQUARE, P-VALUE
FRONTAL – IPSILATERAL	-2.200, 0.028
FRONTAL – CONTRALATERAL	-1.258, 0.208
IPSILATERAL – CONTRALATERAL	**-2.403, 0.016**

FMA and SULCS scores are significantly positively correlated with the three grasps with distance on the three different reach directions, as shown in Table 4-10. Also, spasticity at the wrist level is significantly negatively correlated with all grasps with distance on the three different reach directions (Table 4-10). At the elbow level, the results are similar, except for the lateral grasp on the ipsilateral reach direction. At last, at shoulder level, it only significantly negatively correlates with distance with global grasp at frontal reach direction.

Table 4-10 - Correlation Coefficient and p-value between frontal, ipsilateral and contralateral reach distances, and motor and functional assessments (FMA, SULCS, and mAS). Bold values represent that significant differences were found. G – Global grasp; T – Tripod grasp; L – Lateral grasp. FMA-UE – Fugl-Meyer Assessment – Upper Extremity; SULCS - Stroke Upper Limb Capacity Scale; mAS – modified Ashworth Scale.

			DISTANCE								
			FRONTAL REACH			IPSILATERAL REACH			CONTRALATERAL REACH		
			G	T	L	G	T	L	G	T	L
FMA		r	**0.848**	**0.900**	**0.874**	**0.850**	**0.956**	**0.854**	**0.909**	**0.856**	**0.791**
		p-value	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.001**
SULCS		r	**0.716**	**0.803**	**0.807**	**0.725**	**0.844**	**0.721**	**0.768**	**0.725**	**0.609**
		p-value	**0.006**	**0.01**	**0.001**	**0.005**	**<0.001**	**0.005**	**0.002**	**0.005**	**0.027**
mAS	Shoulder	r	**-0.561**	-0.427	-0.507	-0.354	-0.384	-0.355	-0.447	-0.387	-0.416
		p-value	**0.046**	0.100	0.077	0.235	0.195	0.234	0.126	0.192	0.157
	Elbow	r	**-0.691**	**-0.593**	**-0.566**	**-0.567**	**-0.658**	-0.479	**-0.693**	**-0.569**	**-0.568**
		p-value	**0.009**	**0.033**	**0.044**	**0.043**	**0.015**	0.098	**0.019**	**0.042**	**0.043**
	Wrist	r	**-0.755**	**-0.813**	**-0.724**	**-0.633**	**-0.811**	**-0.687**	**-0.762**	**-0.801**	**-0.635**
		p-value	**0.003**	**0.001**	**0.005**	**0.020**	**0.001**	**0.009**	**0.002**	**0.001**	**0.020**

Regarding the range of movement, shoulder flexion, abduction and internal rotation, elbow extension, and forearm supination significantly correlates with distance in all reach directions (Table 4-11). Shoulder external rotation is significantly positively correlated with distance in ipsilateral reach direction using all grasps and frontal reach direction using global and tripod grasps. Elbow flexion significantly correlates with distance in frontal reach direction but only when using a tripod and lateral grasps, while it correlates with all grasps for contralateral reach direction. Finally, the forearm significantly correlates with distance using a global grasp at frontal and ipsilateral reach directions.

Table 4-11 - Correlation Coefficient and p-value between frontal, ipsilateral, and contralateral reach distances, and shoulder, elbow, and forearm range of movement. Bold values represent that significant differences were found. G – Global grasp; T – Tripod grasp; L – Lateral grasp.

			FRONTAL REACH DISTANCE			IPSILATERAL REACH DISTANCE			CONTRALATERAL REACH DISTANCE		
			G	T	L	G	T	L	G	T	L
SHOULDER	Flexion	r	**0.671**	**0.806**	**0.793**	**0.723**	**0.879**	**0.790**	**0.751**	**0.717**	**0.698**
		p-value	**0.012**	**0.001**	**0.001**	**0.005**	**<0.001**	**0.001**	**0.003**	**0.006**	**0.008**
	Abduction	r	**0.592**	**0.742**	**0.737**	**0.675**	**0.817**	**0.814**	**0.686**	**0.692**	**0.568**
		p-value	**0.033**	**0.004**	**0.004**	**0.011**	**0.001**	**0.001**	**0.010**	**0.009**	**0.043**
	External rotation	r	**0.637**	**0.564**	0.551	**0.767**	**0.595**	**0.675**	0.483	0.393	0.544
		p-value	**0.019**	**0.045**	0.051	**0.002**	**0.032**	**0.011**	0.094	0.184	0.055
	Internal rotation	r	**0.792**	**0.735**	**0.721**	**0.709**	**0.732**	**0.601**	**0.715**	**0.634**	**0.608**
		p-value	**0.001**	**0.004**	**0.005**	**0.007**	**0.004**	**0.030**	**0.006**	**0.020**	**0.027**
ELBOW	Extension	r	**0.617**	**0.673**	**0.766**	0.356	**0.601**	**0.604**	**0.743**	**0.756**	**0.673**
		p-value	**0.025**	**0.012**	**0.002**	0.233	**0.030**	**0.029**	**0.004**	**0.003**	**0.012**
	Flexion	r	0.543	**0.618**	**0.716**	0.273	0.551	0.537	**0.704**	**0.717**	**0.628**
		p-value	0.055	**0.024**	**0.006**	0.367	0.051	0.058	**0.007**	**0.006**	**0.021**
FOREARM	Pronation	r	**0.558**	0.473	0.447	**0.631**	0.554	0.465	0.527	0.483	0.479
		p-value	**0.047**	0.103	0.126	**0.021**	0.050	0.110	0.064	0.094	0.678
	Supination	r	**0.829**	**0.889**	**0.824**	**0.757**	**0.780**	**0.780**	**0.727**	**0.729**	**0.902**
		p-value	**<0.001**	**<0.001**	**0.001**	**0.003**	**0.002**	**0.002**	**0.005**	**0.005**	**<0.001**

4.2.4. Discussion

4.2.4.1. Size of objects Vs. Reach Distance

The study found a significant correlation between object size and the distance of frontal and ipsilateral reach when grasping objects of different sizes. Additionally, grasping smaller objects is easier when the reach distance is higher. Gentilucci *et al.,* [278] refer that the reach distance changes according to the object's size, object position, and the distance of the individual from the object. Thus, it is necessary to be aware that the size of objects and the type of grasp can determine how arm and hand movements coordinate during reaching and grasping tasks [279]. However, only the reach distance on the contralateral side significantly correlated with the global grasp, not the tripod and lateral grasps. This may occur because, on the contralateral side, the movement follows the pathological flexion synergy pattern associated with the sequela. Therefore, the limitations in the proximal joints, such as the shoulder and elbow, do not restrict the movement as the flexor pattern is maintained [280].

4.2.4.2. Size of objects

In the grasping movement, there was a negative correlation between the FMA, SULCS and the grasp strength, with the size of the object being grasped in both global and lateral grasp. This means that the higher the scores obtained, the smaller the object individuals can grasp. However, the correlation with the tripod grasp was not confirmed. The range of movement on the wrist and the first three fingers can be useful indicators to choose the object's size to be used for the three grasps studied to achieve the farther reach distance without compensatory movements.

Results indicate a negative correlation between the size of an object and the scores of wrist flexion and extension. This suggests that the wrist plays an important role in facilitating hand movements, as difficulties in moving the wrist joint can result in problems performing fine grasping tasks. As a result, it becomes easier to grasp larger objects with better wrist capacity. Rainbow *et al.,* [281] have also identified this connection between wrist mobility and hand movement. It is important to note that the amplitude of the metacarpophalangeal joints was expected to correlate with the object's size, which only occurred in the distal joints during the tripod grasp. This can be attributed to the tenodesis movements common with stroke individuals with lack of hand strength [278], [282].

One finding of this study is that the size of the object remains consistent during lateral grasping, regardless of which side is used. However, this is not the case for global and tripod grasping. This can happen because to perform a lateral grasp, one only needs to orient the wrist and pre-mold the fingers to have a stable grasp, as mentioned by Paulignan *et al.,* [283]. However, to grasp a cylindrical object, which is used for global and tripod grasp, additional hand reorientation, such as forearm supination, is required to establish contact with the object, as pointed out by Sangole *et al.,* [265].

4.2.4.3. Reach Distance

Upon analysis of the reach distance, we found that individuals reached shorter distances to the ipsilateral side and longer distances to the contralateral side where the target was placed. According to the literature, healthy subjects can reach objects within 90% of the arm's length with no compensatory movements [284]. However, in post-stroke individuals, it was already expected that they would not reach this distance, as the literature suggests they reach about 75% without compensatory movements [282]. Thus, these individuals often use compensatory movements, such as trunk recruitment, even when the target is within arm's reach, in order to coordinate reaching and grasping movements [280].

During the study, participants were evaluated while seated and leaning against the table in order to prevent trunk compensatory movements and encourage the use of natural reaching and grasping motions [285]. This approach resulted in lower distances being measured. The results regarding the difficulty in reaching the ipsilateral side align with the study by Levin *et al.,* [286], who observed that individuals have shorter reach distances when objects are in this direction. A possible explanation for the higher contralateral reach is that it favors the pathological pattern of internal rotation and pronation.

We also verified that significant differences exist between the reach distances for the tripod grasp, namely between the distance to the ipsilateral and contralateral sides. This can be explained by post-stroke individuals adopting a wrist flexion pattern, since the average wrist flexion amplitude was 46,4º and the extension wrist amplitude was 30,4º. In fact, the tripod grasp utilizes wrist flexion on the contralateral side, while wrist extension is naturally performed on the ipsilateral side.

Regarding FMA and SULCS scores, it was verified that the higher the scores, the greater the range distance. As these tests evaluate the upper limb's function, this result is expected, as better function is related to a higher range of motion. Similarly, the elbow and wrist mAS scores correlate negatively with the reach distance. However, the same does not occur with the shoulder, possibly because of low levels of spasticity in this segment. Due to this change in tonus, it is expected that post-stroke individuals will have a shorter elbow extension and maintenance of pronation, which will make reaching difficult and lead to compensatory strategies use, such as increased anterior trunk displacement and greater shoulder abduction [262], [268]. When reaching movements were analyzed, we found that flexion, abduction, and rotation of the shoulder, as well as elbow extension and forearm supination, correlated significantly with reach distances. In fact, the frontal reaching movement was with the shoulder in flexion and neutral rotation, the elbow extended, and the forearm in a neutral position, requiring co-activation of the upper limb muscles, which is difficulty in these individuals [266]. Accordingly, the greater the range of motion of the shoulder, elbow, and forearm, the greater the distance of reach, regardless of the grasp used.

4.2.4.4. Limitations

The present study has some limitations, such as the small sample size, which does not allow for a generalization of the results. Also, using goniometry as an assessment method to collect the range of motion introduces subjectivity in the evaluation, which was attempted to overcome with only one evaluator.

4.2.5. Conclusions

Our results suggest that regardless of the type of grasp used, the farther the forearm, elbow, and shoulder can move, the greater the reach distance will be. It is possible to predict a higher reach distance with higher FMA and SULCS scores and lower mAS on the elbow and wrist. Additionally, our findings indicate that individuals who have suffered a stroke have a shorter reach on the ipsilateral side and a longer reach on the contralateral side, making the tripod grasp more difficult to complete on the same side. Regarding grasping, it appears that the size of an object correlates with the amplitude of wrist flexion and extension movements during grasping. Despite the findings from the study, it is crucial to further explore the theme of this research. This will facilitate the development of more suitable interventions for post-stroke patients and help minimize the adoption of poorly adaptive strategies.

Chapter 5. Design and Development of the Interactive Table

In this chapter, we will describe the development of the serious games and the interactive table. Section 5.1 covers the process of creating four serious games for upper limb motor rehabilitation, detailing the specific characteristics of each game, and section 5.2 focuses on the development process of the interactive table.

5.1. Development of the Serious Games

The primary goal for the serious games that were developed was to provide a portfolio of tasks suitable for the rehabilitation of upper limb motor function. For that purpose, five motor skills we would like the games to address were identified: strength, grasping, dexterity/fine motor skills, finger individualization, and range of motion. Some of these skills imply interaction with tangibles. Therefore, we explored common materials used in traditional therapy together with our expertise in occupational therapy to determine which conventional materials could be utilized with potential therapeutic benefits. These materials should be relatively easy to develop, for example, in wood or through 3d printing. The following objects were identified (Figure *5-1*): 1) Therapeutic cones, 2) Resistive pinch

Figure 5-1 - Materials identified as having potential therapeutic benefits (therapeutic cones, resistive pinch pins, small wooden pieces, geometric objects, therapeutic putty and plasticine).

pins, 3) Small wooden pieces, 4) Geometric objects, 5) Therapeutic putty, and 6) Plasticine.

Having determined the motor skills our games should target for rehabilitation and the tangible objects that would serve as interfaces, it was important to thoroughly understand the physical characteristics of each object, in order to define every possible way in which each object could be used to interact with the games (Figure 5-2).

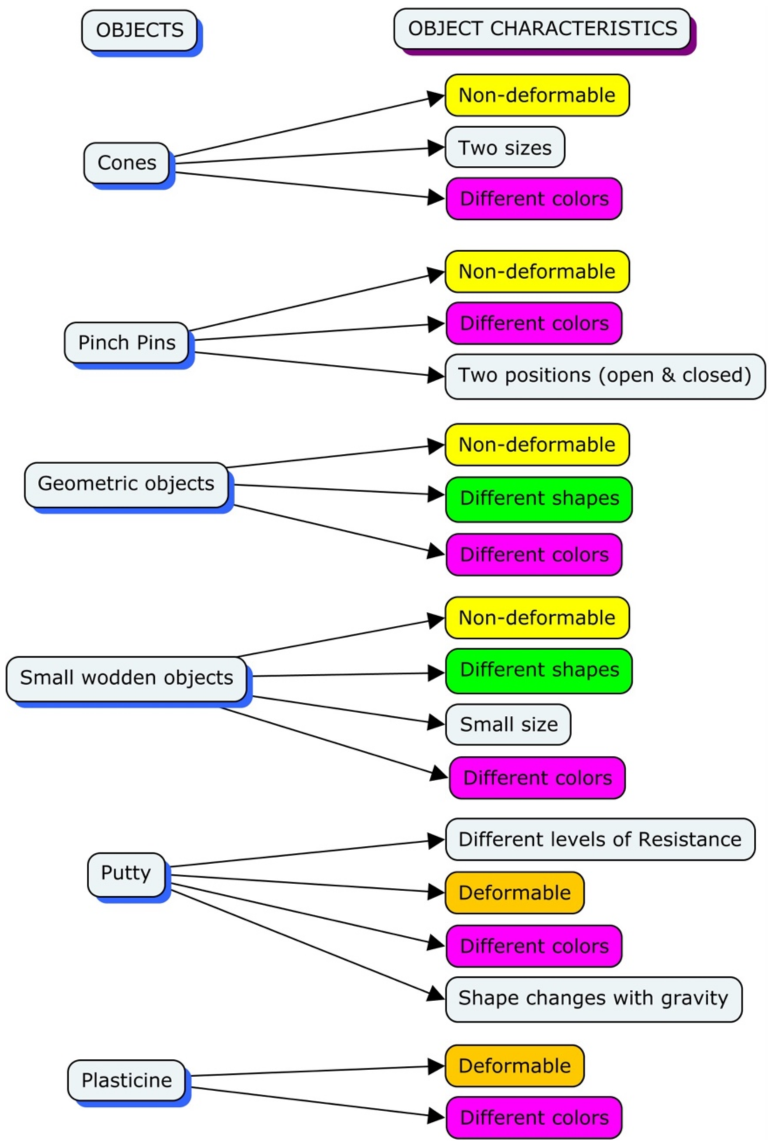


Figure 5-2 - Physical characteristics of the objects chosen to interact with the games.

Subsequently, several game mechanics were identified. These included pushing, selecting or deleting, grabbing, dragging and dropping, drawing lines, creating shapes, filling spaces, and distinguishing based on color. A mini-game was designed for each game mechanic, which resulted in the tasks used in Chapter 4.1 (Maze, Paint, Follow the line, Slide, and Fill the figure).

Working towards the development of the serious games, we engaged in a brainstorming session with colleagues with game design background and knowledge about the purpose of our work, to come up with a variety of potential games. This led to the creation of 21 different game concepts, which are displayed in Table 5-1.

Table 5-1 - 21 game concepts that raised from a brainstorming session. [1]ROM (range of movement).

Game Name	Description/Objective	Materials	Therapeutic Goal
Pacman	Prevent the small characters from falling into holes by covering them with a material.	- Putty - Objects	- Hand strength - Upper limb ROM[1] - Grasps
Sheepdog	In a maze of fences, guide sheepdogs to bark and direct the sheep.	- Objects	- Upper limb ROM - Grasps
Plumber I	Several water pipes connected between with several holes that need to be plugged.	- Putty - Objects	- Hand strength - Upper limb ROM - Grasps
Plumber II	Create a network using puzzle pieces in pipe shapes by manipulating and aligning them with specific grips.	- Objects	- Upper limb ROM - Grasps - Hand-eye coordination
Whack-a-mole	Catch moles appearing in holes hitting them with an object.	- Objects	- Upper limb ROM - Grasps - Hand-eye coordination
Angry Birds	Destroy towers of pieces or insects by throwing objects. Use silicone for finger extension resistance (open hand movement). A factory-like setup where one throws while others shape silicone, either for throwing or as obstacles.	- Putty	- Hand strength (fingers extension)
3 in a Row	Speed game of connecting 3 in a row where each player molds their pieces and then plays.	- Putty	- Hand strength (fingers flexion)
Painting	Paint freely or with a specific goal together.	- Objects	- Grasps
Pong	Similar to Pong, but the paddle is movable all over the screen.	- Objects	- Upper limb ROM

			- Grasps
Air Table	Use the mechanic of hitting a disc towards a goal.	- Objects	- Upper limb ROM - Grasps
Endless Runner	Navigate through obstacles, jump if needed (lifting the object), collect coins for arm amplitudes, destroy walls, open doors, collect bonuses.	- Objects	- Upper limb ROM - Grasps
Follow the Master	A person selects circles with various colors or animals in a grid and others repeat the sequence (memory game).	- Objects	- Upper limb ROM - Grasps
Candy Crush	Players must shoot to create lines of consecutive balls of the same color.	- Objects	- Upper limb ROM - Grasps
Spacecraft or Firefighters	A person controls a spaceship and engages in combat with other spaceships while avoiding enemy fire. Alternatively, the game can involve firefighters battling a blaze.	- Objects (lateral grasp to control shooting direction)	- Upper limb ROM - Grasps
Cooking	Gather ingredients in a specific order to fulfill restaurant orders. Include cooking movements such as scraping carrots, stirring pots, washing pots, adding salt, shaking ingredients, peeling potatoes, and cleaning tables.	- Objects (similar to the real objects)	- Upper limb ROM - Grasps
Connect Numbers	Players must connect numbers, images, and colors without crossing lines.	- Objects	- Upper limb ROM - Grasps
Cooking II	Participants work together to prepare and combine ingredients while completing various tasks towards a final goal. They must also maintain cleanliness and shoo away flies.	- Objects	- Upper limb ROM - Grasps
Balance of Forces	Players must manipulate a maze by raising and lowering their sides to guide a ball to its goal.	- Objects	- Upper limb ROM - Grasps
Balance of Forces II	Control the trajectory of an object through a path using the average position of multiple players. A correct trajectory earns bonuses.	- Objects	- Upper limb ROM - Grasps
Balance of Forces - Water	Players must work together to control a bucket that catches moving water.	- Objects	- Upper limb ROM - Grasps
Dusting	Some people sweep the dust, while others use fans to spread it or place objects as barriers.	- Objects	- Upper limb ROM - Grasps

For each game, both the objects needed (interfaces) and the therapeutic goal were defined to help decide which games we should implement. From there, considering its feasibility, we reduced the list to six options and added three more. One of these three games is based on the task *Fill the figure.* The other two games were added because they enabled the interaction directly through hand touch (Table 5-2).

Table 5-2 - List of games chosen to be part of the set of rehabilitation games for the interactive table.

