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Reviewing the Evidence: In Pursuit of a Framework for Parkinson Disease Rehabilitation with Games

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Abstract. Exercise gaming has been receiving a significant interest from both consumers and researchers. Be it for the purposes of weight loss, physical fitness or even just enjoyment, the potential of games to support rehabilitation has also been under investigation for a while. Due to our aging society, game based therapies could be a solution for optimizing resources and reducing rehabilitation costs. This paper aims to discuss the potential capacity of games as systems to enhance the relation of physical exercise and cognition for the rehabilitation of Parkinson Disease. Our investigation demonstrates that there is no established methodology for games in rehabilitation of Parkinson's addressing how games can encapsulate physical exercise strategies while providing safety, continuous monitoring and cognitive development exercises in facilitation of rehabilitation. Since rehabilitation with games is trending, yet to be developed rehabilitation strategies would benefit from new insights into the relationship between game worlds, physical exercise and motor-cognitive training. Therefore, it is useful to do further research into realizing (1) a relational model that demonstrates the relation between game world (composed of game features including formal game elements, audio-visual features, mechanics and dynamics), motor skills, cognition and physical exercise for both generic and specific rehabilitation purposes, (2) a structured task creation approach for game features that reconciles specific rehabilitation outcomes, correct level of engagement, task difficulty and safety requirements for target demographic.

Keywords. Parkinson's disease, rehabilitation, exercise games, cognitive training, motor training, tasks, methodology

Introduction

Parkinson's disease (PD) is a progressive neurodegenerative disorder with an increasing prevalence across the world [1]. The primary symptoms of PD are motor symptoms; tremor (trembling fingers, hands etc.), rigidity, bradykinesia (slowness in movement), and postural instability (balance impairment) caused by the deterioration of muscle strength. Although subtle bradykinesia is also observed in healthy elders with declining capacity for repetitive movements, the scale of bradykinesia caused by PD is the most common neurodegenerative cause of parkinsonism. Besides the motor-symptoms, there

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are also non-motor symptoms including depression, cognitive impairment, visual disturbances and sensory abnormalities, autonomic dysfunction, fatigue, apathy and sleep disorders. These non-motor complications lead to decreased quality of life and decreased independence as PD progresses with combined motor and non-motor symptoms. At the later stages of the disease, many patients need continuous assistance to maintain their daily living activities besides continuous treatment. The economic impact of PD in USA exceeded $14.4 billion in 2010, expenditure comprising the costs for medical treatment and surgery, compensation for income, and social security payments [1]. While the age group for diagnosis is mostly between 40-70, prevention strategies reducing the progress of cognitive decline with lower costs are important.

Game based interventions look promising as individualized rehabilitation tools that can potentially reduce the rehabilitation costs [14]. However, there is neither enough development on how game based exercise rehabilitations should be structured for a higher clinical validity and reliability nor enough discussion into the selection process of game elements. The question we pose is how games can encapsulate physical exercise strategies, contribute to exercise-cognition relationship positively, and provide appropriated game elements as a safe and reliable system; in particular, for PD rehabilitation. Therefore, it is beneficial to develop (1) a relational model demonstrating the relation between game world, motor-cognitive skills and physical exercise and (2) a task creation framework that reconciles specific rehabilitation outcomes, correct level of engagement, task difficulty and safety requirements for target demographic.

This paper presents a perspective by reviewing the existing game based and physical exercise strategies in the rehabilitation of PD. As a preliminary step towards formulating a relational model and a framework to inform future game based exercise rehabilitation strategies for PD, this paper comprises the following sections: exercise strategies and rehabilitation of PD, cognitive training and games, game based exercise interventions for PD and discussion.

