Chapter 4

The Design Process and Usability Assessment of an Exergame System to Facilitate Strength for Task Training for Lower Limb Stroke Rehabilitation

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Additional information is available at the end of the chapter

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Abstract

Successful stroke rehabilitation relies on early, long-term, repetitive and intensive treatment, which is rarely adhered to by patients. Exergames can increase patients' engagement with their therapy. Marketed exergaming systems for lower limb rehabilitation are hard to find and, none yet, facilitate Strength for Task Training (STT), a novel physiotherapeutic method for stroke rehabilitation. STT involves performing brief but intensive strength training (priming) prior to task-specific training to promote neural plasticity and maximize the gains in locomotor ability. This research investigates how the design of an exergame system (game and game controller) for lower limb stroke rehabilitation can facilitate unsupervised STT and therefore allow stroke patients to care for their own health. The findings suggest that specific elements of STT can be incorporated in an exergame system. Barriers to use can be reduced through considering the diverse physiological and cognitive abilities of patients and aesthetic consideration can help create a meaningful system than promotes its use in the home. The semantics of form and movement play an essential role for stroke patients to be able to carry out their exercises.

Keywords: engagement, rehabilitation, stroke, exergame, game controller, serious games, strength for task training

1. Background

With over 15 million cases worldwide every year [1], strokes are a leading cause of serious long-term disability [2, 3]. Up to 75% of people affected by stroke have lower limb mobility limitations [3, 4], including hemiplegia (muscle paralysis) or hemiparesis (muscle weakness) down one side of the body [5]. The World Health Organization (WHO) has highlighted the need for home health care that calls for rehabilitative devices, self-monitoring tools and self-management skills [6].

Success for stroke rehabilitation relies on early, intensive, long term repetitive treatment to regain motor control [5, 7] by learning to use existing redundant neural pathways [8]. However, although abundantly prescribed by clinicians, as little as 31% of patients perform these exercises correctly and consistently, often due to their monotonous nature [9].

Recent studies show that systems of rehabilitative devices with incorporated digital games for exercising (exergames) improve patient engagement with their home-based therapies. This has promoted beneficial patient outcomes for different long-term conditions, including upper limb stroke rehabilitation [5, 10, 11], and more effective recovery [12]. While there exist systems designed for upper-limb stroke rehabilitation [5, 13, 14] and for improving gait and balance [15–17], only one was found targeted specifically towards lower limb stroke rehabilitation [18].

1.1. Strength for task training

Strength for task training (STT) is a novel and promising approach to lower limb stroke rehabilitation [19]. STT combines priming the brain for learning through strength-based exercises, with task-specific movements promoting neural plasticity. Neural plasticity finds new pathways or rebuilds obsolete ones in the brain. These pathways establish the connection between the brain and subsequent muscle movement. Relearning these movements helps the patient attain better locomotion [19]. Priming involves the strengthening of the muscles using a weight or a resistance band while getting the patient to exert themselves as much as possible. This exertion creates corticomotor excitability. This primes the neural pathways in the brain so when followed promptly with task-specific training the brain is better equipped to promote neural plasticity [19].

While there are many systems of exergames for stroke rehabilitation, there currently exists an opportunity for the development of an exergame system that facilitates unsupervised STT for home-based lower limb rehabilitation. As an adjunct to clinical rehabilitation, this system could help promote therapy, optimizing recovery of lower limb function and reduce the load on the public health system.

2. Methodology

This project reports on the design and usability testing of a system that involves an exergame and game controllers for facilitating home-based STT for stroke rehabilitation. We used a research-through-design approach based on design criteria through a user centered and iterative design (UCD) methodology to involve the clinicians and stroke patients in the designing of the system [5, 14, 20]. Shirzad et al. [14] proposed that UCD for rehabilitative exergames consists of three stages:

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1. Understanding the contextual and functional needs
2. Generating feasible concepts and prototypes
3. Development of solutions and clinical assessment

Initial design criteria were developed through literature and design reviews [21, 22], expert reviews, workshops and interviews with stroke clinicians [23]. The design reviews included hundreds of sketches, paper models and quick prototypes. The interviews and workshops involved a PhD and practitioner in physiotherapy, a PhD and neurophysiologist expert in stroke rehabilitation, a PhD and Associate Professor psychologist and a PhD and Senior Lecturer in a Graduate School of Nursing, Midwifery and Health. Initially, we interviewed clinicians through semi-structured interviews and asked them how they facilitate STT. We developed hundreds of sketches and showed them to clinicians in a design workshop that lasted 3 hours to discuss the different ways in which STT could be deployed. The most promising concepts were prototyped and showed to clinicians in an expert review workshop that lasted 3 hours.

The design criteria are listed in **Table 1**. The list of criteria was used to design and build prototypes, test them with participants and clinicians, iterate several times and then to assess the final designs. The list of criteria was also useful to explicitly communicate the design knowledge produced through this research-through-design process. There is much embedded tacit design knowledge within the designed products in this type of research-through-design processes that it is necessary to make it explicit to clarify the findings of the research.

Function
The design should provide sufficient load for intensive hip abduction and extension during the priming component
The design should enable the user to perform part and whole tasks to maintain intensity during the task training component
Ergonomics and usability
The shoe should be able to be put on and taken off using one hand
The design should allow for load to be removed quickly and easily to facilitate priming
The design should allow for load to be added/removed handsfree
The shoe and weighted sole should be able to be put on and taken off without written instruction
The design should be easy to setup and use, reducing the number of steps required for interaction
The design should use materials that consider the movement of the stroke patient
The design should be comfortable
The design should be usable for patients at different stages of recovery
The design should allow for increasing complexity and challenge to facilitate the state of flow and increase engagement
The design should involve competition as an option to increase engagement
The design should include positive feedback along its many interactions and avoid negative feedback to increase engagement
The design should involve social interaction to increase engagement

Aesthetics
Areas of high contrast should help distinguish between the shoe's inner and outer
Areas of high contrast should help distinguish Key points of interaction
The designs aesthetic should reflect contemporary footwear appropriate for the audience
The user should not feel embarrassed wearing and using the design
The games should look like a game familiar to the audience

Table 1. List of design criteria that the design should fulfill based on literature review, review of existing systems, expert reviews, interviews with clinicians and stroke patients.