Game	Therapeutic Goal	Interface	Mechanics	Hardware
Sheepdog - Push and guide a barking dog to lead a flock of sheep to a certain location	- Upper limb ROM - Grasps	- Parallelepiped and cylinders	- Push objects - Labyrinth	Touch panel
Paint - Paint freely or with a background (pen, chalk, spray, crayons)	- Upper limb ROM - Grasps	- Parallelepiped and cylinders	- Painting	Touch panel
Bubble shooter - Move and aim an object to shoot a ball	- Upper limb ROM - Grasps	- Parallelepiped and cylinders	- Object position and direction control	Touch panel
Firemans - Multiple fire sources appear that require different combinations of water to extinguish	- Upper limb ROM - Grasps	- Parallelepiped and cylinders	- Object position and direction control	Touch panel
Tube - Tube with multiple leaks that players must seal using silicone	- Strength	- Putty	- Space filling	Color Tracking
Fill - Fill spaces with silicone	- Strength - Coordination	- Putty	- Space filling	Color Tracking
Cooking - Players have to prepare dishes, where preparing each food requires specific movements, like mixing, shaking, scraping, transferring (simulating contextual everyday movements). We can simulate a restaurant where orders come in and dishes must be prepared within a time frame	- Strength - Grasp - Upper limb ROM	- Parallelepiped and cylinders - Putty	- Complex movements - Select and move	Color Tracking
ColorCollection - Select balls of the same color with fingertips and perform a movement (flexion, extension, abduction, adduction)	- Coordination - Upper limb ROM - Grasps	- Hand - Parallelepiped and cylinders	- Select and move	Touch panel
Piano - Play with 5 piano keys	- Isolation	- Hand	- Select	Touch panel

Having started the development process of the games, and weighting the available time and human resources, we realized that our initial target of developing 9 new games was too ambitious. Therefore, instead of developing all the games as planned, we opted for redesigning games/tasks we had from previous studies and develop just a few new ones. The final list resulted in 4 games, named with the prefix 'MI' (**M**esa **I**nteractiva, which means Interactive Table): MI Tangram, MI Color Catch, MI Balloon, and MI Supermarket, which will be discussed thoroughly in the following sections.

These four games were designed to be played in the collaborative mode. Therefore, we had to impose some restrictions, namely: 1) Number of players between 2-4, 2) Each player should have the same role, and 3) Scoring should depend on the participation of at least two players. Based on the conclusions drawn from the studies we conducted, our objective was to create simple games with minimal mechanics. The restriction of needing to have at least two players contributing to the final score was the most challenging restriction. To make it easier for players to learn different games, we tried to standardize the design of all games. This included using the same background and icons for time and score and keeping the icons in the same places between different games. A black and white background was chosen for simplicity but also to avoid color detection issues during the games.

One of the pillars of our approach is to promote a good sense of self-efficacy. To recall the meaning of self-efficacy, Bandura provides a definition of it as follows: "the conviction that one can successfully execute the behavior required to produce the outcomes" [80]. In this theory, an individual's perceived capabilities are more important than their actual capabilities [82]. Bandura proposed four sources of self-efficacy: performance accomplishments, vicarious experience, verbal persuasion, and emotional arousal [80]. The following table resumes which strategies we used with each game to promote a good sense of self-efficacy according to each one of its sources (Table 5-3).

Table 5-3 - Description of the strategies used for each game to promote self-efficacy.

Self-efficacy sources	**MI Tangram**	**MI Color Catch**	**MI Balloon**	**MI Supermarket**
Performance accomplishments (mastery)	-Visual positive feedback associated with success -Auditory positive feedback associated with success -Information about progress (comparison with highest score)	-Visual positive feedback associated with success - Visual feedback of actions (catching a ball) -Records ranking	-Visual positive feedback associated with success - Visual feedback of actions (when balloon control is activated) -Records ranking	- Tutorial -Auditory positive feedback associated with success - Visual feedback of actions (when a food is collected)

Vicarious Experience	- Observing other players playing	- Observing other players playing	- Observing other players playing	- Observing other players playing
Verbal Persuasion	- Therapist often praised personal achievements and encouraged others to do it	- Therapist often praised personal achievements and encouraged others to do it	- Therapist often praised personal achievements and encouraged others to do it	- Therapist often praised personal achievements and encouraged others to do it
Emotional Arousal	- Positive feedback (score) - Implementations to avoid failure: -- Different sets of shapes	- Positive feedback (score) - Implementations to avoid failure: -- Visual hints about the color to catch -- Blinking yellow square to hint where the object shall be placed. It stops blinking when object is placed	- Positive feedback (score) - Implementations to avoid failure: -- Individual personalization of the control interface in terms of size, orientation, and range of movement	- Positive feedback (score) - Implementations to avoid failure: -- Reduced colliders in obstacles

5.1.1. MI Tangram

This game was developed based on the task *Fill the figure,* referred in Chapter 4.1. The goal is to fill the inside of different shapes using therapeutic putty or objects with shapes similar to tangram pieces that were specifically developed for this game (Figure *5-3*).

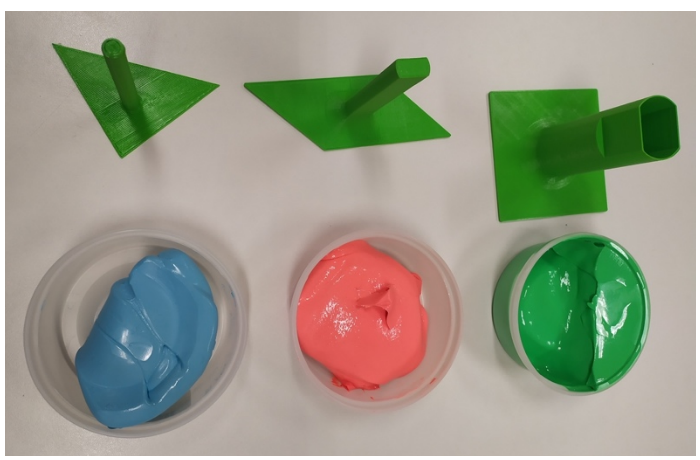


Figure 5-3 - Objects used as interfaces in MI Tangram. On top some examples of the tangram pieces. At the bottom, therapeutic putty.

When a shape is filled (all pixels are overlapped with the object being used), it will burst and provide visual and auditory feedback, rewarding the team with one point. There are always four available shapes to fill, being instantiated at random locations, without overlapping features already instantiated (Figure *5-4*). At the end of the game, players are informed of their score and the highest score achieved from the beginning of the intervention.

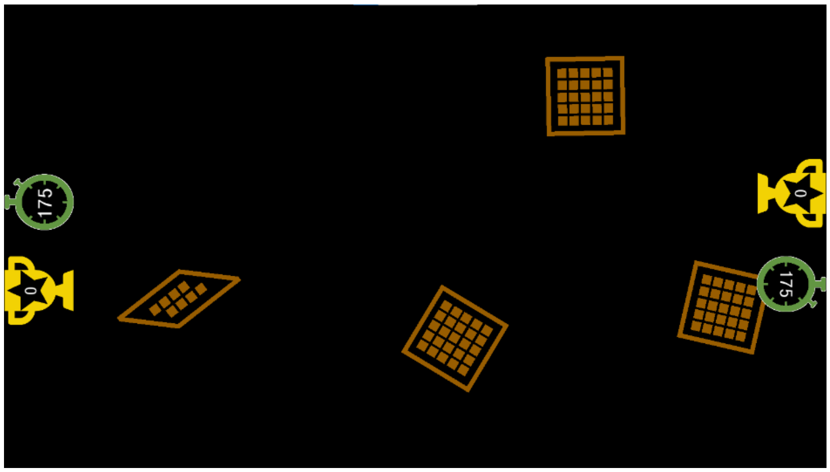


Figure 5-4 - An example screen on MI Tangram displays four shapes with small squares that disappear when an object covers all. The score is shown by a yellow cup and the remaining time is displayed by a timer in seconds.

The therapist can adjust game time and difficulty levels by choosing from four puzzle sets. Another way to adjust difficulty is by selecting different colors of therapeutic putty, as each color has a different resistance. However, the green one works better with this system, given its color properties. Alternatively, tangram objects can be chosen to encourage grasping. However, with tangram objects, the task requires a higher cognitive load, but in the other hand, promotes more social interaction, as they need to share the objects. The number of objects assigned to the team or to each participant can affect the social dynamics of the activity. If there are significant differences in motor or cognitive function among participants, larger shapes can be assigned to those who have more difficulties, thus reducing the task difficulty. If the therapist deems it appropriate, he/she may intervene in the game by destroying shapes outside the participant's range of movement or requesting that the participant use only the affected hand. The therapist may also ask participants to re-stretch the putty between shape completions to avoid using the stretched putty for a long time. Finally, the therapist can use weights or other materials that he/she considers helpful to achieve the established goals.

5.1.2. MI Color Catch

This game was developed based on the games used in both sub-chapters of Chapter 3, where the goal was to catch balls in three different game modes. The objective is that all players catch a ball of the same color. The first ball caught determines the color that other players must catch. This means that until one player catches the first ball, there are no restrictions on the color that can be caught. Once the last player catches its ball, the team is awarded one point, and both visual and auditory feedback are given. To catch the ball, a player needs to grab a ring located on the side of the screen. There is one ring for each active player on each side, housed in a box invisibly divided into three partitions (Figure 5-5).

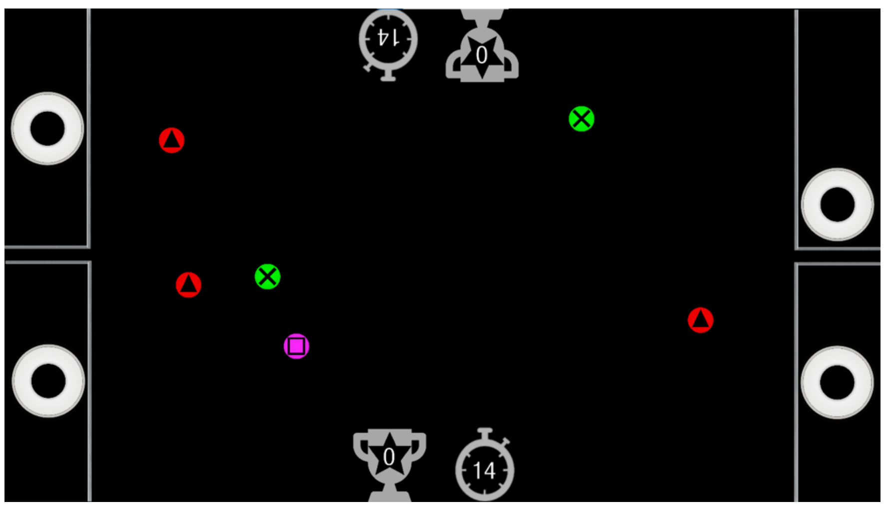


Figure 5-5 - An example of a MI Color Catch screen with four rings on the sides used to catch the colorful balls that move linearly in random directions. The trophy image displays the score and the timer shows the remaining time in seconds.

After all players have caught one ball, the ring automatically returns to its initial box in a different partition from the previous round. However, before the ring appears, a yellow rectangle blinks with an arrow moving, indicating where the object may be placed (Figure *5*-*6*).

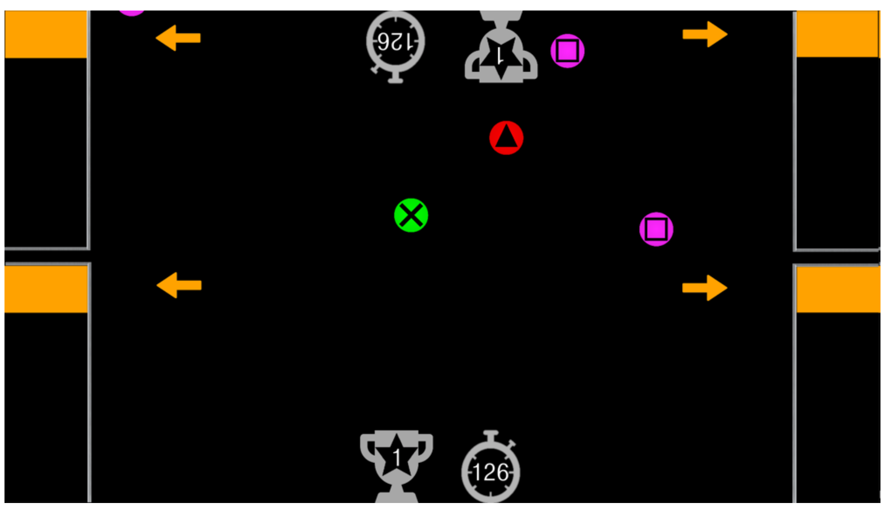


Figure 5-6 - An example moment in MI Color Catch where players receive visual hints to return their object to the initial place and create a new ring.

After the object is placed, a new ring appears in a different partition. This is done with two main purposes: 1) The yellow rectangle intends to hint where the object should be placed visually and 2) By Placing the object in the yellow rectangle, the player is encouraged to repeat grasp and release movements. If the therapist chooses to attribute only one object to the player, grasp and release will not be done. If the player is attributed with two or three objects, each object should be placed in a separate invisible partition. At the end of the game, a ranking that starts in the first session is displayed with the best 6 scores along the sessions.

Participants can interact with the ring using either their own hand or a tangible interface developed by us (Figure *5*-*7*). These interfaces are meant to encourage three different types of grasping (power grasp, lateral grasp and tripod grasp), and difficulty can be adjusted by selecting interfaces of varying sizes. There is the possibility of training different skills using materials such as resistive pinch pins or weights. The design of the tangible interfaces was gradually improved. Figure *5*-*7* illustrates the evolution of our prototypes. The first one was a cheap wooden model, followed by a 3D-printed one with a larger base. The third prototype incorporated all three grasps into one object, eliminating the need of having one object for power and lateral grasp and another for tripod grasp. Finally, after observing that users naturally perform a lateral grasp when the object is smaller, we narrowed the top 3 cm of the object to provide a specific place for this grasp. Otherwise, if the area to grasp is large, users naturally use a power grasp.

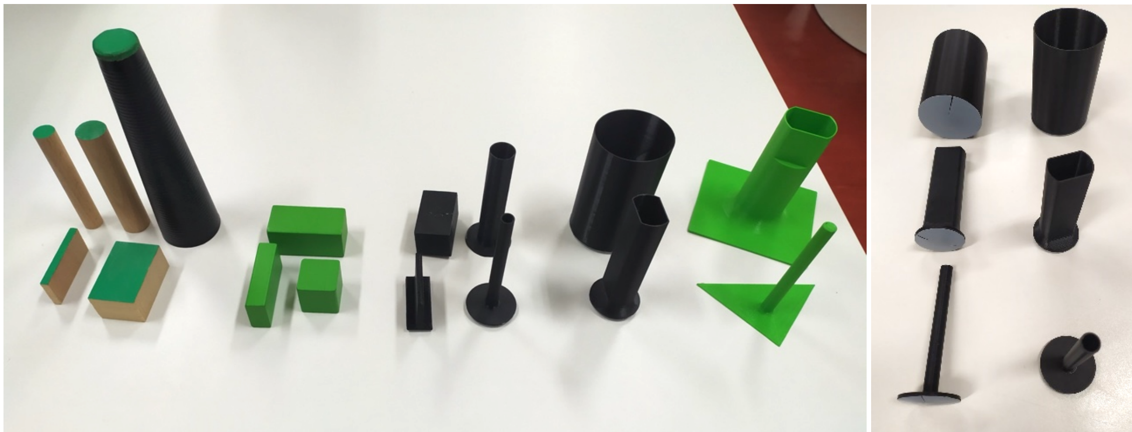


Figure 5-7 – In the left image, objects are arranged in the order of their development from left to right. The right image displays the objects used in MI Color Catch.

In this game, the therapist can modify various features (Figure 5-8), including: 1) Number of players, 2) Player's ring size, 3) Ball size, 4) Time intervals between new ball creations, 5) Ball velocity, and 6) Round duration.

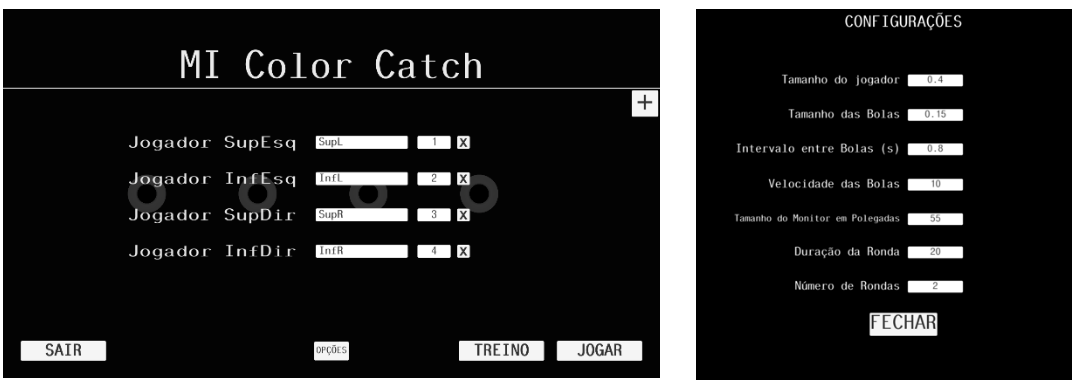


Figure 5-8 – MI Color catch configurations menu available for the therapist to change difficulty of the game.

The therapist is responsible for adjusting the game or using alternate resources to train specific skills. For instance, the therapist can instruct the player to utilize a pinch pin for gripping an object and then catch the ball while still holding the pinch pin. Alternatively, the therapist can ask the same, but holding the object, requiring less dexterity. These little variations can be more suitable for some participants, according to their motor and cognitive skills. Hence, the therapist has an important role in controlling how challenging the task is by implementing cues or changes in the activity. Another example of using the game's characteristics to promote rehabilitation is the person's position relative to the rings. If a participant has a right-side impairment, the therapist can choose to place the rings on the left to increase the challenge of the task in terms of the range of movement. On the other hand, if the therapist wants to reduce the challenge, the rings can be placed on the right. Additionally, if we aim to raise awareness on the affected side, we can position the participant so that the rings are on the side of the lesion.

5.1.3. MI Balloon

This game was developed to improve finger dexterity and control of individual finger movements. The objective of this game is to maneuver an air balloon towards coins. The main balloon has four smaller balloons attached, forming a square around it (Figure 5-9).

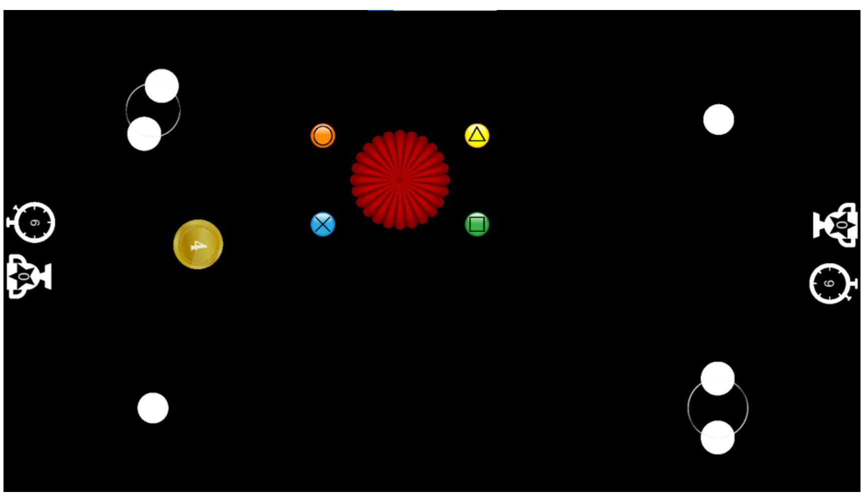


Figure 5-9 - An example screen of MI Balloon with four white interfaces to control the ball direction, two of them activate the correspondent small balloon (with a geometric shape inside) to move the big red balloon. A trophy on the sides displays the score and a timer shows the remaining time in seconds. A coin is also shown with the time left before it disappears.

Each player controls a smaller balloon positioned according to their place at the table. Each one has a corresponding control in front of them that partially inflates their small balloon when activated (Figure 5-10). When the small balloon is inflated, it exerts a force on the main balloon, causing it to move in the direction of the small balloon. The magnitude of the force increases with the size of the smaller balloon but with no interference with the speed.

Figure 5-10 - Players can inflate their small balloon with two methods. On the left, it involves touching with one finger (pinch movement), while the other requires moving two balls to touch (pinch movement) or move outside a white ring (zoom movement). This is set by a therapist.

Before the game begins, the therapist can select the type of interaction for each participant. Additionally, the therapist can customize features to adjust the level of challenge. This game was designed with several features that can be changed to adapt the game to each user, as shown in Table 5-4.

Table 5-4 - Features that can be adapted by the therapist to set difficulty or to personalize therapy. They are divided by their applicability: all participants and individual participants.

