ABSTRACT
This paper investigates the design guidelines for developing exergames that aid cognitive ability in older adults. A great majority of the older adult population suffer from cognitive impairments such as dementia, with limited effective intervention or prevention mechanisms available. I have reviewed seminal work in the area of exergames, focusing on empirical studies that aim to integrate effective video games and physical activities to leverage cognitive ability in older adults. There is a need for exergame design which combines both cognitive and physical training components to help increase motivation, usability, and interaction for the elderly.

Author Keywords
Exergames; exergaming; video game motivation; exercise motivation; physical activity; cognitive performance; cognitive function;

ACM Classification Keywords
H.5.1 Multimedia Information Systems
H.5.2 User Interfaces (D.2.2, H.1.2, I.3.6)
I.3.7 Three-Dimensional Graphics and Realism

INTRODUCTION
Cognitive impairment such as dementia is a common phenomenon observed in older adults, with gradual decline in reasoning, attention, memory, and processing speed [9]. The underlying cause for decline in cognitive performance is usually dependent on individuals' mental and physical conditions. Researchers have suggested that cognitive performance can be improved with increased levels of mental, physical, and social stimulation [9]. The former two mentioned can be achieved through regular involvement with exergames, that combine video games and physical exercises to promote user engagement and motivation [1, 2, 9]. However, a great majority of exergames designed today target young to middle-aged adults, with only a minority focusing on adults above the age of 60 (older adults). The game complexity in terms of the genre used, difficulty level settings, ease of understanding game objectives, and the physical activity involved is not suitable for the older adult population. Since exergames have the potential to improve age-related cognitive performance, there is a dire need for design guidelines for developing exergames that cater to older adults.

A new wave of input technology has been introduced in the gaming industry to ease the effort of game manipulation. Some well-known examples include balance boards, wireless remotes, and motion detectors [2, 3, 4, 7, 8, 9]. These input mechanisms support minimal physical movements for users to manipulate objects in a virtual game. This gives the elderly a chance to interact with the exergames without reducing motivation and risking their health [7, 10]. Similarly, video game designs with simple objectives and game elements have been designed to stimulate cognitive training [3, 5, 6, 8]. There is limited research carried out in identifying cognitive and physical aspects that need to be considered when designing exergames. In this paper we aim to study the recommendations of exergame design for older adults, and review literature where exergames have been designed specifically for them. The scope of this paper includes articles published in 2010 or later, apart from one seminal piece of work published in 2008. The first section reviews four seminal studies, examining the effect of exergames on cognitive performance and the internal game design. In the second section, we examine popular recommendations of exergames design for older adults and analyze the evaluations and findings. We conclude with the overall finding of the paper in relation to the research question, and discuss possible implications for future work.

EXERGAMES AND COGNITIVE PERFORMANCE
There is a dearth of research investigating the effect of exergames on cognitive performance. We will review four seminal body of work that look at different exergames and their internal design of game elements, and how they provide significant evidence for potential cognitive benefits. Three out of the four studies specifically focus on the cognitive improvement for the elderly, while the remaining study focuses on young adults (see Appendix).

Game Manipulation
The exergames in three studies [1, 2, 9] use virtual 3D video games, where actions are either controlled by an external apparatus or through gestures. Only one study focuses on a 2D interactive game that requires full body movements to control the actions in the 2D space [7].
Although the 3D interactive games are similar in terms of the interface, they differed in terms of the control functions used to manipulate objects within the game. Anderson-Hanley et al. (2012) investigated the cognitive benefit of cybercycling when compared with traditional stationary cycling. The game design consisted of 3D virtual-reality tours that can be experienced using a stationary cybercycle. The participants had to interact directly with the virtual game through cycling, an input mechanism, enabling them to navigate through the game. Similarly, Maillot, Perrot, and Hartley (2012) studied the effect of Wii sports on cognitive function. Wii sports are known for their realistic nature of gameplay, where an apparatus such as a Wii balance pad or Wii remote is used to manipulate 3D objects in space.