Initial concepts were produced and assessed using a decision matrix model [24]. This model involved using several potential designs assessed next to prioritized criteria. The criteria were developed and revisited based on literature research, interviews with clinicians and finally user testing. Concepts were evaluated accordingly until a final design concept was formed for subsequent prototyping. Prototypes were reviewed by clinicians then iterated. Subsequent prototypes were submitted to user testing with stroke patients.

3. Iterative design process

3.1. Selection of technology

Based on feedback from interviewed clinicians and from a review of the literature and existing devices, the following criteria were decided upon for the technology to be used (**Table 2**). From the clinician's perspective, the technology should allow STT movements to act as inputs for playing the exergame, including priming and task exercises. The literature includes similar exergaming systems that rely on stationary cameras (for instance Kinect), balance boards (Wii balance board), remote controls (Wii remote) or movement sensors. We compared those systems with the initial criteria for the selection of technology in **Table 2**.

3.2. Defining the therapeutic intervention

In discussion with neuro-physiotherapist experts in STT, two STT exercises were chosen based on their feasibility of being emulated in an unsupervised environment as inputs for the game: Hip abduction and hamstrings (**Table 3**).

3.3. Design process

3.3.1. The physical game controller

The prototypes tested of the physical controller were made up of two components: a pair of shoes and a weighted sole. The weighted sole can facilitate up to 2500 g of weight for use in intense strength priming.

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	Microsoft Kinect	Wii Balance Board	Wii Remote	Wireless IMU sensors and iPad
A	✓	×	✓	✓
B	✓	×	×	✓
C	×	✓	✓	✓
D	✓	✓	✓	×
E	✓	✓	✓	✓
F	×	×	×	✓
G	✓	✓	✓	✓

A: The design should allow STT movements to act as inputs for playing an exergame; B: The design should allow the user to perform priming and task exercise uninhibited by the game controller; C: The design should be reliably accurate; D: The design should be of a similar price to commercial gaming system; E: The design should be easy to setup and use, reducing the number of steps required for interaction; F: The design should be able to be played anywhere in the home; G: The design should have easy to use controls.

Table 2. Criteria for selection of technology.

After many iterations, the final concept builds on the idea of a slipper with a modular sole system. A sleeve around the ankle was added for resistance band attachment and the upper folds across the foot for ease of access. Shoe lasts, which are used to create the pattern for a shoe's upper, were digitally modeled and then 3D printed and iterated. This process allowed the experimentation with different last shapes that represent the dynamic foot types of stroke patients due to spasticity.

Load is applied differently to the foot according to the STT exercise. The priming component for hip abduction requires load to be applied to the foot using a resistance band. The priming component for hamstrings requires weight to be attached to the foot using a Westminster pulley. Modular soles of different weights were proposed to facilitate similar load to what is applied using the Westminster pulley.

3.3.2. The game

Based on feedback from clinicians, the final game is a set of dominoes, with the intention that our target audiences would be familiar with the game's mechanics. Initially, the player performs

Exercise	Hip abduction and sideways walking	Hamstrings and backwards walking
Priming component	Moving a straightened leg away from the midline with a resistance band attached to the ankle.	Sideways stepping with progression to elevated stepping onto a foam mat or stepping board.
Task training component	Attach weight to foot, bend at the Knee and move foot backwards.	Walking backwards with progression to backwards stepping and backwards walking + pivot.

Table 3. Definition of exercises selected to design the games: hip abduction and hamstrings.

strength-based priming exercises while wearing the weighted sole. This movement in turn shuffles a bag of dominoes in the game. Players progress through the game by performing sets of task exercises to push their dominoes into the desired position on the board. For instance, performing sideways walking task exercises moves the chosen piece of dominoes sideways to the desired location on the board. Mapping these rehabilitative processes to their in-game equivalents intends to help maintain immersion.

4. User testing

4.1. Users

Testing of the exergame system involved the smart shoe, weighted sole and gaming media. We completed three sessions of tests of the system at stroke clubs at 2-week interval with the findings influencing iterations to the design between each session. Inclusion criteria: aged >18; had experienced a disabling stroke; has or has experienced hemiplegia or hemiparesis following their stroke and can walk without standby assistance. Exclusion criteria: significant cognitive deficit; unable to follow a one step verbal command; unable to give informed consent; medically unsuitable in the opinion of the screening physiotherapist, G.P. or medical specialist; experiences excessive joint pain and suffering other conditions that could impact results (e.g. substance abuse, significant mental illness such as major depression).

Recruited participants (N: 3) included: one with left hemiplegia with little to no use of his left arm due to contractures and no fine motor control over his left leg; one can walk unassisted but has minor weakness on the right side of her body and one has right hemiparesis with minor issues with her balance.

4.2. Testing protocol

With consent from participants, testing took place in their homes. User testing took 25–30 min and involved usability testing followed by a short semi-structured interview and filling of a Geneva Emotion Wheel [25]. User testing involved the user putting on the smart shoe and playing one round of the Dominoes game 12–12 on the iPad. The game then prompted them to put on, use and remove the weighted sole for the priming component, followed by repetitions of STT's task component. Hip abduction and sideways walking were observed. The think aloud protocol was used to assist our observation to fill usability heuristics. Usability heuristics were created based on the relevant criteria that informed the ergonomic and usability requirements of the design.

4.3. User testing sessions

Three user testing sessions took place and design iterations addressed issues found in each testing sessions. **Table 4** and **Figures 1–4** show some of the main findings from the user testing sessions and how the redesign addressed them.