Applicability	Feature	Description
All participants	Balloon Movement Restriction	Restricts balloon movement to horizontal or vertical directions
	Game Time Limit	Sets a time limit for the game
	Main Balloon Return to Center	Makes the main balloon return to the center of the game area
	Adjust main balloon size and velocity	Allows adjustment of the size and velocity of the main balloon
	Set coin lifetime	Determines the lifetime of coins in the game
	Simultaneous active coins	Adds the ability for multiple coins to be active at the same time
Individual participants	Type of interaction	Defines the type of interaction for each participant
	Minimal distance for pinch interaction	Specifies the minimum distance between fingers to trigger a pinch
	Ring size (zoom mode)	Defines the ring size in zoom mode, determining movement triggers
	Ring size (pinch mode)	Defines the starting fingers' position in pinch mode
	Fingers rotation (zoom and pinch modes)	Specifies the angle for fingers' placement in zoom and pinch modes
	Fingers width	Defines the width of fingers considered for interactions
	Deflate velocity (small balloon)	Sets the velocity at which the small balloon deflates
	Inflate velocity (small balloon)	Sets the velocity at which the small balloon inflates

5.1.4. MI Supermarket

The objective of this game is to deliver the necessary food items to each player's designated area. When this occurs, both visual and auditory signals are provided, and the team scores 1 point. All food items are displayed on the screen at once, some within the player's range of movement and others outside of it. There are obstacles such as food stalls and freezers. There are four different colored areas. These were meant to promote social interaction between players (Figure *5-11*). One of the game's originally intended rules was that each player could only move objects within their color, forcing them to ask other participants to move their food toward their direction. However, we could not implement the rule to be controlled independently by the game due to time limitations. Additionally, this mechanic significantly increased the cognitive load of the task. Therefore, we decided to abandon this rule but keep the colors, allowing the therapist to use them if deemed appropriate. To improve usability, we decreased the size of obstacles' colliders because objects were getting stuck on them when participants passed closer.

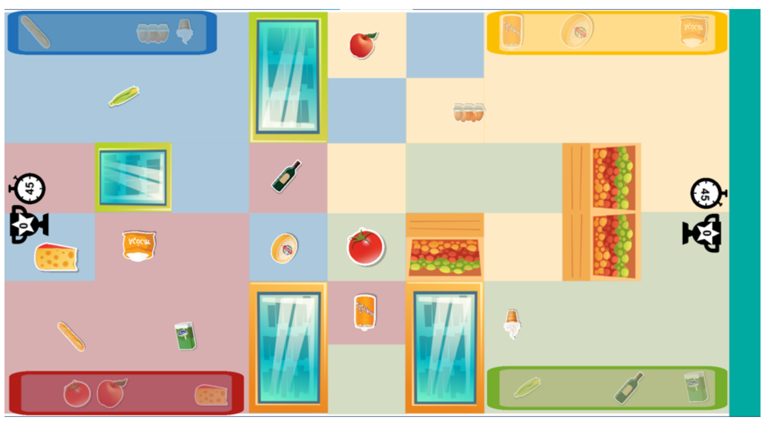


Figure 5-11 - An example screen of MI Supermarket with four individual spaces in the corners for each player. Each space contains transparent images of the objects the player should collect. Food stalls and freezers are obstacles to increase variety in arm movements. The sides display a trophy for the score and a timer for the remaining time in seconds.

Players can interact with the game using their fingers or the same physical objects used in MI Balloon. Some features can be adjusted by the therapist (Figure 5-12), such as: 1) Number of players, 2) Number of objects, 3) Game time, 4) Areas per player, and 5) Turn on/off background music. To expand the therapeutic range of this game, weights can also be used.

Figure 5-12 – MI Supermarket configurations menu available for the therapist to change difficulty of the game.

5.2. Design and Construction of the Interactive Table

Previous research and literature supported that the use of a multi-user interactive table would allow addressing the research questions relating to this work, as it allows:

1. Several participants to use it simultaneously, facilitating social interaction;
2. The use of serious games that are specifically designed for rehabilitation purposes, enhancing motivation and self-efficacy;
3. The use of touch or tangible objects to interact with the games, allowing for upper limb use while also proposing ecologically friendly rehabilitation solutions.

A preliminary version of the interactive table was presented in Chapter 4.1, where we tested the use of tangibles through top-down shape detection using object's color - a feature that is used in the final prototype of the interactive table. As a result, we began designing a sturdier table equipped with a multi-touch panel and intended for multiple users. This version was designed for two players and was used in the study of Chapter 3.2 (Figure *5-13*).

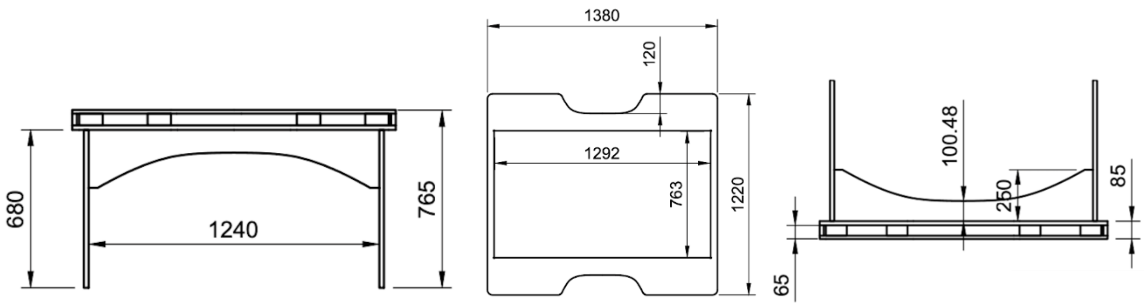


Figure 5-13 - Different views and measures of the interactive table designed for 2 people. It had 765mm height, 1380mm width and 1220 mm depth. The left and right views are seen from the front, while the top view is seen from the center.

The table was built in 2018 when large multi-touch surfaces were still expensive. Therefore, we opted to use a 55'' TV LED (Sony KD-55XF9096AEP) and a 55’’ touch module (E10-TM55F) over the screen to convert the screen to multi-touch (Figure *5-14*). This panel allows for 80 touchpoints. A computer with the following specifications was used: Graphics card - Gigabyte Nvidia GTX 1070 Ti Gaming 8G, Hard disk - CRUCIAL MX500 500GB, Processor - Intel Coffee Lake Core i7-8700K 3.7GHz, RAM - Team Group Elite Plus 8GB DDR4.

Figure 5-14 – 55” TV LED on the left and the 55” touch module on the right.

During the design process, we found some challenges. One of them was the height of the table. A table for someone who is 175 cm should typically be between 66-73 cm in height [287]. Our interactive table had to have at least 78,8cm tall to accommodate a wheelchair (which requires 70cm if armrests are removed), the 55'' screen and multitouch panel (7,2cm), and a wood layer to support the screen (1,6cm). To compensate the approximately 10cm extra height, we used chairs with adjustable height, and a foot support with 15 cm. Another challenge was with the design. We needed to ensure the table was stable without obstructing the legs of the participants. We solved this by placing a vertical wooden piece in the middle of the table, cut with a semi-circle to avoid knee collisions (Figure *5-15*).

Figure 5-15 – Vertical wooden that stabilizes the table with a semicircle cut to avoid knee collisions (view from under the table).

Additionally, we have decided to create a cut-out that is 11cm height and 49cm width. This cut-out allows participants to rest their elbows on the table, improving hand performance [288], [289], while also enabling them to sit closer to the screen. A lateral support for the webcam positioned above the screen was also designed. In its final version, the table was redesigned to accommodate four players, but only the top was changed (Figure *5-16*).

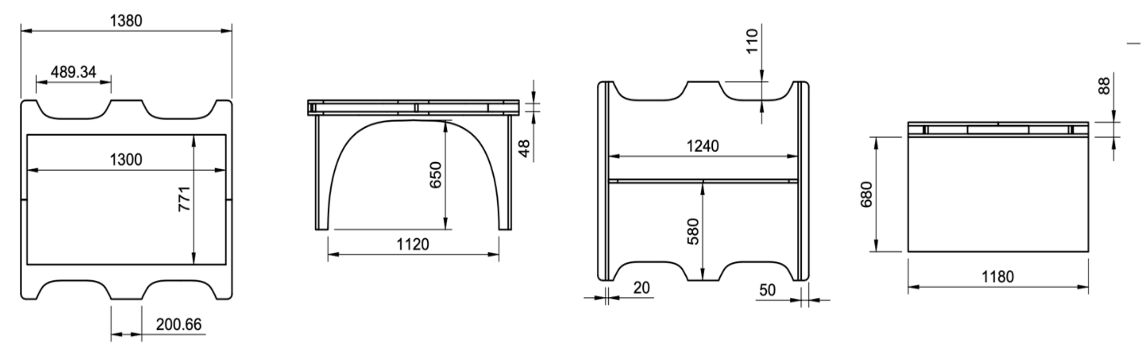


Figure 5-16 - Different views and measures of the interactive table designed for 4 people. The figure shows a view from four different angles. From left to right, you can see the top view, front view, bottom view, and side view.

There is a structure attached to the side of the table that holds a Depth/RGB camera (Real Sense) positioned in the center of the screen. The camera is utilized for identifying objects which are used as game interfaces. This can be observed in Figure *5-17*, which displays the final version of the interactive table.

Figure 5-17 - Final version of the interactive table installed and ready for data collection.

Chapter 6. The Impact of a Group Motor Rehabilitation Protocol Enhanced by Social Interaction and Self-efficacy - a Pilot Study

Parts of this chapter have been submitted for publication in:

F. Pereira, S. Bermúdez i Badia, R. Ornelas, and M. S. Cameirão, “The impact of a group motor rehabilitation protocol enhanced by social interaction and self-efficacy - a pilot study,” submitted.

Contributions: FP, SBB, and MSC designed the study. FP recruited the participants. FP collected data. FP performed the data analysis. FP, SBB, and MSC interpreted the results.

6.1. Introduction

Upper limb impairments can greatly affect the ability to perform daily activities. The most common impairments in patients are muscle weakness, limited joint motion, shoulder subluxation, muscle shortening, sensory changes, pain, and spasticity [15], [16]. The negative impact of hand function loss on occupational performance and independent participation is a common issue in neuromuscular disorders [12], [14]. Hand therapy is needed for 80% of those affected [11].

It is common for physical limitations resulting from a stroke to be associated with post-stroke depression (PSD) [17]. Social isolation and changes in social roles due to PSD make rehabilitation less effective [21], [23]. Indirectly, stroke itself also affects the social dimension, interfering with family dynamics, changing roles and daily routines, and the way stroke survivors engage in family activities and social life [21]. A decline in social networks is common, leading to less social support, which is related to the appearance of depressive symptoms. Physical impairments and increasing depression are, in turn, associated with a low sense of self-efficacy, an important element for the management of stroke that is associated with mobility, balance, and health-related quality of life [28]. A study conducted by Chen *et al.,* [290] aimed to evaluate the impact of social-cognitive factors and motor capability on the use of paretic/hand in stroke survivors in natural environments. The study suggests that, in addition to motor capability, stroke survivors' self-efficacy and momentary social context also influence their paretic arm/hand use behavior. The results of this study propose the development of personalized rehabilitative interventions that target these factors to enhance the effectiveness of rehabilitation programs for stroke survivors [290].

The purpose of this study is to evaluate how a holistic upper limb motor rehabilitation approach that addresses depressive symptoms, social impact, and self-efficacy, influences motor recovery. We use a multi-user interactive table and serious games to address these four domains, allowing stroke survivors to engage in collective therapeutic activities focusing on hand rehabilitation. Games are designed to potentiate social interaction and the sense of positive self-efficacy. A range of objects are utilized to personalize the interaction to each user, facilitating the development of fine and gross motor skills. We expect this approach to potentiate upper limb rehabilitation, reducing depressive symptomatology by increasing social participation and self-efficacy.

6.2. Methods

6.2.1. Experimental Setup

The interactive table setup consists of a PC (OS: Windows 10, CPU: Intel Coffee Lake Core I7-8700K 3.7 GHz 12 MB, RAM: 2x 8GB DDR4 2400 Mhz, Graphics: Gigabyte Nvidia GTX 1070 Ti Gaming 8G GDDR5), a 55" LED TV screen and a 55" infrared multitouch sensitive layer (latency: <15 ms panning, <25 ms touchdown, reporting rate 100 Hz). Additionally, there is an extra screen available for the researcher (Figure 6-1). Attached to the side of the table, there is a structure that holds an Intel RealSense Depth

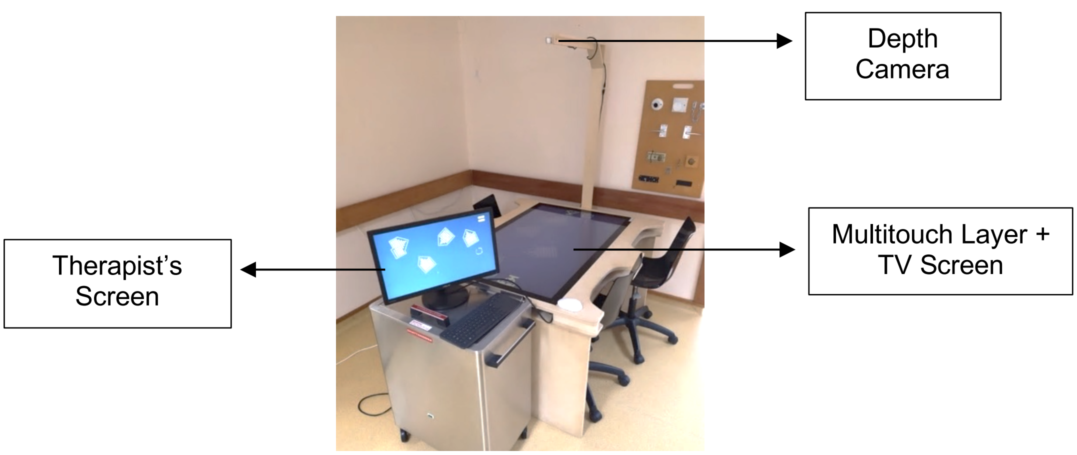


Figure 6-1 - Interactive table and its components.

Camera 435. This camera tracks objects that are used as interfaces. Our custom software, built using the OpenCV library, can detect any number of objects from a predetermined color list. It provides object color values (Hue, Saturation and Value values), center position relative to the camera, area, perimeter, and perimeter coordinate list. The game receives this information via a UDP socket connection. The tracking software requires a previous calibration process to account for changes in lighting conditions. The software applies thresholding operations to each frame using values from calibration to extract BLObs, which are groups of connected pixels in a binary image. Additionally, we developed a perspective calibration procedure to correct image perspective and crop it by selecting the four corners of the display, even when the camera is not perpendicular to the display.

The table accommodates up to four users, two on each side. Adjustable height chairs were provided for non-wheelchair users. A footrest was provided under the table to ensure proper posture while seated. The table has a cut-out of 11 cm height and 49 cm width to allow participants to rest their elbows and improve hand performance [288], [289] while sitting closer to the screen. For the interaction with the interactive table different interfaces were used. All of them were designed not only for interacting with the interactive table, but also as therapeutic devices to improve skills such as grasping and strength. The purpose and materials used for each game are outlined in Table 6-1. The 4 games used are presented in sub-chapter 5.1. All materials have varying levels of resistance and sizes, allowing therapist to choose the most appropriate ones based on participants' skills.

Table 6-1 - Description of each game, including interface and skill-building materials/objects, and the targeted skills. [1]ROM (range of movement).

Games	**Ways of interaction (interfaces) & other objects used**		**Skills**
MI Supermarket	Grasp interfaces		- Lateral, Tripod and Power grasps - Upper limb ROM[1]

	Wrist weight		- Upper limb strength
	Fingers		- Fingers movement individualization - Upper limb ROM
MI Balloon	Fingers		- Fingers movement individualization - Dexterity
MI Tangram	Grasp interfaces with geometric shape basis		- Lateral, Tripod and Power grasps - Upper limb ROM
	Therapeutic putty		- Hand strength
MI Color Catch	Grasp interfaces		- Lateral, Tripod and Power grasps - Upper limb ROM
	Fingers		- Fingers movement individualization - Upper limb ROM
	Wrist weight		- Upper limb strength
	Pinch pins		- Hand strength

6.2.2. Recruitment and Sample

Participants were a convenience sample recruited from two public hospitals in the city of Funchal, and a public Health Center in the city of Caniço, both cities from Madeira Island, Portugal. The single inclusion criterium was to have suffered a stroke. Exclusion criteria included: 1) having no upper limb capacity (<10) or full upper limb capacity (>54) in the ARAT [291]; 2) Score higher than 30 in the Beck Depression Inventory-II (BDI-II) (Severe depression) [292]; 3) Severe aphasia, compromising the understanding of the task (<17 in the Token Test) [226], [254]; 4) Hemi-spatial neglect assessed using the Bells Test [226]; 5) Previous upper limb motor deficits/lesions interfering with upper limb function; 6) History of drugs/alcohol abuse; and 7) Illiteracy. The study was approved by the Ethics Commission of SESARAM (number 24/2018) and was renewed in October 2021. All participants provided written informed consent.

Out of 93 stroke survivors considered for the study, 12 were included (Table 6-2). From the remaining, 76 were excluded due to not meeting the criteria and 5 refused to participate. Our sample comprised 9 males and 3 females, with a mean age of 64.5±10.3 years (range: 49-85), 8.0±7.7 months post-stroke, and 6.4±2.8 years of schooling.

Table 6-2 - Participant's profile - sex (male/female), age, months post-stroke, schooling in years, Montréal Cognitive Assessment (MoCA) scores, Fugl-Meyer Assessment upper extremity scores (FMA-UE), Action Research Arm Test (ARAT) scores, Modified Ashworth Scale (mAS) scores, Beck Inventory Depression – II scores (BDI-II), and Nottingham Sensory Assessment (NSA) for soft touch and pressure touch assessment scores.

PARTICIPANT	SEX (M/F)	AGE	MONTHS POST- STROKE	SCHOOLING (YEARS)	MOCA (0-30)	FM-UE (0-66)	ARAT (0-57)	mAS	BDI-II (0-63)	NSA (HAND)	
										Soft	Pressure
1	M	63	6	6	16	53	48	1	9	2	2
2	M	67	9	4	20	52	34	1+	4	1	1
3	M	61	6	6	17	50	48	0	8	1	2
4	M	66	29	11	27	16	14	3	5	1	1
5	M	69	14	12	18	35	28	1	3	1	1
6	M	49	3	4	28	26	21	1+	26	1	1
7	M	67	2	4	25	41	31	1	11	1	0
8	F	54	12	6	18	45	26	2	0	2	2
9	M	67	1	4	21	51	46	1	2	2	2
10	F	85	2	5	17	44	41	0	4	1	2
11	M	76	6	9	18	33	51	1+	19	1	1
12	F	50	5	6	16	51	27	1	6	2	2

The participants were evaluated for their motor and cognitive abilities using standard clinical scales to characterize the sample. For motor characterization, we used the FMA – Upper Extremity for motor function [255], and the ARAT for hand function [293]. The BBT for gross manual dexterity [256], the Nottingham Sensory Assessment (NSA) for hand tactile sensation, namely soft and touch pressure [294], and at last, the Modified mAS for spasticity [257]. The cognitive characterization was done through the MoCA [206]. In terms of motor function of the upper limb, the sample is varied, with a mean FMA of 41.4±11.6 (range: 16-53) and an ARAT with a mean of 34.6±12 (range: 14-51). Regarding spasticity, 66% of the sample presented a slight increase in muscle tone. The cognitive level averaged 20.1±4.3 (range: 16-28). Regarding depressive symptoms, 75% of the sample scored within the normal range. The remaining 25% had varying degrees of depression, with 1 participant reporting mild mood disturbance, 1 reporting borderline clinical depression, and 1 reporting moderate depression.

6.2.3. Outcome Measures of the Study

The outcome measures chosen aimed to measure the impact of the intervention on motor and functional skills, depressive symptoms, self-efficacy, and social interaction. Additionally, usability and motivation in the use of system were assessed.

Motor skills were assessed using the FMA for upper limb motor function with each item ranging from 0-2 (global score range from 0-66). The ARAT for hand function, with items ranging from 0-3 (global score range from 0-57). The BBT for gross manual dexterity gives the number of cubes moved in 1 minute. The dynamometer measures power grasp strength in kg. The Nine Hole Peg Test (9HPT) measures hand dexterity through the time needed to place 9 objects on the respective holes [295]. A multi-touch app assesses hand mobility, dexterity, and coordination [296]. It comprises several tasks, each one with a respective score: tapping (number of touches in 10 seconds), minimum and maximum area (cm) with five fingers simultaneously and at last an oculo-manual coordination task, that comprises touching the highest number of small circles in 20 seconds. The Reaching Performance Scale in Stroke (RPSS) to assess reaching quality of movement with a close target (1 cm) and far target (30cm), with six different items being assessed from 0-3, resulting on a total score from 0-18 for each target [297].