In contrast, the study by Gao and Mandryk (2012) appeared to be more intuitive for users as it involved hand gestures to interact with the game. The game required participants to pick green and red apples, and avoid bombs falling down. Following this gesture based manipulation, Kayama et al. (2014) designed and implemented a virtual 2D Sudoku game, where placement of numbers was achieved through full body movements (Tai Chi style). This was incorporated to combine the minimal cognitive and physical training required for improving cognitive performance.

Game Types
The genre of the video game being played has an implicit effect on the development of different cognitive domains. Depending on what aspects of the cognitive domain the game makes use of the most, there is a possibility to see an increase in cognitive performance. In the study [1], the authors selected a real-time 3D adventure game, which is known for exerting less pressure on users in terms of complexity and challenges involved. They observed that the 3D virtual-reality tours appealed more to participants who had less or no experience playing video games. The Wii sports belong to the sports genre that are competitive and game, which is evident through [9]. It requires quick decision making skills, long-term attention span, and good eye-body coordination. Incorporation of sport based games in exergame design can enable users to train both mentally and physically. The video game design used in a study [2], requires users to pick certain objects and to avoid others. This gameplay falls into the category of casual games that involve simple rules and challenges, and can cater to a wider audience belonging to different age groups. Lastly, the strategic gameplay used in study [7] showcases the use of game elements that force to increase cognitive ability. The virtual Sudoku game requires users to carefully think and analyze the placement of numbers to win the game. The cognitive domain associated with planning and execution functions are tested and challenged, improving cognition with each additional interaction with the game.

Game Evaluation and Findings
The four studies evaluated the effect of exergames on cognitive performance, differing slightly in the experiment design and participant demographics. The first study [1] carried out a randomized clinical trial over a period of 3 months, involving 79 volunteers over the age of 55. The results showed that older adults who exercised using the exergame had significantly better executive function than the control group. This can be attributed to the inclusion of the 3D virtual video game, intrinsically motivating participants to exercise without feeling overwhelmed by the intensity and time spent. It works as a cognitive training exercise because of the incorporation of game based elements that require a lot of mental preparation, concentration, and decision making skills.

The results of the second study [9] indicates significant benefits of exergame training on cognitive function, specifically executive control and processing speed tasks. This study has a control group that is fully controlled for, when compared to other studies which has participants exercising without the virtual video game. This makes it difficult to imply if exergames alone have the potential to improve cognitive performance, as the effect of exercising without the videogame is not accounted for. However, there is enough evidence to suggest that exergame training with sport play has a positive impact on certain aspects of cognition.

Another study [2] that evaluated the effect of playing a casual exergame for 10 minutes a day has reported a significant improvement in cognitive performance than when compared to other activity types. Although, the study involved young adults and the research topic was by large focused on cognitive benefits on older adults, the promising results found can be extensible to the wider adult population. Short periods of exercise have a positive effect on acute cognitive ability. This claim by the authors is interesting as it opens the possibility of attracting older adults to play casual exergames. The easiness of understanding and setting up the exergame, and interacting with it for short intervals is suitable for the elderly as the process is not exhaustive and physically demanding.

And finally, the results of the study [7] shows that full body movement based game training has a positive influence in improving cognitive functions and physical fitness. Sudoku game involves a lot of cognitive thinking and reasoning, which possibly could have resulted in the improvement observed. However, it is not clear whether the mutual combination of exercise and a mentally challenging game (Sudoku) had an effect on cognitive performance, or if it’s mutually exclusive to the strategic nature of the Sudoku game.

EXERGAME DESIGN FOR OLDER ADULTS
Age-related problems limit the physical and cognitive ability of the elderly, making exergames unappealing and
inaccessible. This section provides an overview of recommendations that promote increased usability, motivation, and appeal to the current exergames. It also discusses the development of exergames adhering to the recommendations (see Appendix).

**Design Recommendations**
We have deduced the top four common recommendations provided by authors from various studies, as listed below [4, 5, 6, 10]. We will further discuss each point in detail to see the implications of integrating them into exergames design.