1. Exercise Strategies and Rehabilitation of PD

Recent studies have been demonstrating exercise therapy to be an effective complementary therapy for the rehabilitation of PD while creating positive effects and supporting symptom management [2]. Regular exercise with moderate to high intensity is commonly advised as a supporting therapy by both physiotherapist and occupational therapist [3]. In fact, there is strong evidence supporting the positive effects of high cadence aerobic exercise [4, 5] with several studies noting that moderate to strenuous exercises, such as cycling, leads to a significant improvement in symptom progress. After an exercise intervention of 16 weeks, Goodwin et al. [4] observed that aerobic endurance exercise (utilizing a treadmill, bicycle, or elliptical trainer) improved overall function, balance, and movement efficiency for patients with mild to moderate PD.

Several reviews evaluating the further potential of exercise based rehabilitation approaches concur that there is a lack of structure in establishing a validated intervention clearly and consistently reporting on the severity of the disease, progression of the conditions, retention and safety measures [2, 4, 6, 7]. Although exercise therapy is known as beneficial, patients do not really seem motivated for physical rehabilitation because of the fear of injury, pain and discomfort [8]. Considering that muscle strength degradation and balance impairment are common

conditions among elders and PD patients, high consideration for falls and protective adjustments to the intensity of the exercise to prevent injury become very important [9]. On the other hand, there is evidence suggesting that motor improvement may not be driven purely by cardiovascular or metabolic mechanisms but with high-cadence low-intensity composition [5]. This could be a useful insight for exercise games targeting PD rehabilitation for clearly identified tasks in relation to the role of exercise and progress of symptoms.

2. Cognitive Training and Games

Abilities that drive the execution of human behaviors are called executive functions and are vital for quality of life. These behaviors require both motor and cognitive skills to be in harmony. Several studies have investigated the cognitive benefits of exercise training, yet the direct relation between physical activity and cognition has not been clearly understood. Even though physical exercises that do not require any cognitive skills are expected to have no contribution to executive functions [10], a former study by Duchesne et al. [11] stated that significant improvement was found for inhibition component of executive function after a three-months aerobic exercise training regimen. However, flexibility component of the executive function was not improved at all. Therefore, when discussion refers to physical exercise and cognitive training, their relation needs to be understood further so that games can be integrated into their connection for a more effective system.

A literature review for cognitive training by Kueider et al. states that videogames can affect global cognitive functioning as well as improving specific cognitive domains for elders [12]. Based on eight studies reporting cognitive performance after training with a variety of commercial videogames, they conclude that "videogames appear to be an effective means of enhancing reaction time, processing speed, executive function, and global cognition in older adults", emphasizing on reaction time and processing speed as the largest impacted aspects. However, their analysis does not present evaluation for the games, their features or effectiveness for a particular cognitive skill. When a specific cognitive training software and Nintendo Wii[2] games are compared via a parallel controlled randomized user study aiming to compare their ability to enhance cognitive performance, researchers concluded that non-specific computerized training, aka. Wii Sports games, at least has the same degree of cognitive benefit as training with the cognitive training tool [13]. Moreover, game based training showed a higher success in transferring the training into the real world.

3. Game Based Exercise Interventions for PD

Most of the studies evaluating the use of games for PD are reporting the use of commercial games in particular Wii Fit games with the Wii balance board peripheral [14]. Although none of these studies explicitly take into account the special requirements for PD patients (requirements related to motor and cognitive demands or any special conditions), a few of them identified potential cognitive benefits in their user studies. Mendes et al.'s controlled trial [15] pointed out the similarities and

[2] http://wiifit.com/

differences between the conditions of early stage PD and aging symptoms of healthy elders. They demonstrated that despite the progressive nature of the disease, PD patients and healthy elders display similar improvements in transferring motor abilities trained in the games to similar untrained tasks. On the other hand, in some games, there were certain barriers preventing patients from performing as effective as healthy elders. They were observed in actions that require fast reaction and dual tasking with further cognitive demands including response inhibition, decision-making, divided attention and working-memory. These cognitive demands are listed among executive functions, and are affected with the development of PD. Although physical exercises were only shown to improve inhibition component of executive functions [11], there could be potential to provide training with a physical exercise strategy that is combined with a game environment posing challenges to train other components of executive functions.