To evaluate the functional performance, we used the MAL, which assesses both quality and frequency of movements in a scale from 0-5 with intermediate values between all unities. Global score also varies between 0-5 for quality and frequency of movements [298]. We assessed depressive symptoms through the Beck Depression Inventory–II, that comprises 21 questions that range from 0-3, and have a global score that ranges from 0-63 [292]. The sense of self-efficacy was measured with the Stroke Self-efficacy Questionnaire (SSEQ), which is constituted with 13 affirmations, each one measured from 0-10 [299], and a global score that ranges from 0-130. Social interaction was measured with the component 'Social Interaction' from Functional Limitations Profile (FLP). Each of the 20 items have different weights and, but the global score is normalized between 0-100 [300].

Additionally, to measure the usability of the system, we used the Portuguese version of the SUS [258], which has 10 items that range from 1-5, being the global score normalized to 0-100 [259]. Motivation with the intervention was measured through 4 domains of the IMI): Interest/Enjoyment, Perceived Competence, Effort/Importance, and Value/Usefulness [260]. All items sum up to 25, with each one ranging from 0-7.

6.2.4. Experimental Procedure

The experimental procedure consisted of four stages: pre-test assessment, intervention, post-test assessment, and one-month follow-up assessment. After identifying three eligible participants through the recruitment process, pre-test assessments were scheduled. After participants signed the informed consent, measures were administered for characterization (NSAH and MoCA, mAS), characterization and outcome (ARAT, Beck-II, FMA), and only outcome (BBT, Dynamometer, 9HPT, MAL, RPSS, SSEQ, Multitouch-app and FLP). On average, this process took about 120 minutes. Then, the intervention program started, which consisted of three 45-minute sessions per week for four weeks. After the intervention, we conducted a post-test assessment that lasted approximately 90 minutes. We used all the outcome measures used in the pre-test assessment plus the measures addressing the usability of the system (SUS and IMI). One month after intervention, we conducted a 75-minute one-month follow-up assessment using all outcome measures.

6.2.5. Data Analysis

Due to the ordinal nature of measures and non-normal distribution of interval data, assessed through the Shapiro-Wilk test, non-parametric statistical tests were used for all dependent variables. For each dependent variable, values of central tendency and dispersion are provided. Interval types of data are presented through their median and inter-quartile range (Median (IQR)). We used the Friedman's test to detect significant differences across time (pre-test, post-test, and one-month follow-up intervention). When differences were found, pairwise comparisons between pre and post-test, and pre-test and one-month follow-up were applied, with a Bonferroni correction to account for the number of comparisons. After Bonferroni correction, significant differences were only accounted if $p<0.025$. The significance threshold was set at $\alpha=0.05$. Data were analyzed using IBM SPSS Statistics (Version 27).

6.3. Results

6.3.1. Rehabilitation outcomes

We found significant differences across time in FMA ($\chi(2)=17.522$, $p<0.001$), ARAT ($\chi(2)=11.619$, $p=0.003$), BBT ($\chi(2)=12.333$, $p=0.002$), MAL in quality of movement ($\chi(2)=9.282$, $p=0.010$), and RPS in reaching an object distant from the trunk ($\chi(2)=10.294$, $p=0.006$) (Table 6-3). Pairwise comparisons revealed significant differences in FMA between pre and post-test ($Z=-2.489$, $p=0.004$), and between pre-test and one-month follow-up ($Z=-3.061$, $p=0.002$). Regarding ARAT scores, we verified significant differences in the same pairs of variables, namely, between pre and post-test ($Z=-2.706$, $p=0.007$), and between pre-test and one-month follow-up ($Z=-2.807$, $p=0.005$). The same with BBT, between pre and post-test ($Z=-2.807$, $p=0.005$), and between pre-test and one-month follow-up ($Z=-2.706$, $p=0.007$), and MAL regarding the section quality of movement, between pre and post-test ($Z=-2.371$, $p=0.018$), and between pre-test and one-month follow-up ($Z=-2.599$, $p=0.009$). RPS had significant differences between pre-test and one-month follow-up ($Z=-2.444$, $p=0.015$) (Table 6-3).

Table 6-3 -Statistical results for the main outcome measures. Median and Interquartile range (Mdn (IQR) from all outcome measures for pre-test, post-test and one-month follow-up. Results from Friedman's test

(Chi-square (χ(2)) and p-Value) for between-groups comparison, and the respective results from Wilcoxon signed-rank test for pairwise comparison (Z, p-Value).

Outcome measures	*Pre-test*	*Post-test*	*One-month follow-up*	*Effect across time*	*Pairwise comparisons*	
	Mdn (IQR)	*Mdn (IQR)*	*Mdn (IQR)*	χ(2) , *p-Value*	**Pre-test Vs Post-test** *Z , p-Value*	**Pre-test Vs one-month follow-up** *Z , p-Value*
FMA	44.50 (17.50)	50.00 (19.75)	53.50 (35.25)	**17.522, <0.001**	**-2.489, 0.004**	**-3.061, 0.002**
ARAT	32.50 (21.25)	40.50 (26)	33.50 (25)	**11.619, 0.003**	**-2.706, 0.007**	**-2.807, 0.005**
MAL (Quality)	0.73 (1.27)	0.84 (1.10)	1.02 (1.25)	**9.282, 0.010**	**-2.371, 0.018**	**-2.599, 0.009**
MAL (Frequency)	0.85 (1.33)	1.00 (1.53)	1.19 (1.26)	2.737, 0.255	-----	-----
BBT	15.50 (12.25)	19.50 (15.25)	20.50 (17.00)	**12.333, 0.002**	**-2.807, 0.005**	**-2.706, 0.007**
RPS (Distant)	13.50 (5.25)	15.00 (4.25)	15.50 (4.75)	**10.294, 0.006**	-2.228, 0.026	**-2.444, 0.015**
RPS (Close)	14.50 (4.75)	15.50 (3.75)	16.50 (2.00)	**8.968, 0.011**	-2.220, 0.026	-1.906, 0.057
9HPT	122 (78.5)	56 (16.5)	43 (59)	**8.400, 0.015**	-2.023, 0.043	-2.023, 0.043
Dynamometer	7.20 (6.65)	7.20 (10.15)	7.90 (10.60)	4.000, 0.135	-----	-----
Multitouch app - Tapping	23 (14)	27 (19)	31 (19)	4.051, 0.132	-----	-----
Multitouch app – Hand opening minimum	2.10 (2.43)	2.00 (0.80)	2.00 (0.13)	0.800, 0.670	-----	-----
Multitouch app – Hand opening maximum	80.45 (16.30)	81.60 (41.52)	80.60 (37.13)	2.600, 0.273	-----	-----
Multitouch app – Oculomanual coordination	7 (8)	12 (7)	11 (8)	4.429, 0.109	-----	-----
BDI-II	5.50 (7.25)	7.00 (10.75)	5.00 (11.25)	0.933, 0.627	-----	-----
FLP	21.20 (21.50)	18.75 (32.25)	21.00 (35.98)	0.194, 0.908	-----	-----
SSEQ	82.5 (49.0)	85.0 (48.0)	92.5 (68.5)	2.085, 0.353	-----	-----

6.3.2. Motivation and systems’ usability

Regarding motivation, the overall score in the IMI was 5.77 ± 0.72 out of 7. The results showed that users found the system to be highly interesting and enjoyable (6.40 ± 0.73), while also having a positive sense of competence (5.51 ± 0.89). The users showed good levels of effort and importance in using the system (5.82 ± 1.15) and found it highly valuable and useful (6.18 ± 0.76). In terms of usability, the SUS score ranged from 60 to 100 out of 100, with a mean score of 77.5 ± 11.1, which is considered "good" (80-85 percentile) [261].

6.4. Discussion

Here we present the results of a study that evaluates the feasibility of an upper limb rehabilitation approach that takes addresses social impact and self-efficacy to reduce depressive symptomatology and in turn, improve motor recovery. Using different outcome measures, we analyzed the impact of our approach on upper limb motor skills, including hand dexterity and coordination, upper limb range of motion, functional performance, depressive symptoms, self-efficacy, and social interaction. We also evaluated the system's usability and how participants perceived it regarding Interest/Enjoyment, Perceived Competence, Effort/Importance, and Value/Usefulness.

6.4.1. Rehabilitation outcomes

The intervention significantly improved all motor outcome measures except for the dynamometer and 9HPT. FMA and BBT scores were significantly different in pre-test vs post-test and pre-test vs one-month follow-up comparisons. We observed that the difference between post-test and pre-test is greater than the difference between post-test and one-month follow-up. The reduction in the speed of recovery potentially indicates that using the interactive table has positively affected motor recovery range of motion and the ability to grasp and release objects. This is supported by the fact that the range of movement is an important component of the FMA assessment [301], while gross manual dexterity and coordination is the focus of BBT [256], which is demonstrated by the ability to grasp and release cubes from one compartment to another. Manipulating the interfaces on the interactive table while performing the serious games was used to train grasping and release skills repeatedly. This suggests that our approach had a direct impact on these skills. To specifically measure the impact of the system with fine motricity skills, we chose ARAT. Concomitantly, it appears that ARAT results show a similar slower pace of rehabilitation after the intervention. These results are very interesting for our rehabilitation system, as they show its potential to intervene in both global and fine motor skills. We selected MAL to evaluate the effectiveness of our rehabilitation method in terms of its functional impact, i.e., the transference to everyday behaviors. From the participant's perspective, significant differences were found in the quality of movement.

Results with RPS showed that the only significant differences were observed between the pre-test and one-month follow-up comparison, and specifically just for distant reach. This result suggests that our approach was not specific enough to cause changes in reaching. This may be due to the design of serious games, which promote action in random places on the screen with almost no therapist control. Additionally, the games allowed participants to choose when to reach an object, making it easier to perform most of the time. According to Toney *et al*., there was a tendency for actions to occur in the "comfortable screen area" [302], which did not challenge participants and, therefore, did not promote improvements in this area. Therefore, having more control over the areas where participants interact could potentially have led to better results in reaching.

We have only come across one study that utilized a tabletop surface display integrated with tangible interfaces for motor rehabilitation purposes with stroke survivors [240]. Their rehabilitation protocol has much in common with ours, including similarities in the system and target population. They also have a similar therapy dosage, consisting of three weekly sessions, each lasting 30-40 minutes, for four weeks. The sample size in the group that used a combination of VR and conventional therapy was 10. They had a set of 7 different tasks, some similar, only more complex. They also used the BBT as their only outcome measure, which we also used [240]. The results regarding this outcome are similar to ours in terms of variability. In our study, the variability increased by 4 points from the pre-test to the post-test, while it increased by 17 points in their study. However, the variability remained relatively stable from post-test to follow-up, increasing by only one point in both studies.

No differences were found in terms of power grasp strength through the dynamometer. This can be due to the specificity of movements required to shape therapeutic putty, which naturally was to use a lateral grasp to stretch it and shape it to the intended shape. We believe that using a pinch meter would have been more adequate.

Although we did not directly address depressive symptoms, we expected to see a reduction in them due to our implementation of strategies to promote self-efficacy and social interaction. However, the results indicate a higher median score in the post-test (a higher score means an increase in depressive symptoms) compared to the pre-test but a lower median score in the one-month follow-up. If we compare the medians of social interaction and self-efficacy, we can see that social interaction exhibited a similar pattern to depressive symptoms, while self-efficacy increased in the post-test and again at the one-month follow-up. Based on our observations, we have found that follow-up procedures tend to yield better outcomes in this aspect. This can be attributed to the fact that almost half of the participants started the study while hospitalized and were discharged between the post-test and one-month follow-up [303]. If we look at the literature, Rogers *et al*., [240], who used a similar rehabilitation protocol, report a significant reduction in depression using a subscale from *Neurobehavioural Functioning Inventory*.

Regarding group management and rehabilitation delivery, the therapist found it very demanding to properly support the participants and manage the systems simultaneously. If there is a chance, the elements should be chosen based on their personality, cognitive level and functional level [183], [304].

6.4.2. Motivation and system usability

Results from IMI were extremely positive, with participants considering this rehabilitation system very interesting and enjoyable (6.40 out of 7) but also very valuable and useful (6.18 out of 7). Levels of effort and importance attributed to the system for their rehabilitation are interesting (5.82 out of 7), as is the reported sense of competence (5.82 out of 7). It is important to have a high score in this aspect as it can positively impact the participant's self-efficacy during rehabilitation. A study that used a VR-based collaborative exergame on a virtual tabletop with elderly who had experienced some reduction in their physical strength due to physical inactivity, and compared collaborative with single-playing, reported less 0.52 points of enjoyment (5.84) compared to our study, more 0.06 points of usefulness and more 0.29 points of effort using the system [305]. In terms of usability, they report a mean score of 83.75 ± 13.3. Their system received a slightly higher score of 6.25 out of 100 when compared to ours. Moreover, their system lacks the ability to allow for direct interaction or to use tangible interfaces to interact with the game, which is a feature that our system has. We believe that this aspect adds more value to their SUS score, because, according to Khademi *et al*. [138], the lack of direct interaction makes the interaction harder. On the other hand, it is important to note that our system was not designed to be used independently, and always requires the therapist to control and adapt the games. As a result, the final System Usability Scale score may have been affected, as at least two items on the scale are assess the independent use of the tool.

6.4.3. Limitations

The primary constraint of this study is the limited number of participants, what restricts the generalization of the results to a broader population. Moreover, the sample is not balanced sex wise (3 females, 9 males), although stroke is more prevalent in men [306]. Another important limitation is not having a control group, which limits the efficacy evaluation of the proposed rehabilitation approach. Regarding assessments, the initial plan was to use the multitouch app to evaluate the impact of rehabilitation on finger isolation, as it is a crucial skill trained on Mi Balloon. While collecting this data, several issues were encountered. Some participants had difficulty touching the right place with their fingers, resulting in fewer touches being counted than were actually made. Furthermore, the task was quite challenging, with only 7 participants successfully completing it, reasons why we excluded it from the analysis. Regarding strength assessment, using a pinch meter instead of a dynamometer to measure strength changes would have been more appropriate since the movement required to shape therapeutic putty in the game was naturally a lateral grasp. Regarding the efficacy and replicability of the system, due to the subjectivity of the therapist who manages rehabilitation, replicating this study is difficult, given the dependency of success on how serious games and interfaces are used. Finally, it is important to identify the impact of different serious games on specific skills. This will optimize their efficacy and assist therapists in selecting the appropriate tool.

6.5. Conclusions

This study assesses the feasibility of an approach for upper limb rehabilitation with stroke patients based on different constructs. We proposed addressing issues that affect motor rehabilitation outcomes, such as depressive symptoms, social interaction, and the sense of self-efficacy, through group rehabilitation sessions with an interactive table that utilizes custom-designed serious games and tangible interfaces specifically created to enhance various hand grasps. Participants reported high enjoyment and interest in the system, considered it valuable and useful, and reported increased levels of competence and effort put into their performance. The usability of the system was considered ‘’good’’. Significant differences were found in several motor outcomes, such as FMA, ARAT, BBT, RPS (with distant object), and MAL (regarding the quality of movement). No significant differences were found regarding depressive symptoms, sense of self-efficacy, and social interaction. To conclude, our results suggest that the participants accepted and appreciated the proposed approach but also indicate a positive impact on motor rehabilitation when used alongside conventional rehabilitation. To ensure that the results can be applied to a larger population, it is necessary to conduct additional tests with larger sample sizes and compared the results against traditional rehabilitation.

Chapter 7. Conclusions

This chapter discusses the most relevant aspects of the thesis. A summary is provided for each chapter, discussing findings and contributions to the state of the art for a comprehensive overview of our approach. Limitations regarding the software development and field studies are also described. Finally, this section synthesizes future research directions for group motor rehabilitation using serious games with stroke survivors in an interactive table setting.

7.1. Main Findings and Contributions

Health practitioners face daily challenges in maintaining effectiveness in their practice. Every person who experiences functional loss aims to recover their ability to perform daily occupations. After a stroke, it is not common to experience complete and sudden recovery within a few days or weeks. Symptoms or complications may persist for weeks or even years after the stroke event. It is important to note that stroke affects each individual uniquely in terms of severity and impacted abilities. Due to motor or cognitive deficits from stroke, these individuals undergo significant life changes. These deficits contribute to other deficits, such as social isolation, role changes, loss of autonomy, and decreased self-efficacy, which are correlated with depressive symptoms [24]–[27]. Hence, it is important to address not only the motor deficits after a stroke, which are the most obvious, but also other secondary symptoms that may arise. Focusing solely on motor rehabilitation is insufficient as there is an interdependency between several symptoms. Implementing an effective motor stroke rehabilitation program is a complex and challenging task, not only because of this interdependency of factors but also because every stroke survivor has unique characteristics, such as age, previous health status, comorbidities, interests, and other personal specificities that need to be considered. Additionally, stroke can affect different brain areas with varying impacts, making it a condition with endless particularities.

Upon reflection, we could easily conclude that one-to-one intervention is already complex, and that intervention in a group setting would be too overwhelming and, therefore, not a good option. However, group rehabilitation offers many benefits, and our results provide evidence that it should be considered, at the very least, as an additional option to one-to-one rehabilitation due to several psychosocial advantages. Group rehabilitation provides opportunities for social interaction that can be fostered by the therapist and the therapeutical tools being used. Simultaneously, it decreases social isolation and boredom [307]. Moreover, participating in such activities provides individuals with the opportunity to connect with others who are facing similar challenges. This often results in mutual support and empathy among participants, which can be beneficial. Additionally, building relationships with peers enables individuals to compare themselves with others, and this can provide greater insight into their own potential [307]. At the same time, it is a way to foster their sense of self-efficacy, through the observation of others performance, verbal persuasion and encouragement [308]. Our research approach aims to improve upper limb motor function while addressing its relationship with depressive symptoms, social impact, and self-efficacy using a multi-user interactive table with a range of serious games to cover these four domains. We have demonstrated the potential of this paradigm to promote motivation, social interaction, and self-efficacy, leading to better rehabilitation adherence and improved motor rehabilitation outcomes.

Three research questions guided our research (see section 1.2), which we answer below following the results obtained in this thesis.

RQ1: Are there significant differences in engagement and social involvement between three game modes: competitive, co-active, and collaborative?

Our results showed the Collaborative mode to be the more balanced game mode in terms of engagement and social involvement. Both with elderly and a stroke sample, it was the game mode that significantly promoted more social involvement. Regarding engagement, the Collaborative and the Competitive modes promoted significantly more engagement than the Co-active, but not significantly different between them. The collaborative mode was also shown to be more cognitively demanding, which shall be considered if participants have significant cognitive deficits. These results were important as they directed us in how to approach/design serious games for group settings.

RQ2: What types of objects and task mechanics are more adequate to be used for rehabilitation according to patients' levels of impairment?

Shapes with cylindric and rectangular shapes showed to be feasible to promote power, lateral and tripod grasp. Depending on the size of the objects, some mechanics have shown to be more adequate to be used with. The strength materials used also had satisfactory levels of enjoyment. The software used to track objects proved to be reliable. Aspects that interfere with the usability of the objects and the system were identified, such as the need to calibrate the interaction space, consider the objects affordance and implement strategies to diminish the incidence of hand occlusions. Additional findings about the reach distance on the ipsilateral side allowed us to previously identify the better location on the table for the participants during the intervention. Lastly, the wrist range of movement seems to be a good indicator to predict the object size used by the participant without eliciting abnormal movement patterns.

RQ3: Does the proposed rehabilitation methodology result in improved motor recovery?

Results showed significant differences in 5 different motor outcomes, namely FMA, ARAT, BBT, RPS (with distant object), and MAL (regarding quality of movement), when using the approach concomitantly with conventional therapy.

The rehabilitation tool we developed resulted from comprehensive studies that informed our decision-making process and that individually also represent relevant contributions to the field, which are summarized in Table *7-1*.

Table 7-1 - Summary of main findings and contributions organized by thesis sections.

Chapter	Subsection	Main Findings/Contributions
Chapter 3 – Impact of game modes	- Motivation/engagement - Social involvement/interaction	• Collaborative (Collab) mode better impacts social involvement compared to Competitive (Comp) and Co-active (Co-act) • Collab mode more cognitively demanding compared to Comp and Co-act • Collab mode tends to have better results with participants with a more empathic profile, more behaviorally involved, and preserved cognitive skills • Not significant differences in engagement, flow and challenge between the Collab and Comp modes • Comp mode favours participants with better cognitive and motor skills • Co-active mode favours participants with less skills
Chapter 4 – Interfaces and Serious games	- Tangible interfaces/tracking	• Freely available software developed for tracking size of objects through color (CTPro) (Developed by Rúben Ornelas) • Research on properties of object in terms of usability and feasibility for object tracking • Development of personalized interfaces for grasping (lateral grasp, power grasp, and tripod)

	- Task mechanics feasibility	• Research on task mechanics feasibility for top-down tangible interaction and identification of their challenges, potentialities, and needed improvements
Chapter 5 – Interactive table development	- Interactive table construction	• Designed a group rehabilitation table up to 4 participants using a with touch-based screen and top-down object tracking for interaction, plus an auxiliary screen for therapist.
	- Serious games design	• Set of 4 collaborative serious games (Developed by Fábio Pereira and Rodrigo Lima) • Serious-games able to be used for group while allowing individual difficulty personalization • Implementation of mechanics to promote motivation, social interaction, and self-efficacy
Chapter 6 – Interactive table pilot	- Pilot study evaluation	• Impact of the proposed approach on motor outcomes (Fugl-meyer Assessment, Action Research Arm test, Box&Blocks test, Reaching Performance Scale, and Motor Actvity Log), with maintenance 1-month follow-up.