1. A clear user interface
2. Less complex core mechanics
3. Simple interaction
4. Minimal physical activity
5. Difficulty level

The user interface is the visual display that users can see and interact with, and therefore should be designed keeping the size of elements on screen in mind [5, 10]. Because a great majority of older people have eye-sight problems, the instructions and game elements on the screen should be slightly larger than usual. The instructions should be clear and easy to understand, and avoid high contrasting colours in the background [5]. Lastly, it should integrate a “help” feature for continuous user support while playing the game [10].

Less complex game elements within the game will foster quick learning and understanding of the game rules and goals. This will be useful for users with cognitive impairments, who can improve their cognitive ability by regular interaction with simple games that target different cognitive functions [4, 5]. The design should avoid action oriented components as it demands high level of cognitive performance [4]. Strategic, adventure, and casual games are more suitable for this age group, as they exert less pressure on cognitive performance.

The simple interaction takes into account the physical and cognitive aspects of gameplay. The manipulation of objects, whether through an apparatus or gestures, should be intuitive, easy to follow and recall. If gestures are to be used, an optional tutorial or pre-game trial should be offered to users [6]. Also, the importance of visual and audio feedback has been reported to increase engagement [4]. Designers could associate positive visual and audio effects for successful experiences, and negative effects for alerting them of unsuccessful experiences. Finally, the interaction mechanism should cater to different input mechanisms, for example, navigation of a virtual object either through standing on a balance board or while sitting and controlling a remote [10].

The physical activity of the body can be reduced by using simplified hand gestures or minimal body movements. Because video games span over a longer period of time, the physical activity will induce exhaustion that may hinder users’ gameplay or affect their health condition [10]. In order to prevent this, the exercise part of the exergames should consider less physical exertion, avoid extensive or sudden movements, and monitor the heartrate to ensure it complies with their health parameters [4, 6, 10]. Additionally, providing short breaks between gameplay will help with relaxing and recovering from fatigue more effectively [6].

The game design must be flexible and adjustable to suit the players’ level of comfort. It is important to consider the effect of cognitive impairment on gameplay competence. Therefore, the option to choose the difficulty setting, which applies to the speed, challenge complexity, and type of input, should be accommodated [4, 6, 10]. Although, the difficulty of the game may be reduced, the game elements integrated should be designed for cognitive training. The motor skills of the user should not be hindered in any manner, but instead be matched with the exergames [6]. This ensures that the usability and accessibility of the exergames is increased for both active and non-active players [4].

**Exergames Developed and Evaluated**

We will summarize the development and evaluation of exergames that have been designed to comply with the recommendations discussed above. The studies vary in terms of the guidelines selected for implementation, and the implications of adhering to recommended is discussed in the evaluation section.

Gerling, Schulte, and Masuch (2011) developed SilverPromenade specifically targeting older adults living in rest homes. The in-game design requires users to experience virtual walks in a forest, with additional mini games along the way (Figure 1). The two inputs for game manipulation are through Wii balance board and Wii remote. The walking movements are controlled by steps taken on the balance board. The mini games incorporated involve the user to pay attention to the surrounding forest area, watching out for specific animals. Once an animal is spotted they have to either point or shake the Wii remote accordingly to gain points. This simple exergame design adheres to the five recommendations mentioned earlier. The user interface is made simple with less visual elements on screen at any given time. The adventurous genre reduces pressure on cognitive function as only attentive gameplay is increased for both active and non-active players [4].
Gerling, Schild, and Masuch (2010) implemented a very simple exergame that requires users to avoid obstacles on the screen to obtain scores (Figure 2). The users have to control a red square, which represents the user, through a balancing act on the Wii balance board. The difficulty is incremented after a set of obstacles have passed, increasing the speed of destructive objects being dropped. The core mechanics of the game requires less cognitive effort to understand the instructions and objectives. The input can be used while standing or sitting down, catering to different physical needs of the user. Although, the difficult increases as the game is played, the ease of usability and competitive nature of the game motivating. A very similar exergame was developed by Leinonen et al. (2012), where certain coloured objects had to be collected and certain objects had to be avoided. The input mechanism was through a mobile phone, either held in hand or connected to a balance board. The cognitive complexity of the game was reduced with minimal interaction with game elements. The user interface provided had a white background with distinctive coloured objects, making it visually pleasing for the elderly.