A number of studies, as seen in Table 1, explored motor-cognitive training with the Nintendo Wii platform. Some positive results were obtained in these studies, yet there is not much discussion into the other aspects of motor-cognitive training targeting any specific symptoms, game selection criteria or the relation of game elements to the training. Esculier et al.'s work [16], among all, was the only home-based balance training program, showing that moving the rehabilitation out of the clinic/lab is possible. However, neither was the difficulty of play reported for the selected games, nor were they discussed in connection with rehabilitation purposes identifying their relation with the training.

Some custom games were also developed in a few studies. Assad et al. [17] developed a set of mini games utilizing the Sony EyeToy for whole body interaction to promote upper body exercise with circular/horizontal arm movements and big hand gestures with the idea of motor and cognitive training. However, the connection between the games' features and training was not clearly identified, and no progress monitoring or customization was present. Galna et al.'s [18] participatory design workshop empowered patients to help in designing a game for their own rehabilitation. Their design and the tasks were informed by an existing theoretical model of balance dysfunction and focused on specific aspects inherited from this model. However, the discussion about the relation between game features, exercise regimen and specific symptoms (both motor and non-motor) was insufficient.

Hermann et al. [19] presented a local multiplayer game with the Kinect SDK to understand the cooperation aspect of gaming referring to group training sessions for PD. Since their study was aiming to look into multiplayer aspects of play (perhaps towards the motivation via social play) rather than the game design, there was no explicit discussion regarding the task creation, difficulty consideration, appropriateness of actions or how those actions were related to the rehabilitation.

There are also a few game based exercise studies for elders [20, 21], mostly investigating fall prevention by targeting balance and upper body movement. Although some of these contain training and assessment features more so than game features, the investigation into the potential of home based rehabilitation deserves recognition. However, no work has been done on motivational factors to encourage long-term use of a game based exercise that also combines cognitive and physical training while assessing and ensuring patient safety.

Table 1. Studies that employ the Nintendo Wii platform and Wii games for game based rehabilitation of PD

Study	Games	Platform & Peripherals	Objectives of the study	Notes
Mendes et al. [15]	TT, PS, SH, TTw, BS, BRP, TC, RP, OC	Wii Fit + Balance board + Wii Mote	Motor and cognitive training with tasks that require planning, sequencing, flexibility, physical motion, weight shifting and inhibition.	Mendes et al. reported that PD patients were unable to improve their performance in SH, BRP and OC. SH was especially reported difficult because of quick decision making and inhibition of action.
Pompeu et al. [22]	TT, PS, SH, BS, BRP, TC, RP, OC	Wii Fit + Balance board + Wii Mote	To verify performance improvement on Wii Fit games and comparison of motor-cognitive training with Wii against balance exercise therapy for activities of daily living.	Cognitive demands of the games were attention, working memory and performance management, while further discussion was referred to Mendes et al.'s study [15]. Nonetheless, they reported that Wii-based motor-cognitive training and balance exercise therapy showed similar gains in activities of daily living; also, Wii based rehabilitation potentially improved motivation.
Esculier et al. [16]	TT, BB, SJ, SS, PS	Wii Fit + Balance board	To improve balance and functional abilities of PD patients via improving muscle strength.	No specific discussion was provided regarding the games or play sessions. The study concluded on the potential of improvements in static and dynamic balance.
Zettergren et al. [23]	TT, BB, PS, RP, FS, IC, OC	Wii Fit + Balance board	Effects of Wii training on gait speed, balance, functional mobility, depression.	IC was discontinued due to difficulty, yet no discussion or reasoning was provided. RP was also discontinued because participant found it very difficult due to the fast paced rhythm. OC was discontinued because the participant found the required series of stops and starts difficult to perform.
Zimmermann et al. [13]	Table Tennis Archery Swordplay Air Sports	Wii Sports Resort + Wii Remote + Nunchuk	Non-specific training for cognitive purposes compared against specific cognitive training	Researchers reported that specific cognitive training did not provide greater cognitive benefits than Wii training for attention, working memory, inhibition, and planning as followed up with neuropsychological assessment. However, there is no discussion regarding games' features or selection criteria.
Herz et al. [24]	Bowling Tennis Boxing	Wii Sports + Wii Remote + Nunchuk	Effects of training with Wii on motor and non-motor symptoms of PD.	They stated that the selected games required logic, visio-spatial function, sequencing and motor planning with correctly timed action. However, there is no explicit discussion on which features are fulfilling these requirements. No significant difficulty was reported.
Mhatre et al. [25]	BR, Skiing, MT	Wii Fit + Balance board	Improved balance, decreased postural sway, and improved quality of life. Also, balance confidence.	No discussion regarding the game selection is present despite mention of the need of specificity through the selection of games.
Liao et al. [26]	Football MB, BB, SS	Wii Fit + Balance board	Improve muscle strength, sensory integration ability, and walking abilities in comparison with traditional exercise.	No discussion regarding the selected games, their features or any difficulties in playing those. They found that Wii Fit training is as effective as traditional exercise.