7.2. Limitations

7.2.1. Software Design

Four serious games were designed for motor rehabilitation, but their development posed challenges. We believe that the proposed approach relies significantly on them. Annet *et al.,* [309] corroborate this belief, as they suggest that the success of technology-assisted rehabilitation is heavily influenced by the design of the activity rather than solely relying on the use of technology. It would significantly enhance their quality if we could allocate additional resources and time toward developing games. We planned to previously test the games regarding their impact on social interaction and sense of self-efficacy, as they were two factors that were being tested as influencing motor outcomes. However, we could not iterate the games due to time constraints. Instead, we focused on eliminating game bugs through several internal iterations to ensure they would not cause problems when collecting data.

The serious games could have been better personalized to participants based on interests, difficulty, and skill specificity. Mi Balloon was the game that we think should be taken as a good example of personalization in terms of difficulty and skill specificity. This game offers an interface that enables therapists to customize the game's difficulty level for each participant. Moreover, therapists can choose different skills to train with each participant while playing the same game, thus enhancing the specificity of the training for each participant. The only thing lacking is the ability to customize according to the interests of the participants. However, we could compensate for the lack of personalization in other games by adjusting the tangible interface, influencing the difficulty level and training specificity.

As a conclusion, the serious games, besides being designed to be good for specific goals, were developed with a focus solely on research goals, resulting in unrefined software in terms of user interface and versatility. Also, the fact they were designed to be used by the person who developed them without external interactions can lead to some limitations, such as usability difficulties faced by people unfamiliar with the software. To make these games suitable for clinicians, user interfaces should be redesigned to be more user-friendly, and natural improvements to the games should be progressively implemented as long they are tested by other clinicians and users.

7.2.2. Recruitment and Research Process

As we conducted our research on a small island with a population of ≈250,000 inhabitants, we faced difficulties recruiting sufficient stroke survivors for our studies. Besides this, we chose to implement strict exclusion criteria to guarantee the best quality possible for our research protocols. Overall, we approached 523 individuals, of which 468 were stroke survivors. Of the studies that included stroke survivors only, 368 potential participants were excluded because of not meeting inclusion criteria and 35 refused to participate. Finally, 55 agreed to participate. Takin into consideration the challenges regarding recruitment, we had to compromise between the number of participants to enroll and the time needed to collect the initially planned data.

For our pilot study study in particular, we had a small sample size of 12 participants, which limited the outreach of our results and their generalization. Moreover, we had to make significant changes to the study's design due to recruitment difficulties. Originally, the study was planned with one intervention group and one control group, each consisting of at least 21 participants. However, in the first 6 months of our study, we could only arrange 2 groups for data collection. Therefore, we realized that to achieve our goals, we needed to change the study design without losing the data we had already collected.

As a result, we decided to abandon the control group and focus on a pilot study. We were able to collect data from 2 more groups of participants as part of the pilot study.

Finally, throughout the studies we presented, we noticed we should have systematically collected qualitative data regarding the participants' input about the systems we tested. Incorporating this type of data would have been valuable for supporting our results and better understand the user's perspective. It is important to note that the rehabilitation system being developed relies heavily on human interaction, making the inclusion of participants' input even more crucial.

7.3. Future Work

Future work mainly involves software, specifically improving and developing the serious games to enhance their effectiveness:

- It is important to improve the specificity of skills trained by each serious game individually, allowing for more specialization in the realm of serious games. As mentioned in previous chapters, serious games already have some specialization in terms of the skills they aim to train. However, these games can be further refined to increase their specificity and effectiveness. This would also assist therapists in selecting the most appropriate tool for their needs.

- Serious games should be more customizable to match the interests of the participants. Facilitating participant interest in a game can be achieved through allowing participant to choose colors, characters, backgrounds or even his/her name on the game.

- Implement different strategies to enhance self-efficacy, such as feedback (audio, verbal, visual), progress trackers, points, bonuses, mini-games, challenges, quests, badges, virtual goods, leaderboards, and rewards that include color, power, achievements and levels.

- Initially, we did not consider the cooperative game mode because it requires players to have different roles, while the modes we chose to compare (competitive, collaborative, and co-active) all involve players having the same role. However, having different roles can actually be beneficial for rehabilitation settings. This is because participants with varying levels of skills can be assigned roles that are best suited to them.

- We think the games should take into consideration a number of aspects that were not addressed. For example, stroke patients may have visual perceptual deficits. To address this issue, we need to focus on answering the following research questions. Does distance and body positioning affect the perception of visual cues on table-top surfaces? What is the optimal distance for a stroke survivor to interact with objects on a shared table-top surface? Lastly, which visual cues should be used, where and how, on table-top surfaces to encourage social interaction between users?

- When participants are involved and motivated in a serious game with scores, we observed that they tend to cheat to score more, if their performance is being affected by their motor/cognitive difficulties. Although participants want the best for themselves, they may cheat to achieve a better score or avoid failure in front of other players. Cheating may seem from their perspective like a good short-term solution, as it can help them avoid failure or guarantee happiness for a good score without apparent consequences. However, cheating is not in their best interest in terms of rehabilitation. If the therapist-to-patient ratio is 1:3 or more, it becomes difficult for the therapist to prevent cheating. Thus, strategies should be researched to prevent this behavior.

- Serious games can provide a wealth of valuable data for both therapists and researchers. It is crucial to establish methods for collecting and processing this data to support therapists' decisions, increase the game's autonomy in adapting to real-time challenges, inform participants about their performance, and ultimately help researchers make informed decisions based on collected data. Proper implementation of these strategies can greatly benefit the efficacy of serious games as a therapeutic and research tool.

- The use of tangible interfaces and objects for skill training should be diversified based on specific skills, exploring alternative solutions.

List of Selected Publications

Chapter 3

***F. Pereira**, S. Bermúdez i Badia, R. Ornelas, and M. S. Cameirão, "Impact of game mode in multi-user serious games for upper limb rehabilitation: a within-person randomized trial on engagement and social involvement," J Neuroeng Rehabil, vol. 16, no. 1, p. 109, 2019, doi: 10.1186/s12984-019-0578-9,* (see sub-section 3.1)

Contributions: FP, SBB and MSC designed the study. RO developed the software. FP recruited the participants. FP and RO collected the data. FP performed the data analysis. FP, SBB and MSC interpreted the results.

***F. Pereira**, S. Bermúdez i Badia, C. Jorge, and M. S. Cameirão, "The use of game modes to promote engagement and social involvement in multi-user serious games: a within-person randomized trial with stroke survivors," J Neuroeng Rehabil, vol. 18, no. 1, 2021, doi: 10.1186/s12984-021-00853-z, (*see sub-section 3.2)

Contributions: FP, SBB, and MSC designed the study. Yuri Almeida developed the software. CJ recruited the participants. FP and CJ collected the data. FP performed the data analysis. FP, SBB, and MSC interpreted the results.

This study was also published with preliminary data:

***F. Pereira**, S. Bermúdez i Badia, C. Jorge, and M. S. Cameirão, "Impact of Game Mode on Engagement and Social Involvement in Multi-User Serious Games with Stroke Patients," International Conference on Virtual Rehabilitation 2019, Tel Aviv, Israel*

Chapter 4

***F. Pereira**, S. Bermúdez i Badia, R. Ornelas, and M. S. Cameirão, "Feasibility, Usability and Engagement of a Tangible Interface for Upper Limb Rehabilitation after Stroke," submitted,* (see sub-chapter 4.1)

Contributions: FP, SBB, and MSC designed the study. RO developed the software. FP prepared the hardware and materials. FP recruited the participants. FP and RO collected the data. FP performed the data analysis. FP, SBB, and MSC interpreted the results.

This study was also published with preliminary data:

***F. Pereira**, S. Bermúdez i Badia, R. Ornelas, and M. S. Cameirão, "Exploring Materials and Objects Properties in an Interactive Tangible System for Upper Limb Rehabilitation,"* International Conference on Disability Virtual Reality and Associated Technologies 2018. Nottingham, United Kingdom **(Best Student Paper Award)**

***F. Pereira**, A. Fernandes, C. Coelho, "Impact of distance and object size on reach and grasp in stroke," submitted.* (see sub-chapter 4.2)

Contributions: FP, AF, and CC designed the study. FP and CC prepared the material for the setup. CC recruited the participants. CC collected data. AF performed the data analysis. FP and AF interpreted the results.

Chapter 6

***F. Pereira**, S. Bermúdez i Badia, R. Ornelas, and M. S. Cameirão,* "The impact of a group motor rehabilitation protocol enhanced by social interaction and self-efficacy - a pilot study," submitted. (see Chapter 6)

Contributions: FP, SBB, and MSC designed the study. FP recruited the participants. FP collected data. FP performed the data analysis. FP, SBB, and MSC interpreted the results.

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Appendix A.

Motor Assessment Tools

- Fugl-Meyer Assessment – Upper Extremity
- Reaching Performance Scale in Stroke
- Motor Activity Log
- Box & Blocks – Dynamometer – 9 hole peg test
- Action Research Arm Test
- Modified Ashworth Scale
- Stroke Upper Limb Capacity Scale

SPECS-IUA, Universitat Pompeu Fabra

Evaluation Stage:	Date:
Subject:	
Hist nr.:	

FUGL-MEYER ASSESSMENT

Motor Function UPPER EXTREMITY (66 points)

A- SHOULDER/ ELBOW/ FOREARM	
I. REFLEX ACTIVITY	
Flexors - Biceps and finger flexion reflex	
Extensors – Triceps reflex	
II. a. FLEXOR SYNERGY	
Shoulder retraction	
Shoulder elevation	
Shoulder abduction	
Shoulder external rotation	
Elbow flexion	
Forearm supination	
II. b. EXTENSOR SYNERGY	
Shoulder adduction/ internal rotation	
Elbow extension	
Forearm pronation	
III.	
Hand movement to lumbar spine	
Shoulder flexion 0-90º	
Forearm supination/ pronation (elbow at 90º, shoulder at 0º)	
IV.	
Shoulder abduction 0º-90º	
Shoulder flexion 90º-180º	
Forearm supination/ pronation (elbow at 0º)	
V. NORMAL REFLEX ACTIVITY	
Biceps, triceps and finger flexors reflexes	
B- WRIST	
Wrist stability with elbow at 90º (wrist extension against resistance)	

A.I
0: no reflex activity
2: reflex activity in flexors/ extensors
Max score in I: 4 points

A.II
0: cannot perform
1: performs partially
2: performs fully
Max score in II: 18 points

A.III
Hand move to lumbar spine
0: cannot perform
1: hand passes the anterior-superior iliac spine
2: performs fully
Shoulder flexion
0: cannot perform, or at the beginning of the movement the arm is already abducted or the elbow flexed
1: in a later phase of the movement, shoulder abduction or elbow flexion occurs
2: performs fully
Forearm supination/ pronation
0: cannot perform, or correct position of the shoulder and the elbow cannot be obtained
1: active supination/ pronation in a limited range, but with shoulder and elbow well positioned
2: performs fully
Max score in III: 6 points

A.IV
Shoulder abduction
0: cannot perform, or at the beginning the elbow is already flexed or forearm is deviated from pronated position
1: performs partially, or during the motion the elbow is flexed
2: performs fully
Shoulder flexion
0: cannot perform, or at the beginning of the movement the arm is already abducted or the elbow flexed
1: in a later phase of the movement, shoulder abduction or elbow flexion occurs
2: performs fully
Forearm supination/ pronation
0: cannot perform, or correct position of the shoulder and the elbow cannot be obtained
1: active supination/ pronation in a limited range, but with shoulder and elbow well positioned
2: performs fully
Max score in IV: 6 points

A.V
Performed only if score = 6 in stage IV
0: at least 2 of the 3 phasic reflexes are markedly hyperactive
1: one reflex markedly hyperactive or at least 2 reflexes lively
2: no more than one reflex lively and no reflexes markedly hyperactive
Max score in V: 2 points

Fugl-Meyer AR, Jaasko L, Leyman I, Olsson S, Steglind S (1975) The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. Scand J Rehabil Med 7: 13-31

Wrist flexion/ extension with elbow at 90º	
Wrist stability with elbow at 0º (wrist extension against resistance)	
Wrist flexion/ extension with elbow at 0º	
Wrist circumduction	
C- HAND	
Fingers mass flexion	
Fingers mass extension	
Grasp a (extension of mcp joints and flexion of proximal and distal joints)	
Grasp b (thumb adduction, paper interposed)	
Grasp c (thumb opposition against the second finger, pencil interposed)	
Grasp d (cylinder)	
Grasp e (tennis ball)	
D- COORDINATION/ SPEED	
Finger-to-nose tremor	
Finger-to-nose dysmetria	
Finger-to-nose speed	
TOTAL	

B

Elbow 90º - wrist stability
0: no dorsiflexion of the wrist
1: dorsiflexion can be performed but no resistance can be taken
2: performs fully
Elbow 90º - wrist flexion/ extension
0: cannot perform
1: performs partially
2: performs fully
Elbow 0º - wrist stability
0: no dorsiflexion of the wrist
1: dorsiflexion can be performed but no resistance can be taken
2: performs fully
Elbow 0º - wrist flexion/ extension
0: cannot perform
1: performs partially
2: performs fully
Circumduction
0: cannot perform
1: jerky motion or incomplete circumduction
2: performs fully
Max score in B: 10 points

C

Finger mass flexion
0: no flexion
1: some, but no full active finger flexion
2: full active flexion
Finger mass extension
0: no extension
1: some, but no full active finger extension
2: full active extension
Grasp a
0: the position cannot be acquired
1: the grasp is weak
2: the grasp can be maintained against resistance
Grasp b-e
0: cannot perform
1: object kept in place but not against a slight tug
2: object is held well against a tug
Max score in C: 14 points

D

Tremor
0: marked tremor
1: slight tremor
2: no tremor
Dysmetria
0: pronounced or unsystematic dysmetria
1: slight and systematic dysmetria
2: no dysmetria
Speed
0: the task repeated 5 times is at least 6 seconds slower on the affected side
1: 2 to 5 seconds slower on the affected side
2: less than 2 seconds difference
Max score in D: 6 points

Fugl-Meyer AR, Jaasko L, Leyman I, Olsson S, Steglind S (1975) The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. Scand J Rehabil Med 7: 13-31

***Reaching Performance Scale for Stroke – RPSS* versão português do Brasil**

(Escala de Desempenho do Alcance pós-AVE)

1. Deslocamento do Tronco	
Alvo Perto	**Alvo Longe**
3. Nenhum ou quase nenhum deslocamento do tronco para frente. 2. Pequeno deslocamento do tronco (flexão, rotação ou flexão acompanhada por rotação). 1. Mais da metade do movimento é feito pelo tronco. 0. A tarefa é realizada somente pelo deslocamento do tronco para frente.	3. Deslocamento apropriado do tronco para frente em relação a quantidade de extensão do cotovelo. 2. Deslocamento excessivo do tronco relacionado à limitação do movimento ativo do cotovelo ou do ombro. 1. Deslocamento excessivo do tronco: cerca de metade do deslocamento da mão em direção ao alvo é realizado pelo tronco, mas a mão chega no alvo. 0. Deslocamento excessivo do tronco: mais de três quartos do deslocamento da mão até o alvo é realizado pelo tronco, e a mão não chega até o alvo.
Suavidade do movimento [a]	
vo Perto	**vo Longe**
A combinação do movimento do braço e do tronco é fluida e suave. Mais de um movimento do braço é feito para realizar a tarefa, ou o movimento é segmentado (não suave). Vários pequenos movimentos do braço e do tronco são feitos de maneira sequencial. Não há combinação (segmentação completa) do movimento do tronco e do braço.	A combinação do movimento do braço e do tronco é fluida e suave. Mais de um movimento do braço é feito para realizar a tarefa, ou o movimento é segmentado (não suave). Vários pequenos movimentos do braço e do tronco são feitos de maneira sequencial. Não há combinação (segmentação completa) do movimento do tronco e do braço.
3. Movimentos do ombro	
Alvo Perto	**Alvo Longe**
Flexão e adução horizontal do ombro adequadas com elevação escapular para realizar a tarefa. Flexão e adução horizontal do ombro ocorrem com excessiva elevação escapular. Flexão do ombro ocorre somente em combinação com elevação escapular excessiva. Adução horizontal do ombro está diminuída (abdução presente). Nenhuma ou quase nenhuma flexão e adução horizontal do ombro são possíveis (todo o movimento é feito pela escápula).	Flexão e adução horizontal do ombro adequadas com protração e elevação escapular para realizar a tarefa. Flexão e adução horizontal do ombro ocorrem com excessiva protração ou elevação escapular. Flexão de ombro é combinada com elevação escapular. Adução horizontal do ombro está diminuída (abdução presente). Nenhuma ou quase nenhuma flexão e adução horizontal do ombro são possíveis (todo o movimento é feito pela escápula).
4. Movimentos do cotovelo	
Alvo Perto	**Alvo Longe**

A extensão da mão até o alvo é atribuída principalmente à extensão do cotovelo. Mais da metade do movimento de alcance é atribuído à extensão do cotovelo. Menos da metade do movimento de alcance é atribuído à extensão do cotovelo. Não ocorre extensão do cotovelo.	A extensão do cotovelo é quase completa. Mais da metade do movimento de alcance é atribuído à extensão do cotovelo. Menos da metade do movimento de alcance é atribuído à extensão do cotovelo. Não ocorre extensão do cotovelo.
5. Preensão	
Alvo Perto	**Alvo Longe**
Abertura e fechamento da mão adequados para a realização da tarefa. Abertura ou relaxamento da mão é difícil. Uso de estratégias de preensão compensatórias (ex. engancha os dedos ao redor do cone utilizando-o para auxiliar e desliza de cima para baixo no cone). A preensão do cone não é possível.	Abertura e fechamento da mão adequados para a realização da tarefa. Abertura ou relaxamento da mão é difícil. Uso de estratégias de preensão compensatórias (ex. engancha os dedos ao redor do cone utilizando-o para auxiliar e desliza de cima para baixo no cone). A preensão do cone não é possível.
Pontuação Global	
Alvo Perto	**Alvo Longe**
3. A tarefa pode ser feita com facilidade, com ou sem leve tremor ou dismetria, seguido por uma trajetória suave e direta. 2. A tarefa é feita com a presença de tremor, dismetria, pequenos movimentos bruscos, trajetória em forma de arco, ou segmentação. Preensão é possível, mas pode ser modificada ou difícil. 1. A tarefa é feita parcialmente (mais de 50%), ou com modificação (como estabilização do cone, deslizando o cone em cima da mesa, modificação da altura da mesa, diminuição da distância do cone). Preensão pode estar ausente. 0. Menos da metade da tarefa é realizada apesar das modificações.	3. A tarefa pode ser feita facilmente, com ou sem leve tremor ou dismetria, seguido por uma trajetória suave e direta. 2. A tarefa é feita com a presença de tremor, dismetria, pequenos movimentos bruscos, trajetória em forma de arco, ou segmentação. Preensão é possível, mas pode ser modificada ou difícil 1. A tarefa é feita parcialmente (mais de 50%), ou com modificação (como estabilização do cone, deslizando o cone em cima da mesa, modificação da altura da mesa, diminuição da distância do cone). Preensão pode estar ausente. 0. Menos da metade da tarefa é realizada apesar das modificações.