	How the re-design addressed the feedback
Feedback from user testing session 1	
It was assumed that the participant would place the shoe on the ground, then slide their foot into shoe, so an internal closing mechanism using this interaction was incorporated. This was accurate in one case, however two participants brought their affected foot up towards their midline to put the shoe on.	The internal self-closing mechanism was removed and the ankle straps were lengthened for a more adaptable fit. A heel tab was added to the heel to help with picking up the shoe and to help stop the heel collapsing when put on.
The length of the ankle straps proved to be an issue with how the fit of the shoe adapted from person to person. Although each shoe was designed to the shoe size of each participant, the shoe size of each participant ,the length of the ankle straps did not account for different ankle sizes. This resulted in fit issues as the velcro did not adhere properly.	The toe and heel clips were redesigned to sit on spring loaded rails. This would allow the user to either slide or clip their heels and toes into the weighted sole.
Participants found it very difficult to navigate the different elements of the game.	An overhaul of the user interface was necessary after the interactive elements were found to be too subtle. Objects such as buttons were given idle animations to draw attention and supporting text was made more explicit.
No pain or major discomfort was report from any of the users during the first session	
Issues with participants' balance became apparent during the priming phase. When lifting the leg with load attached all participants became unstable.	Load and mechanism to load weight were adjusted.
Early feedback on the look of the device provided some insight into form was received: " it's fashionable. Nowadays everyone wants to wear boots and I have one on".	
Feedback from user testing session 2	
Putting on the weighted sole proved to be significantly easier than the previous session.	
Confusion as to how to do up the shoe's straps.	The hierarchy of the straps was changed so the user would fold the top strap over their foot then wrap and adhere the ankle strap. The colour of different parts was changed to offer hierarchy and semantics of use.
Discomfort around the toes of the affected foot due to contractures.	The sole of the shoes was altered to consider abnormal foot shapes due to spasticity.
Removal of the weighted soles still provided some difficulty.	A fabric tab was added to the back of the weighted sole for removal and weight increments were recalibrated.
Shoe felt too cold.	The material of the shoe was changed to a felted wool outer and ultra-fine merino wool inner.
Regarding the game, more animated elements were needed, particularly for prompting players which exercise they needed to perform when.	Animations were implemented.
More encouraging feedback was also needed for possible mistake players might make during interaction.	Feedback elements were added.
Multiple testers become unsure of what to do when they made a mistake but the times they received assistive text they could reorient themselves without our assistance.	More feedback was implemented.

	How the re-design addressed the feedback
Feedback from user testing session 3	
The following issues were resolved: participants found the revised order of strapping a lot more intuitive and easy to use. All participants reported the shoes were a lot more comfortable and secure than the previous design. All participants could quickly remove the weighted sole after priming. Issues observed: one participant had trouble with getting the vamp over the top of his affected foot. One participant required assistance in engaging the weighted sole. No participant reported feelings of embarrassment towards wearing the shoes. Two participants commented that they would be proud to wear the shoes in their homes. One of them expanded on this saying he enjoyed that he was wearing something that "useful (to his rehabilitation) and fashionable". Two participants related their feelings of enjoyment and relief towards the hardware as it symbolized their steps towards making progress towards regaining their independence.	

Table 4. Feedback from the user testing sessions and how the design iterations addressed them.

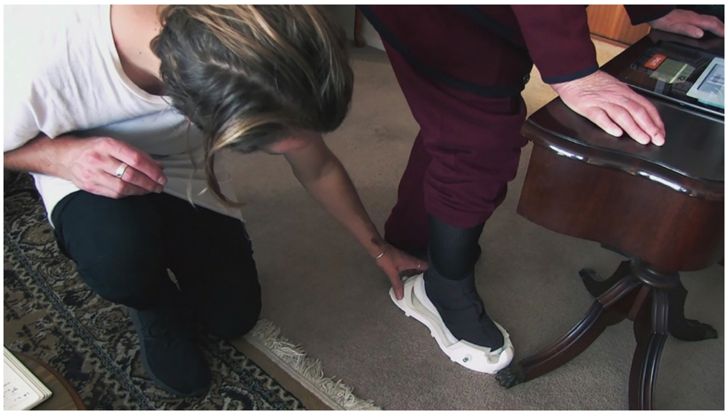

Figure 1. Helping a participant put on the shoes in the first user testing session.

Figure 2. The design of the shoe is intended to be used with one hand, which participants could do well.

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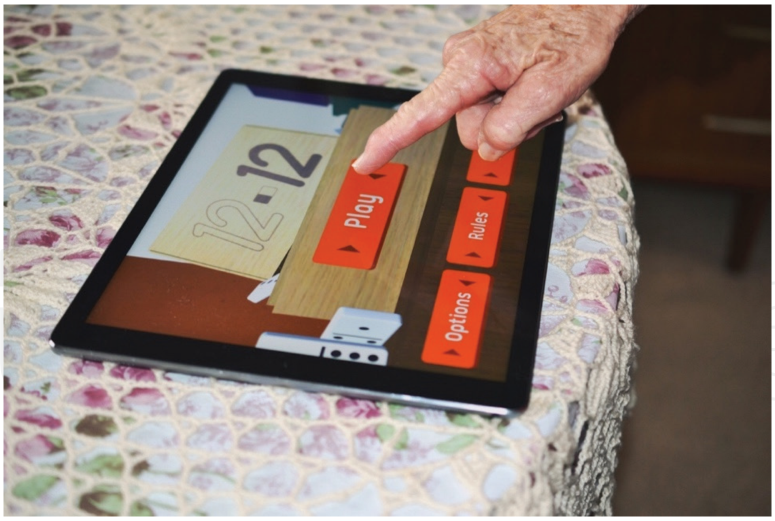

Figure 3. A participant using the game on a tablet.

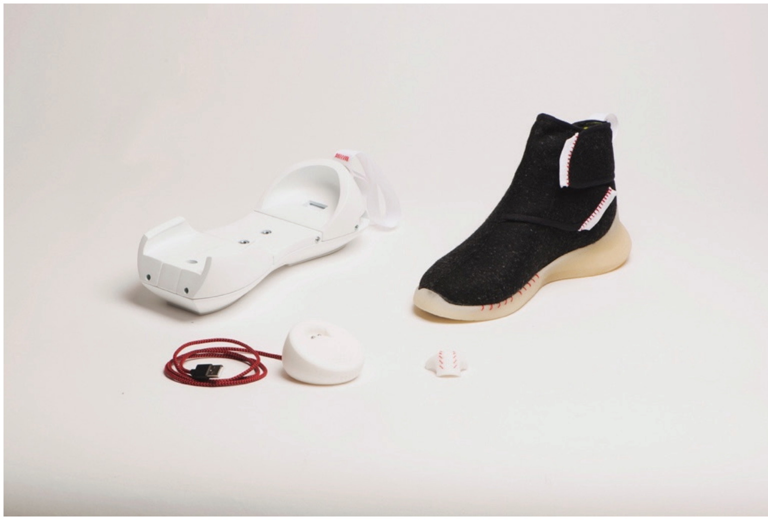

Figure 4. The physical game controller system: shoe, weighted sole, recharging dock, iMu sensors and cables.