TT = Table Tilt; PS = Penguin Slide; SH = Soccer Heading; TTw = Torso Twists; BS = Basic Step; BRP = Basic Run Plus; TC = Tilt City; RP = Rhythm Parade; OC = Obstacle Course; BB = Balance Bubble; SJ = Ski Jump; SS = Ski Slalom; RP = Rhythm Parade; FS = Free Step; IC = Island Cycling; BR = Bubble Rafting; MT = Marble Tracking; MB = Marble Balance.

4. Discussion

A common factor that is missing in many of the aforementioned studies is consideration of the game world. A game world is composed of game features including audio-visual elements, game mechanics and dynamics. Considering the relation between mechanics, dynamics and aesthetics as a useful model to motivate game design [27], it is important to realize the relation of the design with physical and cognitive training approaches. Some design principles already emerged through Assad et al.'s [17] development. These principles were based on the specific needs of patients, comprising appropriateness of movement, positive feedback, simplicity, adaptability, rhythm, and familiarity. Although these principles are very sensible as usability guidelines, they present limited insight for the design regarding the relation of game elements and cognitive aspects, or a relation of game elements to active physical exercise. They may be useful to inform the design of mechanics and dynamics; however, they are not detailed enough to enable a deeper understanding of how physical and cognitive training can inform the design of specific game features for specific conditions. Also, neither audio-visual aspects of the games nor aesthetics imposed by the design have been considered so far.

4.1. Need for a Relational Model

A relational model regarding the mediating effects of exercise on cognition was suggested by Etnier [28] in order to identify the nature of the exercise-cognition relationship; *mediation* as the explicit relation, the *mediators* as the influence mechanism, and the *moderators* as the elements influencing the properties of the relationship. Common pitfalls of game based interventions are inconsistent measures, lack of monitoring, suitability of game elements and psychology of feedback mechanisms [14]; a further insight into the relation of games to both physical and cognitive training would be beneficial. This insight can be developed via a model that explains what games can offer in relation to exercise-cognition relationship. An example of this is a classification framework for clinical decision making in pediatric rehabilitation to facilitate the selection of appropriate equipment [29]. Similar to this classification framework [29] and Rego et al.'s [30] serious games for health classification, a methodology to identify and select or develop appropriate games for specific training purposes is needed. By using Rego et al.'s taxonomy, a recent study [31] looked at some existing game platforms, yet there was no consideration of any games/products coming with the platforms under investigation, and even no elaboration on how to apply the classification points. Therefore, it is not possible to know whether a particular platform that seems appropriate based on its capabilities identified in the classification framework is going to be useful or not because the motor and cognitive load of the game/environment provided with the platform is undefined. Besides, there are contrary perceptions about the mini-games provided in the Wii Fit library: some studies were using a game for just targeting motor or cognitive skills while some others were using the same game for both [13, 15, 31]. For an effective rehabilitation, the connection of game elements to motor-cognitive training and executive functions is as important as the gaming platform. Hence, a model that demonstrates the relation of game system, game features, task sets, physical exercise and target motor-cognitive

skills would help to establish a grounded structure for both developing game based customizable rehabilitation strategies and utilizing existing gaming platforms.