Total alvo perto: _______ (máximo 18 pontos) Total alvo longe:_______ (máximo 18 pontos)

TOTAL GERAL: _______ (máximo 36 pontos)

[a]*Exclui a avaliação do tremor (movimentos rítmicos de frequência constante) ou dismetria (inacurácia ao tocar o alvo)*

Motor Activity Log (UE MAL) Folha de Cotação

	Escala de Frequência	Escala de Qualidade	
1. Ligar a luz com um interruptor	__________	__________	Caso não, razão? (código) ______ Comentários: __________________________
2. Abrir gaveta	__________	__________	Caso não, razão? (código) ______ Comentários: __________________________
3. Remover um item de roupa de uma gaveta	__________	__________	Caso não, razão? (código) ______ Comentários: __________________________
4. Atender um telefone	__________	__________	Caso não, razão? (código) ______ Comentários: __________________________
5. Limpar o balcão da cozinha, ou outra superfície	__________	__________	Caso não, razão? (código) ______ Comentários: __________________________
6. Sair do carro *(inclui apenas os movimentos necessários para mover o corpo de sentado para de pé para fora do carro, com a porta já aberta)*	__________	__________	Caso não, razão? (código) ______ Comentários: __________________________
7. Abrir frigorífico	__________	__________	Caso não, razão? (código) ______ Comentários: __________________________
8. Abrir uma porta rodando a maçaneta	__________	__________	Caso não, razão? (código) ______ Comentários: __________________________
9. Utilizar um controlo remoto da TV	__________	__________	Caso não, razão? (código) ______ Comentários: __________________________
10. Lavar as mãos *(inclui ensaboar e enxugar as mãos e não incluí abrir e fechar a torneira)*	__________	__________	Caso não, razão? (código) ______ Comentários: __________________________
11. Abrir/fechar uma torneira	__________	__________	Caso não, razão? (código) ______ Comentários: __________________________
12. Secar as mãos	__________	__________	Caso não, razão? (código) ______ Comentários: __________________________
13. Vestir as meias	__________	__________	Caso não, razão? (código) ______ Comentários: __________________________
14. Despir as meias	__________	__________	Caso não, razão? (código) ______ Comentários: __________________________
15. Calçar os sapatos (inclui apertar os atacadores e tiras de fixação)	__________	__________	Caso não, razão? (código) ______ Comentários: __________________________
16. Descalçar os sapatos	__________	__________	Caso não, razão? (código) ______ Comentários: __________________________

(inclui desapertar os atacadores e retirar tiras de fixação)			______
17. Levantar-se de uma cadeira com apoio para braços	______	______	Caso não, razão? (código) ______ Comentários: ______
18. Afastar a cadeira da mesa antes de se sentar	______	______	Caso não, razão? (código) ______ Comentários: ______
19. Empurrar a cadeira contra a mesa depois de se sentar	______	______	Caso não, razão? (código) ______ Comentários: ______
20. Alcançar copo, garrafa, chávena ou lata *(não inclui beber)*	______	______	Caso não, razão? (código) ______ Comentários: ______
21. Lavar os dentes *(não inclui preparação da escova ou escovar dentaduras a não ser que as dentaduras sejam escovadas enquanto estão na boca)*	______	______	Caso não, razão? (código) ______ Comentários: ______
22. Pôr maquilhagem, loção, ou creme de barbear na face.	______	______	Caso não, razão? (código) ______ Comentários: ______
23. Utilizar uma chave para abrir uma porta.	______	______	Caso não, razão? (código) ______ Comentários: ______
24. Escrever em papel *(Se a mão utilizada para escrever for a mais afetada)*	______	______	Caso não, razão? (código) ______ Comentários: ______
25. Transportar um objeto na mão (transportar sobre o braço não é aceitável).	______	______	Caso não, razão? (código) ______ Comentários: ______
26. Utilizar garfo ou colher para comer (refere-se à ação de trazer comida à boca com garfo ou colher).	______	______	Caso não, razão? (código) ______ Comentários: ______
27. Pentear o cabelo	______	______	Caso não, razão? (código) ______ Comentários: ______
28. Pegar numa chávena pela asa.	______	______	Caso não, razão? (código) ______ Comentários: ______
29. Abotoar uma camisa.	______	______	Caso não, razão? (código) ______ Comentários: ______
30. Comer meia sanduiche ou outros petiscos.	______	______	Caso não, razão? (código) ______ Comentários: ______

9 Hole Peg Test | Box and Blocks | Dinamómetro

ID: ______________

Hemicorpo afetada:
- ☐ Direito
- ☐ Esquerdo

Hemicorpo dominante:
- ☐ Direito
- ☐ Esquerdo
- ☐ Indiferente

Avaliação: Data: ____/____/______			
	9 Hole Peg test	Box and Blocks	Dinamómetro
Hemicorpo não afetada:	___________	___________	______ ; ______ ; ______
Hemicorpo afetada:	___________	___________	______ ; ______ ; ______
Reavaliação: Data: ____/____/______			
	9 Hole Peg test	Box and Blocks	Dinamómetro
Hemicorpo não afetada:	___________	___________	______ ; ______ ; ______
Hemicorpo afetada:	___________	___________	______ ; ______ ; ______
Follow up: Data: ____/____/______			
	9 Hole Peg test	Box and Blocks	Dinamómetro
Hemicorpo não afetada:	___________	___________	______ ; ______ ; ______
Hemicorpo afetada:	___________	___________	______ ; ______ ; ______

ACTION RESEARCH ARM TEST SCORE SHEET

neuroquip

Date: / /

Patient Name / Number:...

Tester Name:...

TEST #		TASK / TARGET	SCORE LEFT	SCORE RIGHT
	GRASP SUBSCALE			
1	10cm BLOCK	DISPLACE VERTICALLY TO SHELF	0 1 2 3	0 1 2 3
2	2.5cm BLOCK	DISPLACE VERTICALLY TO SHELF	0 1 2 3	0 1 2 3
3	5cm BLOCK	DISPLACE VERTICALLY TO SHELF	0 1 2 3	0 1 2 3
4	7.5cm BLOCK	DISPLACE VERTICALLY TO SHELF	0 1 2 3	0 1 2 3
5	CRICKET BALL	DISPLACE VERTICALLY FROM TIN LID TO SHELF	0 1 2 3	0 1 2 3
6	STONE	DISPLACE VERTICALLY TO SHELF	0 1 2 3	0 1 2 3
			Subtotal............/18	............./18
	GRIP SUBSCALE			
7	TUMBLERS	POUR WATER FROM ONE TO THE OTHER	0 1 2 3	0 1 2 3
8	2.5cm (WIDE) TUBE	DISPLACE DISTALLY FROM TALL TO SHORT WOODEN PEG	0 1 2 3	0 1 2 3
9	1.0cm (THIN) TUBE	DISPLACE DISTALLY FROM SHORT PINK TO TALL GREEN BOLT	0 1 2 3	0 1 2 3
10	WASHER	DISPLACE DISTALLY FROM LINED TIN TO TALL GREEN BOLT	0 1 2 3	0 1 2 3
			Subtotal............/12	............./12
	PINCH SUBSCALE			
11	BALL BEARING	BETWEEN RING FINGER AND THUMB FROM TIN TO SHELF	0 1 2 3	0 1 2 3
12	MARBLE	BETWEEN INDEX FINGER AND THUMB FROM TIN TO SHELF	0 1 2 3	0 1 2 3
13	BALL BEARING	BETWEEN MIDDLE FINGER AND THUMB FROM TIN TO SHELF	0 1 2 3	0 1 2 3
14	BALL BEARING	BETWEEN INDEX FINGER AND THUMB FROM TIN TO SHELF	0 1 2 3	0 1 2 3
15	MARBLE	BETWEEN RING FINGER AND THUMB FROM TIN TO SHELF	0 1 2 3	0 1 2 3
16	MARBLE	BETWEEN MIDDLE FINGER AND THUMB FROM TIN TO SHELF	0 1 2 3	0 1 2 3
			Subtotal............/18	............./18
	GROSS MOVEMENTS			
17	HAND BEHIND HEAD		0 1 2 3	0 1 2 3
18	HAND TO TOP OF HEAD		0 1 2 3	0 1 2 3
19	HAND TO MOUTH		0 1 2 3	0 1 2 3
			Subtotal............/09	............./09
			TOTAL ..../57	***............./57***

ITEM #	***TASK COMPONENTS***	***KEY COMPETENCIES*** ***Hand Movements***	***Arm Movements***
1 - 4	BLOCKS: TABLE TO SHELF	Hand voluntarily opens to the size of the block. Any type of grasp involving thumb & fingers in opposition.	(a) Forearm is between mid-position & pronation. (b) Elbow flexed when first grasping object then extends to reach the top of the shelf. (c) Shoulder flexion to reach top of shelf & shoulder stabilization to hold position as object released. (d) Thumb & finger extension to release the object.
5	CRICKET BALL: TABLE TO SHELF	Spherical grasp with fingers and thumb slightly flexed and abducted to the size of the ball.	
6	STONE: TABLE TO SHELF	Lateral grip: stone held 'twixt pad of thumb & radial side of index finger at or near interphalangeal joints.	
7	POUR WATER FROM TUMBLER	Cylindrical grasp around tumbler.	(a) Forearm pronation to pour / supination to return. (b) Thumb & finger extension to release the tumbler.
8 - 9	TUBES TO TARGET POINT	Any grasp (eg. 3 jaw chuck pinch) involving the pads of the thumb opposed with pads of any number of digits in a successful grasp of the tube.	(a) Forearm between mid-position and pronation. (b) Elbow extends sufficiently to reach target. (c) Shoulder movement & stabilization to maintain position as object is released. (d) Thumb & finger extension to release the object.
10	WASHER FROM TIN TO TARGET	Pincer or 3 jaw chuck pinch with thumb & finger pads in opposition in order to grasp the washer.	
11,13,14	BALL BEARING: TIN TO SHELF	Opposition of pads of ring, middle and index finger with thumb respectively.	(a) Forearm between mid-position and pronation. (b) Elbow flexed when first grasping object then extends to reach top of shelf. (c) Shoulder flexion to reach top of shelf & shoulder stabilization to hold position as object released.
12,15,16	MARBLE: TIN TO SHELF	Opposition of pads of index, ring and middle finger with thumb respectively.	
17 - 19	HAND FROM LAP TO HEAD	Palm side of hand (hand does not have to be open) reaches to back and top of head and mouth.	(a) Forearm pronation and supination. (b) Full elbow flexion. (c) Shoulder abduction, flexion & external rotation.

Evaluation Stage:	Date:
Subject:	
Hist nr.:	

MODIFIED ASHWORTH SCALE	
Normal muscle tone	0
Slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of the range of motion when the affected part(s) is moved in flexion or extension	1
Slight increase in muscle tone, manifested by a catch, followed by minimal resistance throughout the remainder (less than half) of the ROM	1+
More marked increase in muscle tone through most of the ROM, but affected part(s) easily moved.	2
Considerable increase in muscle tone, passive movement difficult	3
Affected part(s) rigid in flexion or extension	4

Bohannon RW, Smith MB (1987) Interrater reliability of a modified Ashworth scale of muscle spasticity. Phys Ther 67: 206-207.

6

What **Grasping a high ball**

Preparation: The patient is standing (sitting, if necessary) with no other support within reach. The therapist holds a tennis ball in front of and above the affected shoulder in such a way that the patient has to fully extend the affected arm and must raise the arm ±120° to grasp the tennis ball.

Task: The patient reaches for the ball and takes it with the affected hand.

7

What **Combing one's hair**

Preparation: The patient is standing (sitting, if necessary) at a table. A comb is within reach on the table.

Task: The patient combs his/her hair with at least two strokes on the top and each side of the head.

Note: The head should be held straight. The patient may reach the sides from above or from the side. Where the personal situation is less suited to this test, an 'as-if' movement should be made.

8

What **Fastening buttons**

How **Working with two hands**

Preparation: The patient is sitting at a table. A man's shirt is on the table directly in front of the patient. The collar is at the top, facing upwards. The top button is fastened, all the others are unfastened.

Task: The patient fastens four buttons within 60s using both hands.

Note: The affected fingers must be used actively, either to hold the material or the button, or to open the button hole.

9

What **Writing**

How **See Appendix 1.2**

Preparation: The patient is sitting at a table. The sheet of paper, included as Appendix 1.2, is 15 cm/6 inches in front of the patient on the table. A pen is on the sheet of paper.

Task: *(affected side not the dominant side):* The patient picks up the pen and draws three circles between the two circles on the sheet, without touching the edges of the printed circles or any circle already drawn.

Note: Explain the instruction in full before-hand and suggest the patient starts near to the inner circle. The patient may move the sheet of paper.

Task: *(affected side is the dominant side):* The patient picks up the pen and writes his/her first and last name legibly in his/her own handwriting between the lines.

Note: The patient may move the sheet of paper.

10

What **Manipulating coins**

How **See Appendix 1.2**

Preparation: The patient is sitting at a table. The sheet of paper, included as Appendix 1.2, is on the table, directly in front of the patient. There are a 50 eurocent coin, a 2 eurocent coin and a 1 eurocent coin (or their equivalents in size and weight) on the table. The affected forearm is on the table with the hand facing palm-up. Using the non-affected hand, the patient puts the coins in the affected hand.

Task: The patient manipulates the coins within the affected hand, one at a time to between the tips of the thumb and index finger and places them on their designated positions on the sheet.

Note: It does not matter in which order the coins are placed in their designated spots. During the manipulation, the forearm must rest on the table.

TOTAL SULCS SCORE

Stroke Upper Limb Capacity Scale (SULCS)

Score
0 = patient is unable to perform the task in the manner described
1 = patient is able to perform the task in the manner described

	Description	Picture	Score
1	**What** **Using the forearm for support while seated** **How** **Reaching forward across the body, leaning on the affected forearm** Preparation The patient is seated at a table. The affected arm is on the table, parallel to the edge where the patient is sitting. A pen is placed on the table, in front of the affected elbow and far enough away that complete extension of the non-affected arm and movement of the upper torso is needed to reach the pen. Task The patient reaches to pick up the pen with the non-affected hand. The affected forearm is used as a support. Note The affected arm must not move position as the patient reaches forward to pick up the pen.		
2	**What** **Clamping an object between torso and affected upper arm** **How** **Pressing the arm firmly against the side of the body** Preparation The patient is standing (sitting, if necessary) at a table. A magazine folded lengthways in half is on the table. The affected upper arm is hanging freely next to the body. Task The patient picks up the magazine using the non-affected hand and clamps it between the torso and the affected upper arm. Note The magazine must be held firmly for 10 s. The therapist checks this, if necessary, by lightly pulling on the magazine.		
3	**What** **Sliding on object across a table while seated** **How** **Using controlled sliding movement of the affected hand** Preparation The patient is seated at a table. The affected hand is on a tea towel that has been folded in four, with the palm facing downwards and the fingers pointing forwards. Task The patient pushes the tea towel forwards over the table. Note The elbow must be extended by at least 160°, and may be lifted off the table. Fully extended fingers are not necessary.		
4	**What** **Turning a screw top lid** Preparation The patient is sitting at a table with both arms on the table. A closed peanut butter jar with a plastic screw top lid is 15cm/ 6 inches in front of the patient on the table. Task The patient holds the jar firmly on the table with the non-affected hand and, using the affected hand, turns the lid at least a quarter of a turn. Note The jar must remain in the same place on the table and may not turn.		
5	**What** **Picking up a glass of water and drinking from it** Preparation The patient is sitting at a table with both arms on the table. A glass, ½ filled with water, is 15 cm/6 inches in front of the patient on the table. Task The patient picks up the glass from the table using the affected hand, takes a drink and places the glass back on the table without spilling. Note The non-affected hand is not used.		

Appendix B.

Cognitive Assessment Tools

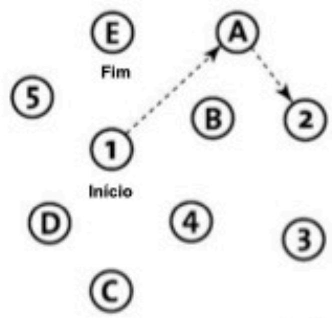
- Montreal Cognitive Assessment
- Token test

MONTREAL COGNITIVE ASSESSMENT (MOCA)

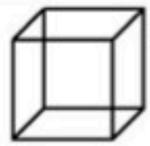
VERSÃO PORTUGUESA – 7.1 VERSÃO ORIGINAL

Nome: ______________ **Idade:** ________
Género: ________ **Data de Nascimento:** ________
Escolaridade: _____ **Data de Avaliação:** ________

VISUO-ESPACIAL / EXECUTIVA



[ ]



Copiar o cubo [ ]

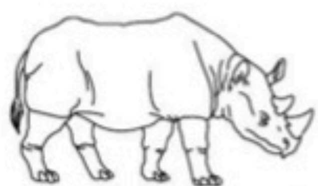
Desenhar um Relógio (onze e dez) (3 pontos)

[ ] Contorno [ ] Números [ ] Ponteiros

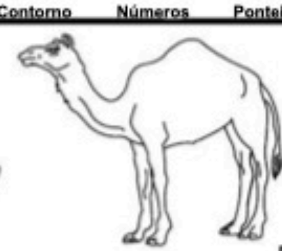
Pontos: ___/5

NOMEAÇÃO

[ ]



[ ]



[ ]

___/3

MEMÓRIA	Leia a lista de palavras. O sujeito deve repeti-la. Realize dois ensaios. Solicite a evocação da lista **5 minutos mais tarde.**		Boca	Linho	Igreja	Cravo	Azul	Sem Pontuação
		1º ensaio						
		2º ensaio						

ATENÇÃO Leia a sequência de números. (1 número/segundo)
O sujeito deve repetir a sequência. [ ] 2 1 8 5 4
O sujeito deve repetir a sequência na ordem inversa. [ ] 7 4 2 ___/2

Leia a série de letras (1 letra/segundo). O sujeito deve bater com a mão cada vez que for dita a letra A. Não se atribuem pontos se ≥ 2 erros.
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B ___/1

Subtrair de 7 em 7 começando em 100. [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
4 ou 5 subtracções correctas: **3 pontos;** 2 ou 3 correctas: **2 pontos;** 1 correcta: **1 ponto;** 0 correctas: **0 pontos** ___/3

LINGUAGEM Repetir: Eu só sei que hoje devemos ajudar o João. [ ] O gato esconde-se sempre que os cães entram na sala. [ ] ___/2

Fluência verbal: Dizer o maior número possível de palavras que comecem pela letra "P" (1 minuto). [ ] ____ (N ≥ 11 Palavras) ___/1

ABSTRACÇÃO Semelhança p.ex. entre banana e laranja = fruta [ ] comboio - bicicleta [ ] relógio - régua ___/2

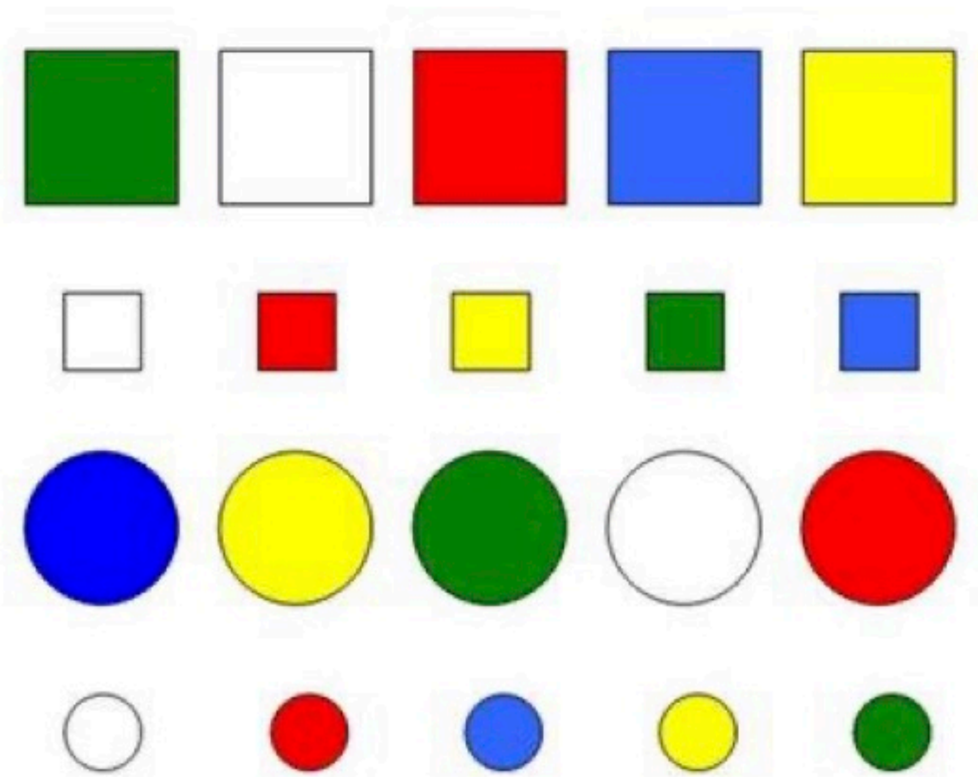
EVOCAÇÃO DIFERIDA	Deve recordar as palavras **SEM PISTAS**	Boca [ ]	Linho [ ]	Igreja [ ]	Cravo [ ]	Azul [ ]	Pontuação apenas para evocação **SEM PISTAS**	___/5
Opcional	Pista de categoria							
	Pista de escolha múltipla							

ORIENTAÇÃO [ ] Dia do mês [ ] Mês [ ] Ano [ ] Dia da semana [ ] Lugar [ ] Localidade ___/6

Examinador: ______________________

TOTAL ___/30

Versão Portuguesa: Freitas, S., Simões, M. R., Santana, I., Martins, C. & Nasreddine, Z. (2013). *Montreal Cognitive Assessment (MoCA): Versão 1*. Coimbra: Faculdade de Psicologia e de Ciências da Educação da Universidade de Coimbra.