5. Final design

Final changes to the design addressed small aesthetic and usability concerns brought up in the final user test. The vamp was given slightly more stretch to help with the upper stretching over the foot to reduce time taken to put the shoe on. Red stitching was used on the toe clips to highlight what foot the user should be using the weighted sole. A small magnet was added to both the back of the heel clip and the fabric loop to minimize risks of tripping. The form of the weighted sole was changed to minimize the look of complexity and bulkiness reported by participants. All mechanisms were internalized concealing any complexity. The form was also streamlined to take away any protruding componentry. The size of steel plates added to increase load was also changed. Small uniform profiles allow the weight to be changed at smaller increments and distributed evenly across the weighted sole. **Figures 5–8** show the final design of the shoe-game controller.

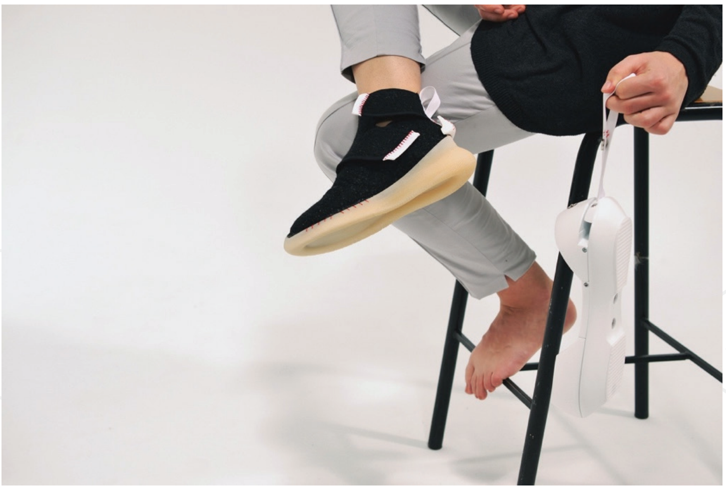

Figure 5. Putting on the weighted sole one-handed.

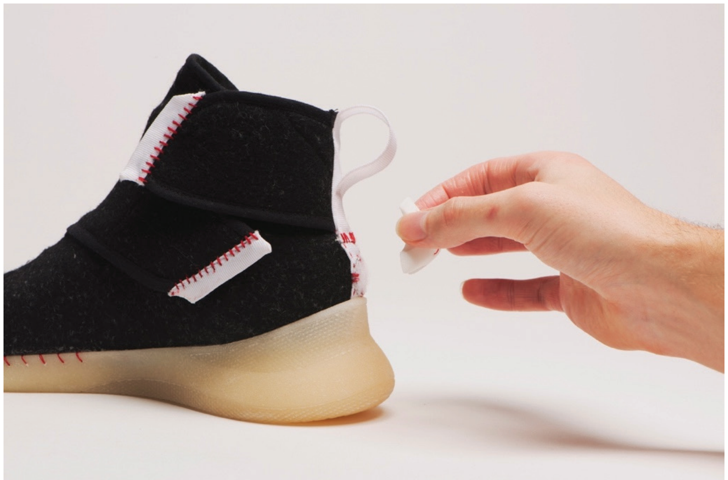

Figure 6. The iMu sensor clips into place on the back of the shoe.

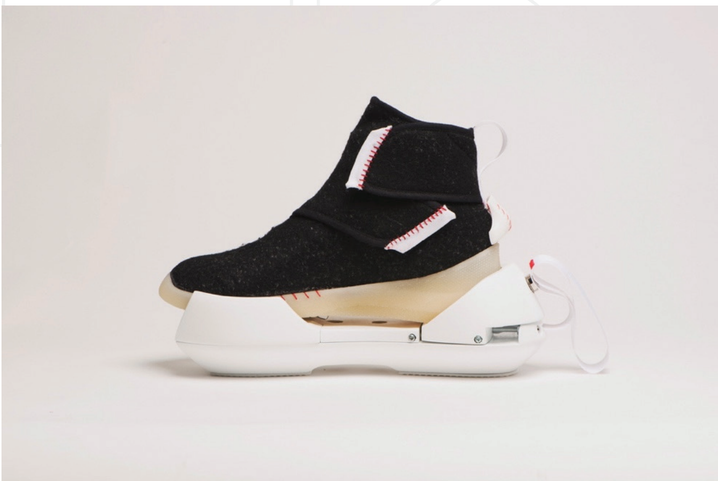

Figure 7. The shoes clipped onto the weighted sole.

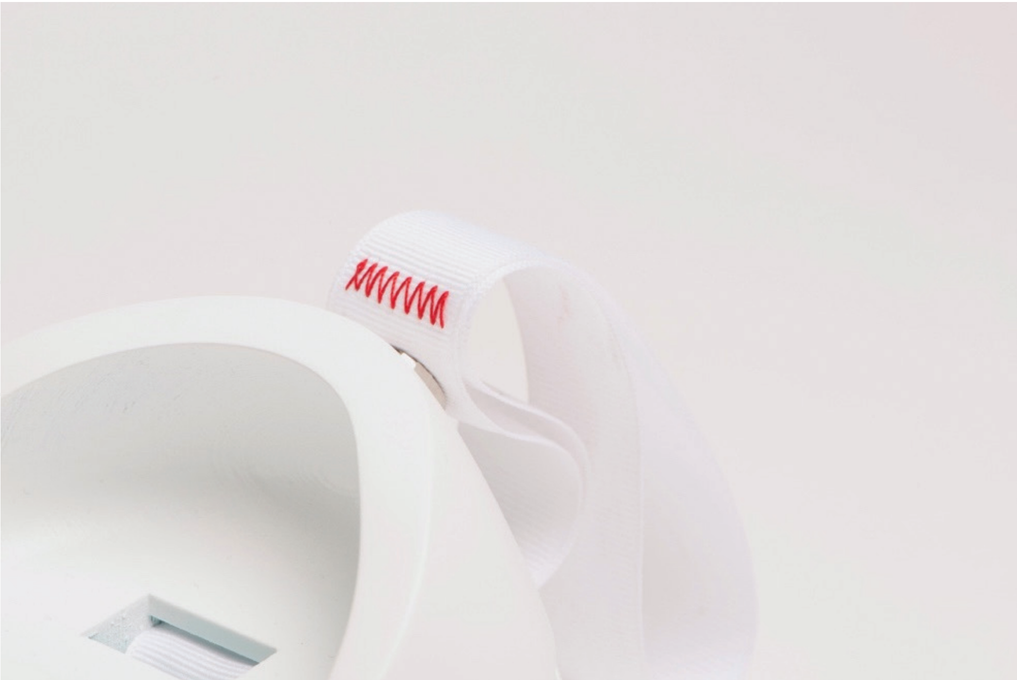

Figure 8. Detail of the clipping mechanism for the weighted sole.