4.2. Need for a Task Creation Framework

Almost all game based interventions have been employing existing commercial games without much explanation about why these games are chosen or how the features of the selected games are serving the particular purpose. Most of the time, the reasons of selection have been about the peripherals and equipment being aligned with the purpose of the rehabilitation, such as using a balance board for balance training, as seen in Table 1. As an exception, Mendes et al.'s study [15] is quite explicit about the target symptoms of the disease, and how these are targeted with certain mechanics in the selected games. However, due to the commercial off-the-shelf nature of these games, there is no possibility of adjusting difficulty based on the various conditions of the participants. Further study into customizable systems and systems that can adapt to the participant's status would improve the quality and effectiveness of interventions. Moreover, established safety precautions including but not limited to considerations about the risk of fall, heart rate, potential injury to joints should be taken into account for further studies, especially the ones reaching up to aerobic exercise levels [24].

In order to develop adaptive, safe, effective and consistent game systems, a task creation framework should address constraints and their impact on symptoms, incorporate exercise principles, enhance symptom improvement and potential activities, and inform the design for appropriate game features. Considering the constraints with regard to visual stimuli and the sensitivity to sensory input (in some cases even causing freezing) [3], games developed for PD rehabilitation should take such sensory complaints into account as well. In addition, task creation must be informed with the relational model for an established game based exercise intervention framework. The relation between a specific game feature and a specific condition of the disease can be very effective, e.g. visual cues making a greater effect than auditory cues on gait initiation in PD [24].

Many of the aforementioned studies target activities of daily living (ADL) through the interventions. ADL is composed of both motor and cognitive abilities, most of the time combined abilities, such as obstacle negotiation while walking or buttoning a shirt. So far, literature does not contain a clear and structured task creation framework for composite tasks, nor game features. Nevertheless, studies with commercial games help to identify the potential of game mechanics and their success for different conditions.

Game based interventions can provide a motivational contribution to the traditional physiotherapy approaches since repetition —especially under the stress of a health condition— can be psychologically demoralizing and demotivating. Taking into account that there is no definitive structure/approach or methodology to target specific positive outcomes [14], exercise games must implement approaches to provide positive feedback and motivation, adaptable challenge to a specific patient's condition and inbuilt safety across all game features. In pursuit of a framework for game based exercise intervention, task creation methodology should build a bridge between established motor-cognitive training tasks and game features.

Conclusion

In this paper, we discussed our perspective on the state of the art towards the development of effective game based rehabilitation systems for PD. Since physical training for PD rehabilitation is more established than game based interventions, we discussed potential lessons from studies in both areas. The evidence shows that games are capable of motivating cognitive and physical exercises for PD rehabilitation, yet there is limited work to inform such therapies for suitability and effectiveness of game elements. As discussed in section 4, there is a significant gap in the literature for game-based therapies that are customizable and adaptive; that have established safety precautions, clear goals and well-structured tasks targeting specific symptoms; and, that utilize game features to enhance the benefits of physical and cognitive training. Iterating from this review towards establishing a methodology, further research needs to be done to find out how games can encapsulate physical exercise strategies while providing safety, continuous monitoring and cognitive training. We believe that further development in this area can hugely benefit from (1) a model explaining the relations of physical exercise, cognition and game features, and (2) a methodology for task creation in conjunction with game features that are suitable for specific conditions.

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