Appendix C.

Game User Research Tools

- System Usability Scale
- Intrinsic Motivation Inventory
- Game Experience Questionnaire

System Usability Scale

	Discordo totalmente				Concordo totalmente
1. Eu gostaria de utilizar este sistema com frequência.	1	2	3	4	5
2. Achei o sistema desnecessariamente complexo.	1	2	3	4	5
3. Considerei que o sistema foi de fácil utilização.	1	2	3	4	5
4. Penso que precisaria de apoio de um responsável técnico/especialista para ser capaz de usar este sistema.	1	2	3	4	5
5. Achei que as várias funções deste sistema estavam bem integradas.	1	2	3	4	5
6. Considero que houve muita inconsistência neste sistema.	1	2	3	4	5
7. Eu diria que a maioria das pessoas conseguiria aprender a utilizar este sistema muito rapidamente.	1	2	3	4	5
8. Achei o sistema muito complicado de utilizar.	1	2	3	4	5
9. Senti-me muito confiante na utilização deste sistema.	1	2	3	4	5
10. Precisava de aprender muitas coisas antes de continuar a utilizar este sistema.	1	2	3	4	5

Interest/enjoyment; Perceived Competence, Effort/importance; Value usefulness

1. Gostei bastante destes exercícios
2. Despendi muito esforço nestes exercícios
3. Penso que sou muito bom nestes exercícios
4. Acredito que estes exercícios podem ser úteis para mim.
5. Estes exercícios foram divertidos de fazer
6. É importante para mim fazer bem estes exercícios
7. Estou satisfeito/a com o meu rendimento nestes exercícios
8. Penso que fazer estes exercícios é útil para reabilitação
9. Descreveria estes exercícios como muito interessantes.
10. Empenhei-me bastante nestes exercícios.
11. Fui bastante bom nestes exercícios.
12. Penso que estes exercícios são importante para a recuperação
13. Enquanto fiz estes exercícios, pensei em como gostei de as fazer.
14. Estes exercícios não me despertaram atenção.
15. Não consegui fazer estes exercícios muito bem.
16. Desejaria fazer estes exercícios novamente porque acho que seria importante/útil para mim.
17. Não me esforcei muito nestes exercícios.
18. Após praticar estes exercícios um bocado, senti-me bastante competente
19. Achei que estes exercícios foram aborrecidos
20. Fazer estes exercícios foi uma ajuda (na recuperação)
21. Penso que fiz estes exercícios muito bem, comparado com os meus parceiros.
22. Acredito que fazer estes exercícios foi benéfico para mim.
23. Não me esforcei muito para fazer bem estes exercícios.
24. Achei estes exercícios muito agradáveis.
25. Penso que estes exercícios são importantes

Game Experience Questionnaire – Core Module

Please indicate how you felt while playing the game for each of the items, on the following scale:

not at all	slightly	moderately	fairly	extremely
0	1	2	3	4
< >	< >	< >	< >	< >

1 I felt content
2 I felt skilful
3 I was interested in the game's story
4 I thought it was fun
5 I was fully occupied with the game
6 I felt happy
7 It gave me a bad mood
8 I thought about other things
9 I found it tiresome
10 I felt competent
11 I thought it was hard
12 It was aesthetically pleasing
13 I forgot everything around me
14 I felt good
15 I was good at it
16 I felt bored
17 I felt successful
18 I felt imaginative
19 I felt that I could explore things
20 I enjoyed it
21 I was fast at reaching the game's targets
22 I felt annoyed
23 I felt pressured
24 I felt irritable
25 I lost track of time
26 I felt challenged
27 I found it impressive
28 I was deeply concentrated in the game
29 I felt frustrated
30 It felt like a rich experience
31 I lost connection with the outside world
32 I felt time pressure
33 I had to put a lot of effort into it

GEQ - Social Presence Module

Please indicate how you felt while playing the game for each of the items, on the following scale:

not at all	slightly	moderately	fairly	extremely
0	1	2	3	4
< >	< >	< >	< >	< >

1 I empathized with the other(s)
2 My actions depended on the other(s) actions
3 The other's actions were dependent on my actions
4 I felt connected to the other(s)
5 The other(s) paid close attention to me
6 I paid close attention to the other(s)
7 I felt jealous about the other(s)
8 I found it enjoyable to be with the other(s)
9 When I was happy, the other(s) was(were) happy
10 When the other(s) was(were) happy, I was happy
11 I influenced the mood of the other(s)
12 I was influenced by the other(s) moods
13 I admired the other(s)
14 What the other(s) did affected what I did
15 What I did affected what the other(s) did
16 I felt revengeful
17 I felt schadenfreude (malicious delight)

Appendix D.

Psychological Tools

- Geriatric Depression Scale
- BECK – II

ESCALA GERIÁTRICA DE DEPRESSÃO

Yesavage et al. (1983) 'Development and validation of a geriatric depression screening scale'

Nome: ____

Responda SIM ou NÃO consoante se tem sentido de há uma semana para cá:

1. Está satisfeito(a) com a sua vida?........ Sim Não
2. Pôs de lado muitas das suas actividades e interesses? .... Sim Não
3. Sente a sua vida vazia? .... Sim Não
4. Fica muitas vezes aborrecido(a)? .... Sim Não
5. Tem esperança no futuro? .... Sim Não
6. Anda incomodado(a) com pensamentos que não consegue afastar? .... Sim Não
7. Está bem disposto(a) a maior parte do tempo? .... Sim Não
8. Tem medo que lhe vá acontecer alguma coisa de mal? .... Sim Não
9. Sente-se feliz a maior parte do tempo?........ Sim Não
10. Sente-se muitas vezes desamparado(a)?........ Sim Não
11. Fica muitas vezes inquieto(a) e nervoso(a)?........ Sim Não
12. Prefere ficar em casa, em vez de sair e fazer coisas novas? .... Sim Não
13. Preocupa-se muitas vezes com o futuro? .... Sim Não
14. Acha que tem mais dificuldades de memória do que as outras pessoas?...... Sim Não
15. Pensa que é muito bom estar vivo(a)?........ Sim Não
16. Sente-se muitas vezes desanimado(a) e abatido(a)? .... Sim Não
17. Sente-se inútil?........ Sim Não
18. Preocupa-se muito com o passado? .... Sim Não
19. Acha a sua vida interessante? .... Sim Não
20. É difícil começar novas actividades?........ Sim Não
21. Sente-se cheio(a) de energia? .... Sim Não
22. Sente que para si não há esperança?........ Sim Não
23. Pensa que a maioria das pessoas passa melhor que o(a) senhor(a)? .... Sim Não
24. Aflige-se muitas vezes com pequenas coisas?........ Sim Não
25. Sente muitas vezes vontade de chorar? .... Sim Não
26. Tem dificuldade em se concentrar? .... Sim Não
27. Gosta de se levantar de manhã? .... Sim Não
28. Prefere evitar encontrar-se com muitas pessoas? .... Sim Não
29. Tem facilidade em tomar decisões?........ Sim Não
30. O seu pensamento é tão claro como era antes?........ Sim Não

BDI-II (A.T. Beck, 1996; Adapt. A.Q. Martins & R. Coelho, 2000)

POR FAVOR LEIA CUIDADOSAMENTE CADA GRUPO DE AFIRMAÇÕES ABAIXO E ESCOLHA EM CADA UM A **FRASE QUE MELHOR DESCREVE COMO SE TEM SENTIDO DURANTE AS *PASSADAS DUAS SEMANAS, INCLUINDO O DIA DE HOJE***. *PODERÃO HAVER VÁRIAS FRASES NO* MESMO GRUPO QUE LHE PAREÇAM ADEQUADAS – NO ENTANTO, **ESCOLHA APENAS UMA** EM CADA GRUPO. **(assinale uma cruz em cada grupo)**

1. Tristeza
- O Não me sinto triste.
- O Sinto-me triste muitas vezes.
- O Sinto-me sempre triste.
- O Estou tão triste ou infeliz que já não aguento.

2. Pessimismo
- O Não me sinto desencorajada em relação ao futuro.
- O Sinto-me mais desencorajada em relação ao futuro do que antes.
- O Já não espero que os meus problemas se resolvam.
- O *Não tenho qualquer esperança no futuro; tudo só pode piorar.*

3. Fracassos Passados
- O Não me considero uma falhada.
- O *Fracassei mais vezes do que deveria.*
- O Revendo o passado, o que noto é uma quantidade de fracassos.
- O Sinto-me completamente falhada como pessoa.

4. Perda de Prazer
- O Tenho tanto prazer como antes com as coisas que gosto.
- O Eu não gosto tanto das coisas como costumava.
- O Tenho pouco prazer com as coisas que costumava gostar.
- O Não tenho qualquer prazer nas coisas que costumava gostar.

5. Sentimentos de Culpa
- O Não me sinto particularmente culpada.
- O Sinto-me culpada por muitas coisas que fiz ou devia ter feito.
- O Sinto-me bastante culpada a maioria das vezes.
- O *Sinto-me culpada durante o tempo todo.*

6. Sentimentos de Punição
- O Não sinto que esteja a ser castigada.
- O Sinto que posso vir a ser castigada.
- O Acho que vou ser castigada.
- O Sinto que estou a ser castigada.

7. Auto-Depreciação
- O Aquilo que acho de mim é o que sempre achei.
- O Perdi confiança em mim própria.
- O Estou desapontada comigo mesmo.
- O Eu não gosto de mim.

8. Auto-Criticismo
- O Não me critico mais do que o habitual.
- O Critico-me mais do que costumava.
- O Critico-me por todas as minhas falhas.
- O Culpo-me de tudo o que de mal me acontece.

9. Pensamentos ou Desejos Suicidas
- O Não tenho qualquer ideia de me matar.
- O Tenho ideias de me matar, mas não as levarei a cabo.
- O Gostaria de me matar.
- O Matar-me-ia se tivesse oportunidade.

10. Choro
- O Não choro mais do que costumava.
- O Choro mais do que costumava.
- O Choro por tudo e por nada.
- O Apetece-me chorar, mas já não consigo.

11. Agitação

- Não me sinto mais inquieta do que o habitual.
- Sinto-me mais inquieta do que o habitual.
- Estou tão agitada que é difícil parar quieta.
- Estou tão agitada que tenho de me manter a fazer algo.

12. Perda de Interesse

- Não perdi o interesse nos outros ou nas minhas actividades.
- Estou menos interessado nas coisas ou nos outros.
- Perdi a maioria do interesse nas coisas ou nos outros.
- É difícil interessar-me pelo que quer que seja.

13. Indecisão

- Tomo decisões como sempre o fiz.
- Acho mais difícil tomar decisões do que o habitual.
- É muito mais difícil tomar decisões do que antigamente.
- Sinto-me incapaz de tomar qualquer decisão.

14. Sentimentos de Inutilidade

- Não me considero incapaz / inútil.
- Não me considero tão válida e útil como costumava.
- Sinto-me mais inútil do que as outras pessoas.
- Sinto-me completamente inútil.

15. Perda de Energia

- Tenho a mesma energia de sempre.
- Sinto-me com menos energia do que o habitual.
- Não me sinto com energia para muitas coisas.
- Não me sinto com energia para nada.

16. Alterações no Padrão de Sono

- Não notei qualquer mudança no meu sono.
- Durmo um pouco mais que o habitual.
- Durmo um pouco menos que o habitual.
- Durmo muito mais que o habitual.
- Durmo muito menos que o habitual.
- Durmo a maior parte do tempo durante o dia.
- Acordo 1-2 horas mais cedo e não consigo voltar a dormir.

17. Irritabilidade

- Não estou mais irritável do que o normal.
- Estou mais irritável do que o habitual.
- Estou muito mais irritável do que o habitual.
- Estou irritável o tempo todo.

18. Alterações no Apetite

- Não notei qualquer alteração no meu apetite.
- Tenho um pouco menos de apetite do que o habitual.
- Tenho um pouco mais de apetite do que o habitual.
- O meu apetite é muito menor do que o normal.
- O meu apetite é muito maior do que o normal.
- Perdi por completo o apetite.
- Anseio por comida o tempo todo.

19. Dificuldades de concentração

- Concentro-me tão bem como antes.
- Não me consigo concentrar tão bem como antes.
- É difícil pensar em qualquer coisa por muito tempo.
- Acho que não me consigo concentrar em nada.

20. Cansaço ou Fadiga

- Não me sinto mais cansada que o habitual.
- Canso-me mais facilmente que o costume.
- Estou demasiado cansada para fazer as coisas do costume.
- Estou demasiado cansada para fazer a maior parte das coisas que costumava fazer.

21. Perda de Interesse Sexual

- Não notei qualquer alteração no meu interesse sexual.
- Sinto-me menos interessada sexualmente do que o costume.
- Sinto-me muito menos interessada pela vida sexual.
  Perdi por completo o interesse que tinha pela vida sexual.

Appendix E.

Other tools

- Stroke Self-Efficacy Questionnaire
- Nottingham Sensory Assessment
- Bell’s test
- Functional Limitation Profile – Social Interaction Items
- Mini – IPIP (Short version of International Personality Item Pool)
- Self-report previous relationship characterization– Likert scale
- Ease of task – Likert scale
- Enjoyment of task – Likert Scale

ESCALA DE AUTOEFICÁCIA APÓS AVC (SSEQ-B)

Quanto confiante você está hoje em dia que você é capaz:

1- Manter-se deitado confortavelmente na cama todas as noites.

Nenhuma confiança — Muito confiante

0 |___|___|___| 3

2- Sair da cama sozinho, mesmo quando você se sente cansado.

Nenhuma confiança — Muito confiante

0 |___|___|___| 3

3- Andar alguns passos, por conta própria, em qualquer superfície dentro da sua casa.

Nenhuma confiança — Muito confiante

0 |___|___|___| 3

4- Andar pela sua casa para fazer a maior parte das coisas que você quer.

Nenhuma confiança — Muito confiante

0 |___|___|___| 3

5- Andar com segurança, por conta própria, em ambiente externo em qualquer superfície.

Nenhuma confiança — Muito confiante

0 |___|___|___| 3

6- Usar as duas mãos para comer sua comida.

Nenhuma confiança — Muito confiante

0 |___|___|___| 3

7- Vestir-se e despir-se, mesmo quando você se sente cansado.

Nenhuma confiança — Muito confiante

0 3

8- Preparar para si mesmo uma refeição que você deseja.

Nenhuma confiança — Muito confiante

0 3

9- Persistir para obter progresso na recuperação após seu AVC, mesmo depois de ter alta da terapia.

Nenhuma confiança — Muito confiante

0 3

10- Fazer seu próprio programa de exercícios todos os dias.

Nenhuma confiança — Muito confiante

0 3

11- Lidar com a frustração de não poder fazer algumas coisas por causa do seu AVC.

Nenhuma confiança — Muito confiante

0 3

12- Continuar a fazer a maioria das coisas que você gostava de fazer antes do seu AVC.

Nenhuma confiança — Muito confiante

0 3

13- Continuar a ficar mais rápido nas tarefas que ficaram lentas desde que você teve o AVC.

Nenhuma confiança — Muito confiante

0 3

Total:____________

32. Connell LA, Lincoln NB, Radford KA. Somatosensory impairment after stroke: frequency of different deficits and their recovery. Clin Rehabil. 2008;22(8):758-67.

33. Clark GS, Siebens HC. Reabilitação geriátrica. In: De-Lisa já, Gans BM (editores). Tratado de medicina de reabilitação: princípios e prática. São Paulo: Manole; 2002. p. 1013-47.

Anexo 1

Avaliação sensorial de Nottingham (Lincoln et al.[19])

Nome: ____________________________ Data do AVE: ____/____/____

Idade:______________ Tel(s): (____) ______________ Tipo do AVE (H/I): __________

Examinador: ____________________________ Data da avaliação: ____/____/____

Lado do corpo afetado: ( ) Direito ( ) Esquerdo ( ) Nenhum ( ) Ambos Se AMBOS, lado avaliado: ______

Presença de edema: ( ) Sim ( ) Não Se sim, onde? ____________

Sensação Tátil													
Regiões do corpo	Toque leve		Pressão		Picada		Temperatura		Localização tátil		Toque bilateral simultâneo	Propriocepção
	D	E	D	E	D	E	D	E	D	E		
Face												
Tronco												
Ombro												
Cotovelo												
Punho												
Mão												
Quadril												
Joelho												
Tornozelo												
Pé												

Estereognosia

- [ ] Moeda de R$ 0,01
- [ ] Moeda de R$ 0,10
- [ ] Moeda de R$ 1
- [ ] Caneta esferográfica
- [ ] Lápis
- [ ] Pente
- [ ] Tesoura
- [ ] Esponja
- [ ] Flanela
- [ ] Xícara
- [ ] Copo

Discriminação entre dois pontos

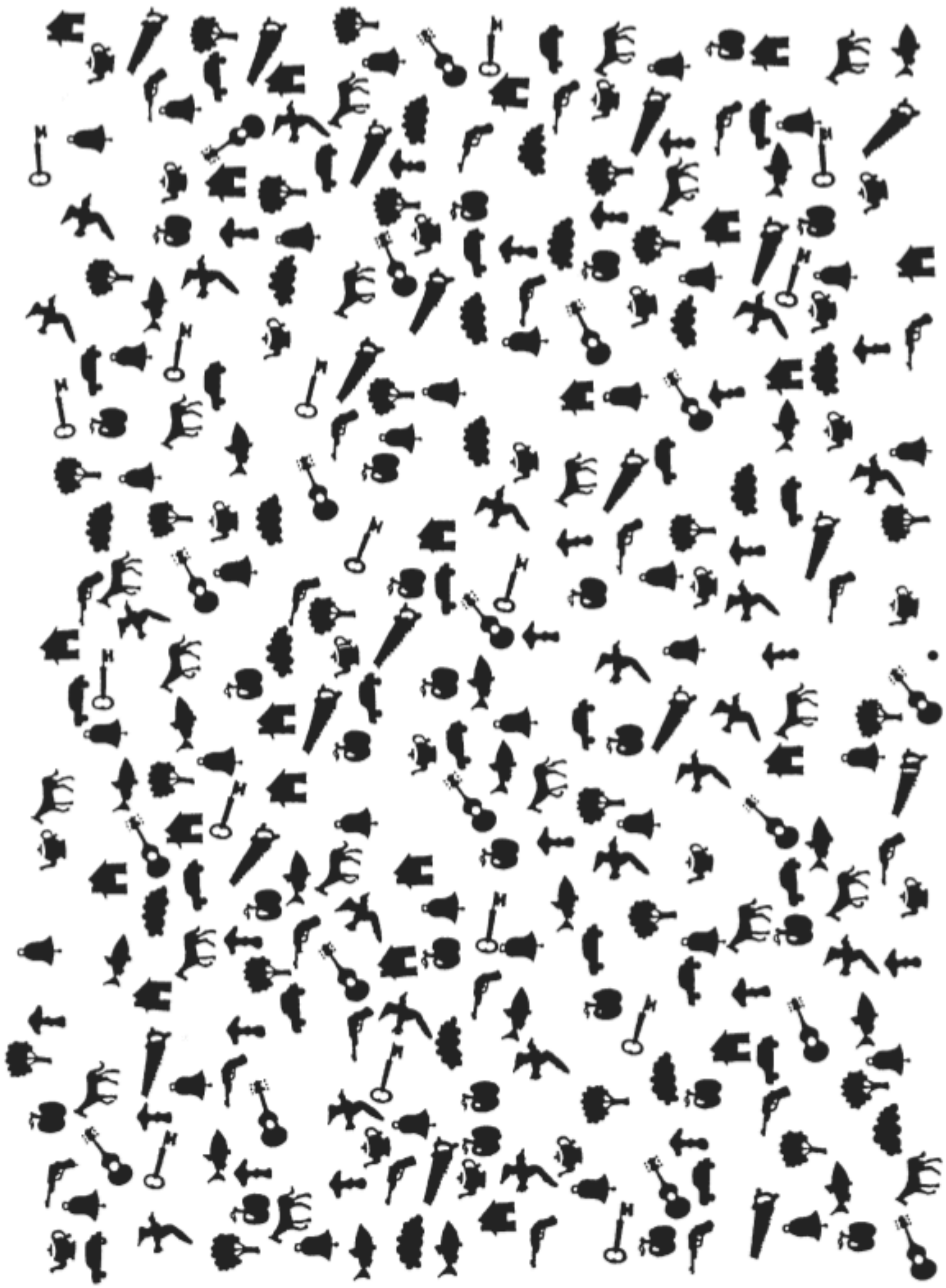
	mm	Pontuação
Palma da mão		

	mm	Pontuação
Pontas dos dedos		

Pontuação

Sensação Tátil e Estereognosia	Propriocepção	Discriminação entre 2 pontos
0: Ausente	0: Ausente	0: Ausente
1: Alterado	1: Execução do movimento (direção errada)	1: >3mm dedos e >8 mm mão
2: Normal	2: Direção do movimento (>10°)	2: <3mm dedos e <8 mm mão
4 a 9: Não testável	3: Normal ou posição articular <10°	4 a 9: Não testável
	4 a 9: Não testável	

Comentários: (por exemplo: edema ou palidez presente, meias de compressão, presença de reflexos).