The final version of 12–12 has a reduced user interface and options menu to minimize the chance of overwhelming new players. Enough options were kept allowing for variation in the game's complexity with a failsafe to ensure the game remained playable regardless of what player changed. 12–12's tutorial feature was enabled by default, taking users through a predetermined game that allowed them to experience the different mechanics. The tutorial requires 15 priming exercises and 30 standard repetitions to complete. **Figures 9–13** show elements of the design of the game.

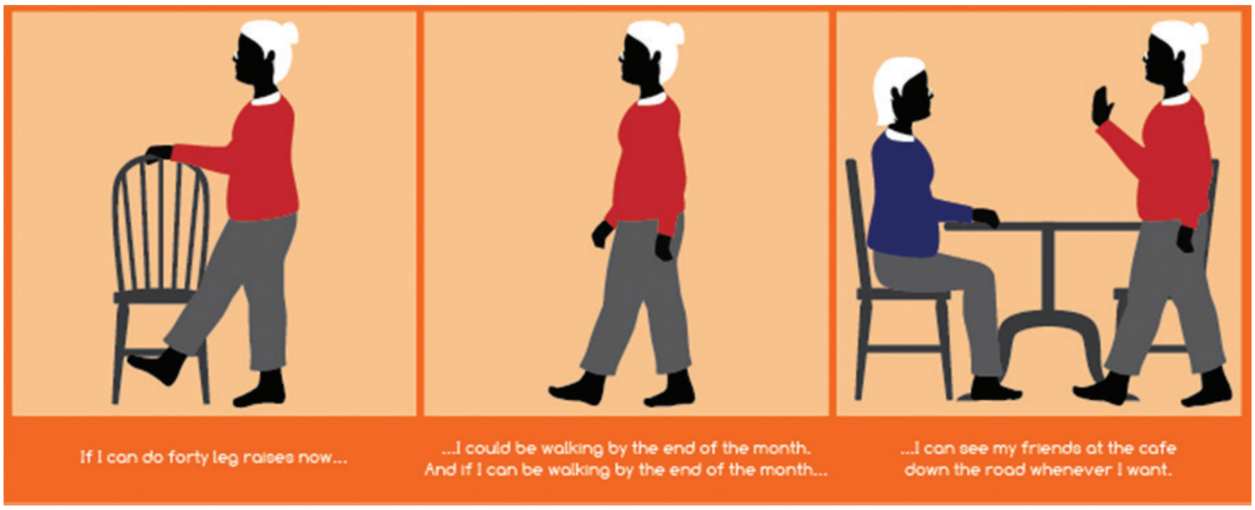

Figure 9. Progression of tasks to motivate users engage in their exercises. Left: "If I can do forty leg raises now…"; centre: "…I could be walking by the end of the month"; right: "…I can see my friends at the café down the road whenever I want".

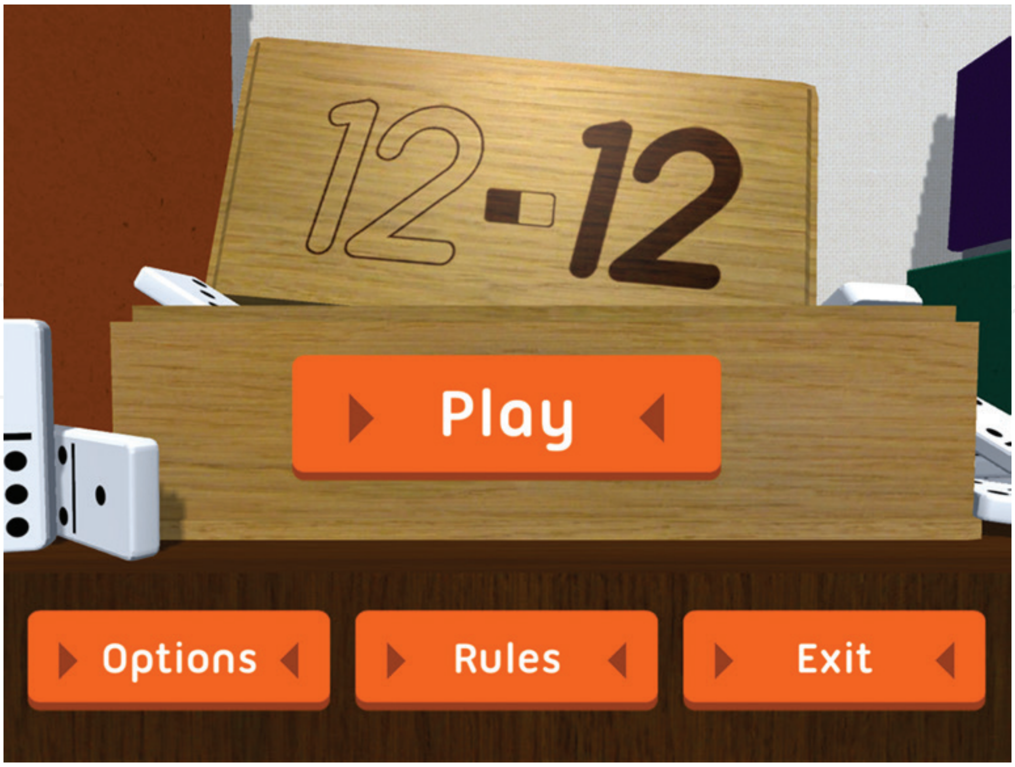

Figure 10. Home menu of the game.