ITENS INTERAÇÃO SOCIAL (COTAÇÃO MÁXIMA POSSÍVEL = 1289)

64. Eu saio menos frequentemente para visitar pessoas.	___	(031)
65. Eu não saio de forma alguma para visitar pessoas.	___	(091)
66. Eu demonstro menos interesse nos problemas das pessoas, por exemplo, eu não oiço quando me contam os seus problemas; eu não me ofereço para ajudar.	___	(050)
67. Eu irrito-me frequentemente com aqueles em meu redor; por exemplo, eu expludo com as pessoas ou critico facilmente.	___	(064)
68. Eu demonstro menos afeto.	___	(044)
69. Eu participo em menos atividades sociais do que era costume; por exemplo, eu vou a menos festas e eventos sociais.	___	(025)
70. Eu estou a reduzir o tempo de visitas com os meus amigos.	___	(031)
71. Eu evito receber visitas.	___	(073)
72. A minha atividade sexual está diminuída.	___	(064)
73. Eu expresso frequentemente preocupação relativamente ao que poderá estar a acontecer à minha saúde.	___	(044)
74. Eu falo menos com outras pessoas.	___	(044)
75. Eu imponho muitas exigências a outras pessoas; por exemplo, eu insisto em que façam coisas por mim ou digo-lhes como fazer as coisas.	___	(076)
76. Eu fico sozinho grande parte do tempo.	___	(091)
77. Eu sou desagradável com a minha família, por exemplo, eu ajo rancorosamente ou com teimosia.	___	(086)
78. Eu fico zangada com a minha família frequentemente; por exemplo, eu bato-lhes, grito-lhes ou atiro-lhes coisas.	___	(103)
79. Eu isolo-me do resto da minha família sempre que consigo.	___	(100)
80. Eu presto menos atenção aos meus filhos.	___	(059)
81. Eu recuso o contacto com a minha família, por exemplo, eu afasto-me deles.	___	(109)
82. Eu não cuido dos meus filhos ou da minha família tão bem como costumo.	___	(066)
83. Eu não brinco com os meus familiares tanto como costumo.	___	(038)

Mini– International Personality Item Pool

	Muito Impreciso	Moderadamente Impreciso	Nem preciso nem impreciso	Moderadamente preciso	Muito Preciso
1. Sou a vida da festa.	O	O	O	O	O
2. Não falo muito.	O	O	O	O	O
3. Estou calmo(a) a maior parte do tempo.	O	O	O	O	O
4. Tenho dificuldade em entender ideias abstractas.	O	O	O	O	O
5. Tenho uma imaginação vívida.	O	O	O	O	O
6. Prefiro manter-me me segundo plano.	O	O	O	O	O
7. Simpatizo com os sentimentos dos outros.	O	O	O	O	O
8. Faço uma confusão com as coisas.	O	O	O	O	O
9. Raramente me sinto triste.	O	O	O	O	O
10.Não me interesso por ideias abstractas.	O	O	O	O	O
11.Não estou interessado nos problemas dos outros.	O	O	O	O	O
12.Realizo as tarefas imediatamente.	O	O	O	O	O
13.Muitas vezes esqueço-me de colocar as coisas no seu devido lugar.	O	O	O	O	O
14.Fico preocupado facilmente.	O	O	O	O	O
15.Não tenho uma boa imaginação.	O	O	O	O	O
16.Falo com muitas pessoas diferentes em festas.	O	O	O	O	O
17.Não estou realmente interessado nos outros.	O	O	O	O	O
18.Gosto de ordem.	O	O	O	O	O
19.Tenho mudanças frequentes de humor.	O	O	O	O	O
20.Sinto as emoções dos outros.	O	O	O	O	O

Self-report previous relationship characterization– Likert scale

Quão próxima é a relação que tem com o seu colega? *

	1	2	3	4	5	6	7	8	9	10	
Sem relação	○	○	○	○	○	○	○	○	○	○	Relação extremamente próxima

Ease of task – Likert scale

Ease *

1	2	3	4	5	6	7
○	○	○	○	○	○	○

Enjoyment of task – Likert Scale

Engagement *

1	2	3	4	5	6	7
○	○	○	○	○	○	○

Appendix F.

Consent Forms

- Inform Consent (study reported in chapter 3.1)
- Inform Consent (study reported in chapter 3.2)
- Inform Consent (study reported in chapter 4.1)
- Inform Consent (study reported in chapter 4.2)
- Inform Consent (study reported in chapter 6)

Inform Consent (study reported in chapter 3.1)

Título do Estudo: Impacto do modo de jogo no envolvimento social e na motivação para o jogo em pessoas que tenham sofrido um AVC

Investigador(es) Principa(l/is): Fábio Pereira, M-ITI, 917499898

Outros investigadores: Rúben Ornelas

Objetivo do Estudo

O objectivo do estudo é perceber as diferenças entre três modos de jogo (competitivo, cooperativo e colaborativo) na motivação e envolvimento social entre os jogadores.

Procedimento

A sessão irá iniciar-se com um momento de treino de forma a possibilitar ao participante perceber como funciona o jogo e o que é esperado de cada participante em cada tarefa.
Após este treino, cada participante deverá responder a um pequeno questionário demográfico e a um questionário de personalidade.
De seguida, os participantes jogarão os três modos intercalados por questionários que irão possibilitar aos investigadores perceberem o que cada um sentiu durante cada modo de jogo.
O tempo esperado para todas estas fases é de aproximadamente 1 hora.

Critérios de Inclusão

Será considerado elegível para participar neste estudo se tiver mais de 50 anos.

Critérios de Exclusão

Será considerado inelegível para participar neste estudo caso apresente alguma limitação motora nos membros superiores.

Riscos

Não existem riscos associados à participação neste estudo.

Benefícios

Não existem benefícios associados à participação neste estudo.

Confidencialidade

O seu nome não será identificado em quaisquer relatórios ou base de dados. Todos os dados recolhidos serão mantidos confidenciais.

Autorização Opcional

Entendo que os investigadores podem querer usar fotografias por razões ilustrativas nas apresentações e publicações deste trabalho, para fins científicos ou educativos. Eu dou autorização para fazê-lo, desde que o meu nome e rosto não apareçam.

Assine no lugar pretendido: ____________________SIM ______________________NÃO

Direitos

A sua participação é voluntária. Você é livre de interromper a sua participação em qualquer momento. A recusa em participar ou interrupção da participação não resultará em qualquer penalização, ou perda de eventuais benefícios ou direitos. O investigador principal poderá decidir, de forma fundamentada, interromper a sua participação neste estudo. Caso se verifique esta situação, esta não resultará em qualquer penalização, ou perda de eventuais benefícios ou direitos.

Esclarecimento de Dúvidas & Contatos

Se você tem dúvidas sobre este estudo, poderá fazer agora todas as perguntas. Se quiser fazer perguntas mais tarde, desejar obter mais informações, ou desejar interromper a sua participação no estudo, entre em contato com o Investigador Principal em pessoa, por telefone ou e-mail. A informação de contato está disponível no início da primeira página deste documento.

Consentimento Informado Voluntário

Ao assinar este documento, você confirma que leu a informação acima descrita sobre este estudo, e que todas as suas perguntas foram respondidas. Assim mesmo, você poderá fazer perguntas adicionais a qualquer momento durante o estudo, e mesmo após este ter terminado. Ao assinar este documento, você concorda em participar neste estudo de investigação. Irá receber uma cópia deste documento de consentimento informado assinada e datada.

ASSINATURA DO PARTICIPANTE	DATA
ASSINATURA DO REPRESENTANTE LEGAL (se aplicável)	DATA

Investigador que Obtém o Consentimento

Como membro da equipa de investigação, confirmo que expliquei ao participante acima referido a natureza e finalidade deste estudo de investigação, e que esclareci quais os potenciais benefícios e eventuais riscos da participação no estudo. Todas as perguntas foram respondidas e estou disponível para esclarecer quaisquer dúvidas que possam surgir ao longo do estudo.

ASSINATURA DO INVESTIGADOR	DATA

Inform Consent (study reported in chapter 3.2)

Título do Estudo: Impacto do modo de jogo no envolvimento social e na motivação para o jogo em pessoas que tenham sofrido um AVC

Investigador(es) Principa(l/is): Fábio Pereira, M-ITI, 917499898
Outros investigadores: Carolina Jorge

Objetivo do Estudo

O objectivo do estudo é perceber as diferenças entre três modos de jogo (competitivo, cooperativo e colaborativo) na motivação e envolvimento social entre os jogadores.

Procedimento

A sessão irá iniciar-se com um momento de treino de forma a possibilitar ao participante perceber como funciona o jogo e o que é esperado de cada participante em cada tarefa.
Após este treino, cada participante deverá responder a um pequeno questionário demográfico e a um questionário de personalidade.
De seguida, os participantes jogarão os três modos intercalados por questionários que irão possibilitar aos investigadores perceberem o que cada um sentiu durante cada modo de jogo. O tempo esperado para todas estas fases é de aproximadamente 1 hora.

Critérios de Inclusão

Será considerado elegível para participar neste estudo se tiver sofrido um AVC e tiver limitações motoras no membro superior.

Critérios de Exclusão

Será considerado inelegível para participar neste estudo se as capacidades motoras no membro superior afectado não permitirem interagir com o sistema.

Riscos

Não existem riscos associados à participação neste estudo.

Benefícios

Não existem benefícios associados à participação neste estudo.

Confidencialidade

O seu nome não será identificado em quaisquer relatórios ou base de dados. Todos os dados recolhidos serão mantidos confidenciais.

Autorização Opcional

Entendo que os investigadores podem querer usar fotografias por razões ilustrativas nas apresentações e publicações deste trabalho, para fins científicos ou educativos. Eu dou autorização para fazê-lo, desde que o meu nome e rosto não apareçam.

Assine no lugar pretendido: ________________SIM ______________________NÃO

Direitos

A sua participação é voluntária. Você é livre de interromper a sua participação em qualquer momento. A recusa em participar ou interrupção da participação não resultará em qualquer penalização, ou perda de eventuais benefícios ou direitos. O investigador principal poderá decidir, de forma fundamentada, interromper a sua participação neste estudo. Caso se verifique esta situação, esta não resultará em qualquer penalização, ou perda de eventuais benefícios ou direitos.

Esclarecimento de Dúvidas & Contatos

Se você tem dúvidas sobre este estudo, poderá fazer agora todas as perguntas. Se quiser fazer perguntas mais tarde, desejar obter mais informações, ou desejar interromper a sua participação no estudo, entre em contato com o Investigador Principal em pessoa, por telefone ou e-mail. A informação de contato está disponível no início da primeira página deste documento.

Consentimento Informado Voluntário

Ao assinar este documento, você confirma que leu a informação acima descrita sobre este estudo, e que todas as suas perguntas foram respondidas. Assim mesmo, você poderá fazer perguntas adicionais a qualquer momento durante o estudo, e mesmo após este ter terminado. Ao assinar este documento, você concorda em participar neste estudo de investigação. Irá receber uma cópia deste documento de consentimento informado assinada e datada.

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ASSINATURA DO PARTICIPANTE DATA

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ASSINATURA DO REPRESENTANTE LEGAL (se aplicável) DATA

Investigador que Obtém o Consentimento

Como membro da equipa de investigação, confirmo que expliquei ao participante acima referido a natureza e finalidade deste estudo de investigação, e que esclareci quais os potenciais benefícios e eventuais riscos da participação no estudo. Todas as perguntas foram respondidas e estou disponível para esclarecer quaisquer dúvidas que possam surgir ao longo do estudo.

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ASSINATURA DO INVESTIGADOR DATA

Inform Consent (study reported in chapter 4.1)

Título do Estudo: Viabilidade do uso de materiais tangíveis em tarefas de reabilitação digitais
Investigador(es) Principa(l/is): Fábio Pereira, M-ITI, 917499898
Outros investigadores: Rúben Ornelas

Objetivo do Estudo

O objectivo do estudo é perceber a viabilidade do uso de materiais tangíveis em tarefas de reabilitação digitais.

Procedimento

Irá ser realizada uma avaliação cognitiva e uma avaliação motora ao membro superior de forma.
A experiência basear-se-á em várias tarefas nas quais o participante terá de manipular vários objectos de forma a atingir os objectivos de jogos específicos. Após cada tarefa irá ser questionado acerca da facilidade/dificuldade e envolvimento que sentiu na tarefa.

Critérios de Inclusão

Será considerado elegível para participar neste estudo se tiver sofrido um acidente vascular cerebral.

Critérios de Exclusão

Será considerado inelegível para participar neste estudo caso tenha:
- Pontuação máxima ou mínima no Action Research Arm Test.
- Hemi-negligência espacial
- Pontuação inferior ou igual a 7 no Token Test

Riscos

Não existem riscos associados à participação neste estudo.

Benefícios

Não existem benefícios associados à participação neste estudo.

Confidencialidade

O seu nome não será identificado em quaisquer relatórios ou base de dados. Todos os dados recolhidos serão mantidos confidenciais.

Autorização Opcional

Entendo que os investigadores podem querer usar fotografias por razões ilustrativas nas apresentações e publicações deste trabalho, para fins científicos ou educativos. Eu dou autorização para fazê-lo, desde que o meu nome e rosto não apareçam.

Assine no lugar pretendido: ____________________SIM ____________________NÃO

Direitos

A sua participação é voluntária. Você é livre de interromper a sua participação em qualquer momento. A recusa em participar ou interrupção da participação não resultará em qualquer penalização, ou perda de eventuais benefícios ou direitos. O investigador principal poderá decidir, de forma fundamentada, interromper a sua participação neste estudo. Caso se verifique esta situação, esta não resultará em qualquer penalização, ou perda de eventuais benefícios ou direitos.

Esclarecimento de Dúvidas & Contatos

Se você tem dúvidas sobre este estudo, poderá fazer agora todas as perguntas. Se quiser fazer perguntas mais tarde, desejar obter mais informações, ou desejar interromper a sua participação no estudo, entre em contato com o Investigador Principal em pessoa, por telefone ou e-mail. A informação de contato está disponível no início da primeira página deste documento.

Consentimento Informado Voluntário

Ao assinar este documento, você confirma que leu a informação acima descrita sobre este estudo, e que todas as suas perguntas foram respondidas. Assim mesmo, você poderá fazer perguntas adicionais a qualquer momento durante o estudo, e mesmo após este ter terminado. Ao assinar este documento, você concorda em participar neste estudo de investigação. Irá receber uma cópia deste documento de consentimento informado assinada e datada.

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ASSINATURA DO PARTICIPANTE DATA

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ASSINATURA DO REPRESENTANTE LEGAL (se aplicável) DATA

Investigador que Obtém o Consentimento

Como membro da equipa de investigação, confirmo que expliquei ao participante acima referido a natureza e finalidade deste estudo de investigação, e que esclareci quais os potenciais benefícios e eventuais riscos da participação no estudo. Todas as perguntas foram respondidas e estou disponível para esclarecer quaisquer dúvidas que possam surgir ao longo do estudo.

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ASSINATURA DO INVESTIGADOR DATA

Inform Consent (study reported in chapter 4.2)

Título do Estudo: Amplitudes máximas de alcance e preensões, sem padrão de compensação, em adultos após AVC
Investigador(es) Principa(l/is): Fábio Pereira
Outros investigadores: Ângela Fernandes, Cátia Coelho

Objetivo do Estudo

O objetivo do estudo é descrever a relação entre as amplitudes de movimentos e a capacidade de alcançar e agarrar (preensões global, tríade e lateral), sem padrão de compensação, em adultos após AVC.

Procedimento

Irá ser realizada uma avaliação motora ao membro superior de forma a perceber quais as amplitudes de movimento, espasticidade, sensibilidade, força da mão e funcionalidade do membro superior afetado pelo AVC. Após a realização da atividade para avaliar a distância máxima de alcance e as preensões, irá ser questionado acerca da presença/ausência de fadiga e dor.

Critérios de Inclusão

Será considerado elegível para participar neste estudo participantes com idade igual ou superior a 18 anos e se tiver sofrido um acidente vascular cerebral.

Critérios de Exclusão

Será considerado inelegível para participar neste estudo caso tenha:
- Incapacidade em realizar nenhuma preensão dos objetos utilizados no estudo;
- Pontuação no mínima e máxima no instrumento *Fugl-Meyer Assessment Upper Extremity* parte A (excluindo os tópicos 1 e 5 – atividade reflexa);
- Graves défices de comunicação e compreensão de mensagens verbais;
- Presença de Neglect;
- Dor no ombro incapacitante ou outras condições neurológicas, ortopédicas e neuromusculares que afetam o desempenho do participante durante a avaliação

Riscos

Não existem riscos associados à participação neste estudo.

Benefícios

Não existem benefícios associados à participação neste estudo.

Confidencialidade

O seu nome não será identificado em quaisquer relatórios ou base de dados. Todos os dados recolhidos serão mantidos confidenciais.

Autorização Opcional

Entendo que os investigadores podem querer usar fotografias por razões ilustrativas nas apresentações e publicações deste trabalho, para fins científicos ou educativos. Eu dou autorização para fazê-lo, desde que o meu nome e rosto não apareçam.
Assine no lugar pretendido: _________________SIM ____________________NÃO

Direitos

A sua participação é voluntária. Você é livre de interromper a sua participação em qualquer momento. A recusa em participar ou interrupção da participação não resultará em qualquer penalização, ou perda de eventuais benefícios ou direitos. O investigador principal poderá decidir, de forma fundamentada, interromper a sua participação neste estudo. Caso se verifique esta situação, esta não resultará em qualquer penalização, ou perda de eventuais benefícios ou direitos.

Esclarecimento de Dúvidas & Contatos

Se você tem dúvidas sobre este estudo, poderá fazer agora todas as perguntas. Se quiser fazer perguntas mais tarde, desejar obter mais informações, ou desejar interromper a sua participação no estudo, entre em contato com o Investigador Principal em pessoa, por telefone ou e-mail. A informação de contato está disponível no início da primeira página deste documento.

Consentimento Informado Voluntário

Ao assinar este documento, você confirma que leu a informação acima descrita sobre este estudo, e que todas as suas perguntas foram respondidas. Assim mesmo, você poderá fazer perguntas adicionais a qualquer momento durante o estudo, e mesmo após este ter terminado. Ao assinar este documento, você concorda em participar neste estudo de investigação.

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ASSINATURA DO PARTICIPANTE DATA

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ASSINATURA DO REPRESENTANTE LEGAL (se aplicável) DATA

Investigador que Obtém o Consentimento

Como membro da equipa de investigação, confirmo que expliquei ao participante acima referido a natureza e finalidade deste estudo de investigação, e que esclareci quais os potenciais benefícios e eventuais riscos da participação no estudo. Todas as perguntas foram respondidas e estou disponível para esclarecer quaisquer dúvidas que possam surgir ao longo do estudo.

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ASSINATURA DO INVESTIGADOR DATA

Inform Consent (study reported in chapter 6)

Promoção da participação social e sentido de auto-eficácia na reabilitação do membro superior após um acidente vascular cerebral através de superfícies tácteis interativas para multi-utilizadores

Eu, abaixo-assinado, fui informado de que o Estudo de Investigação acima mencionado se destina a perceber o impacto social, emocional e motor da realização de jogos sérios num sistema táctil interactivo com recurso a objectos tangíveis.

Sei que neste estudo está prevista a realização de três momentos de avaliação para além de todo o processo de intervenção. Estes momentos serão imediatamente antes e depois da intervenção, assim como follow-up. Foi-me também explicado em que consistem e quais os seus possíveis efeitos.Foi-me garantido que todos os dados relativos à identificação dos participantes neste estudo são confidenciais e que será mantido o anonimato.Sei que posso recusar participar ou interromper a qualquer momento a participação no estudo, sem nenhum tipo de penalização por este facto.

Compreendi a informação que me foi dada e tive oportunidade de fazer perguntas e as minhas dúvidas foram esclarecidas.

Aceito participar de livre vontade no estudo acima mencionado e autorizo a divulgação dos resultados obtidos no meio científico, garantindo o anonimato.

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Data	Assinatura
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Nome do Investigador Responsável

Data	Assinatura
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