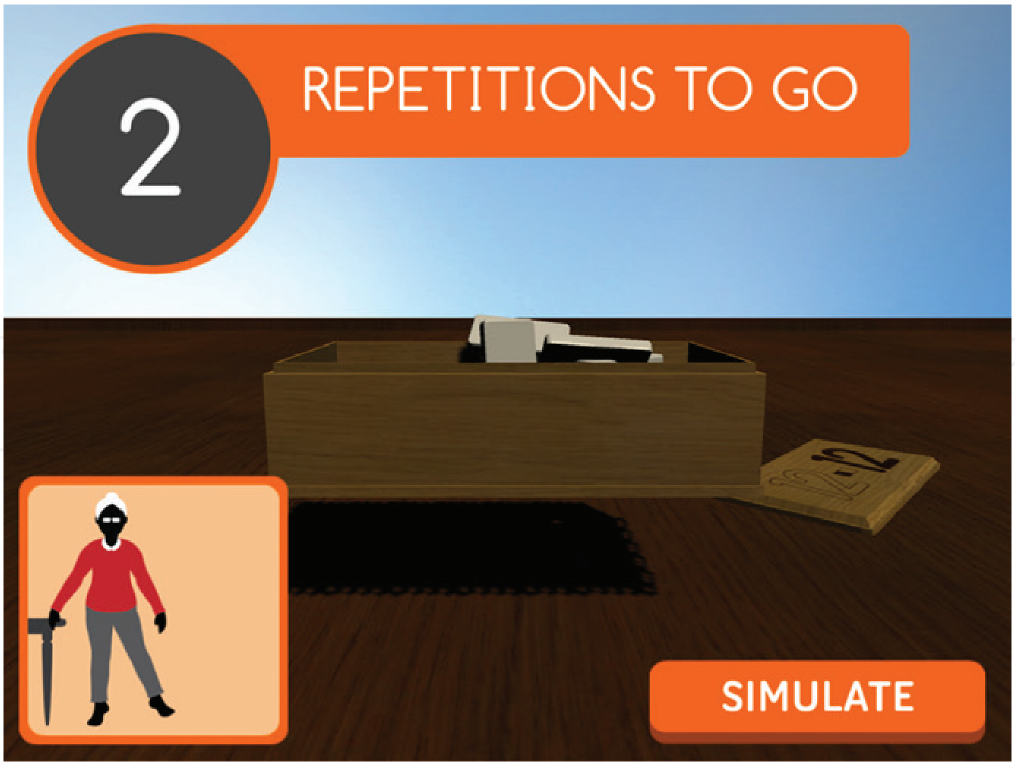

Figure 11. Initially, and to shuffle the box of dominoes, the user performs strength-based hip abduction exercises, which primes their brain for learning.

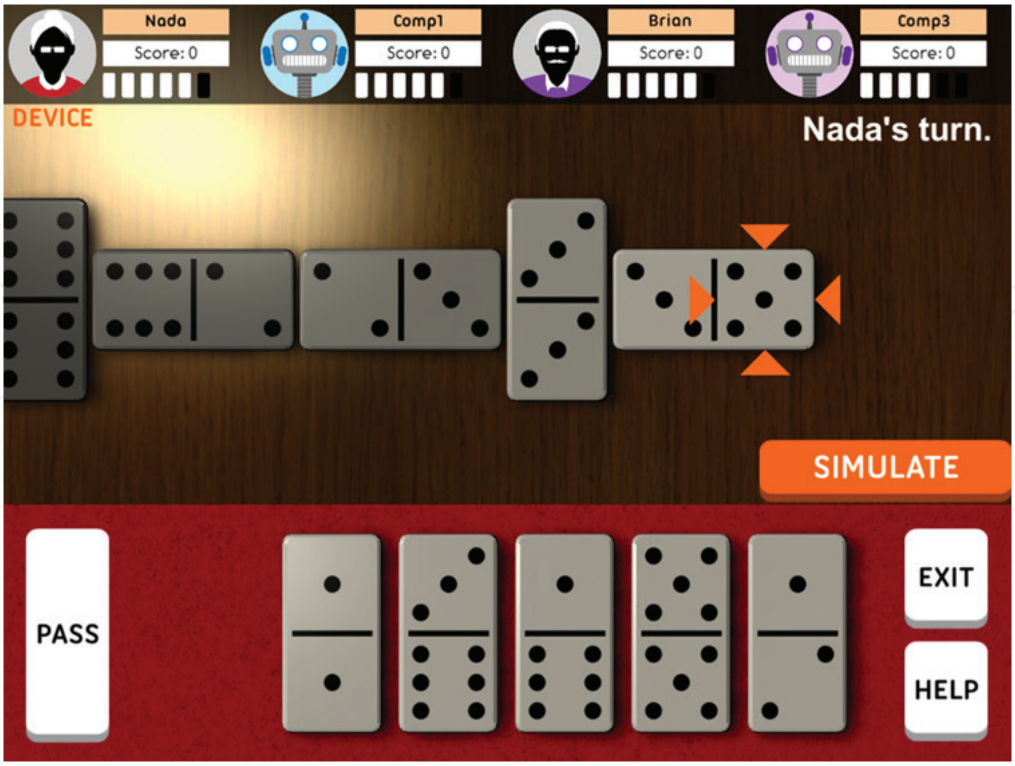

Figure 12. Tabletop of the game.

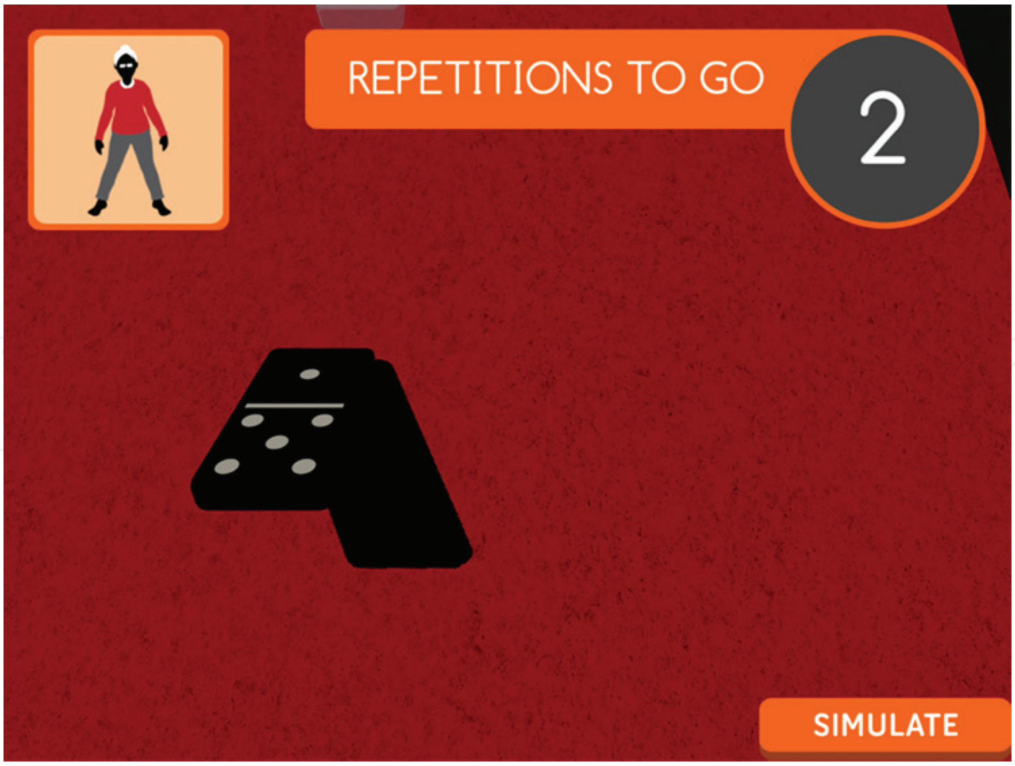

Figure 13. To move the piece of dominoes, the user needs to perform their task exercises. In this case, sideways walking makes the piece of domino roll to the player's chosen location.

6. Discussion

The findings from user testing of the system suggest that the hardware can facilitate aspects of STT in an unsupervised environment. Currently, STT is only conducted in a clinical environment. Facilitating STT through the medium of an exergame could provide an engaging way to motivate the user to perform this lower limb therapy intensively and consistently in their home. This not only can reduce the load on the public health system but also can help maximize patients' locomotive gains and retain their mobility and subsequently their independence.

The design requirements of the system proved to be complex due to the diversity in our target audience. The functional criteria of the hardware were primarily defined by the requirements of STT. Ergonomic and usability requirements aimed to minimize barriers to using the exergame in an unsupervised environment. Addressing the diverse cognitive and physiological abilities of stroke survivors was paramount to overcoming these obstacles. The aesthetics of the system were designed to address the stigma of medical intervention products within the hardware and make the exergame's interface as cohesive as possible for an audience unfamiliar with digital technology.

6.1. Evaluation through design criteria

The final designs were evaluated according to the design criteria developed throughout the process (**Table 5**).

6.1.1. Functional requirements

Priming and task training components of STT can be used as a means of interaction with gaming media. A gaming controller in the form of a smart shoe could be used to track movement of the lower limb noninvasively.

Initial user tests indicate that intensive hip abduction priming can be facilitated by securely and comfortably fixing load in the form of external weight to the smart shoe. Load must also be specific to the user's capabilities through adapting the weight of the sole. Avoiding resistance bands during unsupervised rehabilitation also circumvents fall risks and their observed erroneous use outside of a clinical context. By mitigating the use of resistance bands unsupervised this ensures the priming component is intensive yet safe and manageable, keeping the user motivated to continue using the exergaming system. Clinician review of the weighted sole also indicated that beyond STT, any unsupervised rehabilitative strength training could benefit from the design's ability to mitigate the use of resistance bands.

Maintaining intensity during the task training component requires increasing the complexity of the task. Complexity is increased across nine components, part and whole task being one element where the patient must complete more dynamic movements as they progress. Testing indicates that creating footwear that provides a comfortable and stable base of support can allow the user to perform movements of increased complexity this progression demands.

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Initial design criteria	Assessment based on design criteria	Explicit design knowledge applicable to this system based on criteria
Function		
The design should provide sufficient load for intensive hip abduction and extension during the priming component.	Clinicians reported that the load was sufficient for the patients tested. However, load needs to be adjustable.	The added shoe can add load for STT. However, this adds height and imbalance. Depending on user, exercises should be done either sitting or with good support.
The design should enable the user to perform part and whole tasks to maintain intensity during the task training component.	The users could perform part and whole tasks and maintained intensity.	Exergames can separate between part and whole tasks.
Ergonomics and usability		
The shoe should be able to be put on and taken off using one hand.	All participants were able to put the shoes on using one hand.	Large openings for inserting the feet into the shoe and large straps facilitate one-handed use of shoes.
The design should allow for load to be removed quickly and easily to facilitate priming.	All participants could remove the load immediately when needed.	A pullable tab can facilitate quick release of extra sole.
The design should allow for load to be added/removed handsfree.	All participants could add and remove the load handsfree.	A click step-on system can facilitate adding an extra sole to shoes.
The shoe and weighted sole should be able to be put on and taken off without written instruction.	All participants needed instruction on how to put on the load the first time. They could do it independently subsequently.	Initial instruction of how to put on a new sole system in shoes is needed.
The design should be easy to setup and use, reducing the number of steps required for interaction	There are many steps in the full interaction including shoes, load and game. All were reduced to a minimum during the different interactions were easier with less steps.	Reducing steps in the interaction can help with its usability.
The design should use materials that consider the movement of the stroke patient.	All participants could move and perform the exercises.	Soft felt and flexible 3D printing filament (TPU) can produce shoes that allow movement of stroke patients.
The design should be comfortable.	All participants reported the shoes were comfortable. However, all needed to have the tablet on a table to be able the games.	Soft felt and flexible 3D printing filament (TPU) can produce shoes that users report as comfortable.
The design should be usable for patients at different stages of recovery.	All three participants were at different stages of recovery and all found the games usable. However, the designs have not been tested within participants as they progress in their recovery.	Games with different stages of difficulty can cater and be usable for different stages of recovery in stroke patients.
The design should allow for increasing complexity and challenge to facilitate the state of flow and increase engagement.	All participants reported that the different levels increased complexity. However the results are unclear at this stage whether the participants entered a state of flow. Further research needed in this area.	Different levels of complexity in the design of games can induce different levels of challenge.

Initial design criteria	Assessment based on design criteria	Explicit design knowledge applicable to this system based on criteria
The design should involve competition as on option to increase engagement.	All participants were keen to participate in competition through the game.	Competition based on known games (in this case dominoes) resulted in a natural understanding and willingness to engage in competition in rehabilitative games.
The design should include positive feedback along its many interactions and avoid negative feedback to increase engagement.	All participants reported feeling encouraged by the feedback in the game.	Feedback based on pop up messages as individual tasks are completed (for instance shuffling the dominoes pieces or moving individual pieces within the game) can be encourage for participants.
The design should involve social interaction to increase engagement.	All participants were keen to play with other participants through the game.	A social interaction based on an already known game (dominoes) was easy to adapt to an acceptable social interaction in game for rehabilitation.
Aesthetics		
Areas of high contrast should help distinguish between the shoe's inner and outer.	There was no report on this from participants. When prompted, they agreed that it was easy to distinguish.	High contrast can help distinguish between shoe's inner and outer when this is important for the interaction.
Areas of high contrast should help distinguish key points of interaction.	Participants were able to find key points of interaction.	Areas of high contrast can help users distinguish key points of interaction.
The design aesthetic should reflect contemporary footwear appropriate for the audience.	All participants expressed that the shoes and designs had high aesthetic appeal.	The design of the aesthetics of shoes for rehabilitation is both discernable for users and important for their willingness to use them.
The user should not feel embarrassed wearing and using the design.	The participants initially expressed their desire to own the system and did not express embarrassment.	The aesthetic of rehabilitative system can influence the desire of users to own the system and avoid embarrassment.
The games should look like a game familiar to the audience.	All participants understood the game as a dominoes game immediately.	Using a game familiar to the audience can help with its intuitive use.

Table 5. Assessment of final designs according to the design criteria.

The flexibility of game options allowed for 12-12 to be playable by a range of people with different physical capabilities. User tests made it apparent that there was a cognitive threshold to the game that meant survivors of stroke who had suffered severe cognitive deficits would not be able to play. A version of the game with reduced functionality, therefore reduced expectations of the player, would be necessary for making 12-12 accessible to this subgroup of our target demographic.

6.1.2. Contextual requirements

Ergonomics and usability. The dynamic range of abilities that survivors of stroke possess must be addressed to ensure that the patient can use lower limb exergame hardware independently and intuitively. To consider the physiological effects of hemiparesis, one-handed interaction was necessary to complete all tasks. Observation of tests indicated that, apart from Ned needing assistance to put on the weighted sole, participants could put on and take off the shoe and weighted sole independently. It is critical that hardware promotes its use across all ability levels.

Reducing time between strength and task training components was crucial to facilitate priming. User observation illustrated that the design of the weighted sole enabled the user to remove load and promptly begin task training. This suggests that the hardware can maximize corticomotor excitability during strength training to subsequently enhance neural plasticity during the task component. Effective priming maximizes the patient's gains in locomotive ability helping them regain independence.

An unanticipated but important outcome was the feeling of pride participants felt after figuring out how to complete certain interactions with the exergame system. We speculate that reducing cognitive/physical challenges rather than removing them completely could create a more beneficial experience for the user. In addition to this, it is apparent that more consistent feedback from the system to the user will help maintain their confidence in its use. Our user testers enjoyed the 'you can do it' mentality of the game and wished to see more feedback throughout their experience that let them know if they were progressing or not.

Aesthetics. Feedback suggests that aesthetic consideration of exergame hardware can remove any medical semantics and address the stigma towards using medical devices. By designing a game controller that was considered a "fashionable" piece of footwear, the user avoided the feeling of embarrassment while wearing and using the smart shoes. Counter to the praise of the footwear's aesthetic, the weighted sole receives critique on its perceived complexity.

Beyond "fashionable" semantics, the aesthetic seemed to resonate on a deep emotional level with participants. The design elicited emotions that relate to positive progress that the patient was making in their recovery. Moreover, participants seemed to find that wearing shoes does not just make rehabilitation novel and motivating but also can act as a tool to help them regain their independence. Furthermore, just knowing that there was something designed specifically for them made the user feel valued as a person. Based on these results we speculate that the aesthetics of an exergame controller could transcend the stigma towards medical devices and help create a meaningful object that represents the survivor of stroke's journey back to independence.

Lastly, the aesthetic of the game yielded no complaints from participants. They reported it to be vibrant and the text was easy to read. This aligned with the works of [26], Gerling et al. [27], Ijsselsteijn et al. [28], Kopacz [29] and Martin et al. [30], which informed most of the design decisions regarding the game's interface.

7. Conclusion

Stroke is a leading cause of disability in developing nations leading to impairments affecting patients' locomotion and limiting their independence. Research into exergames for rehabilitation is an emerging field; however, the benefits they present make further exploration a necessity. STT is a novel intervention for lower limb stroke rehabilitation, which aims to promote gains in locomotion, however currently only practiced in a clinical environment. This research has contributed to the greater field of exergame rehabilitation tools by investigating how the design of an exergame controller could facilitate unsupervised STT for lower limb stroke rehabilitation.

The functional and contextual requirements of an exergame and its controller were explored through background research and interviews with stroke clinicians. These initial requirements informed the design and prototyping of exergame and its controlling hardware as part of an exergaming system for unsupervised STT.

Smart footwear that interacts with an adaptable strength training weighted sole to control an exergame was prototyped and tested. Functional requirements of the system promoted a way to strength training safely and comfortably by applying load to the lower limb. The weighted sole that provides load was removed to promptly begin task training to facilitate the merits of priming. The interactions with the system needed to be intuitive and facilitate a one-handed interaction. Aesthetic consideration of the hardware and exergame indicated that the system could disrupt the stigma of using medical devices in the home and become a meaningful HCI system in the user's life.

Reviews with clinicians and feedback from user testing with stroke patients helped to substantiate and build on the functional and contextual requirements and to better understand how exergaming systems can facilitate clinical interventions like STT. The growing population of stroke patients represent a diverse and complex demographic target group. The final design could benefit from further testing with a wider user base of patients over longer periods of time.

There is a growing amount of research examples in the field of exergaming media design; however, little research furthering the design of purpose built game controllers has been done. There is undiscovered potential through a designerly approach to exergaming HCI. More case studies into these processes could help foster an abundance of novel and innovative design discoveries and broaden the abilities of home-based rehabilitation systems.

We have presented a complete exergaming system with meaningful HCI that is user friendly and provides a safe way to participate in home based stroke rehabilitation. This research has proposed a way to enhance the lives of survivors of stroke and potentially the wider population of people living with muscular disabilities, such as multiple sclerosis and cerebral palsy. Further research into similar systems can benefit the ageing population and assist those seeking to reclaim their independence, and it should involve a full assessment on the effectiveness of the system to improve stroke rehabilitation and its ability to increase adherence to therapies.

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