Gerling et al. (2012) designed an exergame involving a gesture set, based on four simple body movements (Table 1). The game requires players to perform full body movements for growing a flower garden. The context of the game and objectives are strategic based, asserting minimal pressure on cognitive function. Prior to the gameplay, the user will be prompted to enter basic information about their individual physical abilities. This ensures that the game elements and difficulty level will be adjusted appropriately. A clear user interface with enlarged game elements was developed to increase the interaction between real and virtual worlds. The interaction was simple as it is guided by a less exhaustive and intuitive input mechanism (gestures). Following this work, Planinc, Nake and Kampel (2013) designed an exergame based on hand gestures. Participants have to use hand gestures to catch yellow coloured fish and avoid red fish. This obstacle based casual game reduces the pressure asserted on the cognitive domain because of the simple game mechanics. A scoring system is displayed on the screen at all times, increasing extrinsic motivation. The in-built audio sounds are enabled when points are scored or lost, alerting the users of the outcome. Lastly, usability is leveraged with settings provided for game difficulty and option to select single-player or multi-player.

<table>
<thead>
<tr>
<th>Gesture</th>
<th>Static</th>
<th>Dynamic</th>
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<tbody>
<tr>
<td>Gesture 1</td>
<td>Hands together</td>
<td>Clap hands</td>
</tr>
<tr>
<td>Gesture 2</td>
<td>Raise one arm</td>
<td>Wave arm</td>
</tr>
<tr>
<td>Gesture 3</td>
<td>Arms to the side</td>
<td>Pretend to fly</td>
</tr>
<tr>
<td>Gesture 4</td>
<td>One-leg stand</td>
<td>Walk in place</td>
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Table 1. Overview of static and dynamic gesture sets.

Overall, the evaluation of exergames designed specifically for older adults yielded positive outcomes. The findings suggest that the exergames provide an enjoyable gaming experience [3]; the minimalistic design allows them to focus on the game more easily [4]; the game improved their motor skills, especially hand-eye coordination [8]; and increased interaction, when gestures are involved [5]. However, further empirical studies need to be carried out to make concrete conclusions.

CONCLUSION

Exergames have been found to increase cognitive performance and physical fitness through combining exercise and gameplay. However, the current generation of exergames are not effectively designed to cater to the physical and cognitive needs of the elderly. Reviewing current literature based on exergame design guidelines and recommendations, it is evident that clear user interface, less complex in-game mechanics, simple interaction, reduced physical activity, and inclusion of managing game difficulty can possibly increase usability of the exergames. In the current project we are looking at improving an exercycle game to aid cognitive performance for older adults. It would be interesting to examine the influence of integrating
different input technologies and game elements into the current game design, to see whether it has any beneficial impact on user motivation and engagement.

**FUTURE WORK**

There is a prominent gap in literature relating to the effects of age-related problems (cognitive and physical) on playing digital games. Most of the studies used to draw design recommendations consist of inadequate empirical data to provide strong evidence. This gap can be addressed through further research, carried out to investigate the interrelationship between gaming and age, gaming and gender, and the influence of gaming on cognitive and physical aspects. The evaluations for a limited number of studies designed for older adults, focused on people living in old age or nursing homes. This introduces a bias, as the game design and findings cannot be generalizable to the wider category of older adults over the age of 60. It would be essential to address the intermediary age range that has not been covered, which may be achieved by investigating distinctive age ranges. Lastly, a longitudinal intervention study would need to be conducted to explore the long term implications of exergaming on both cognitive performance and physical fitness.

**REFERENCES**


### Appendix

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<td>Dual-Task Tai Chi (DTTC) - virtual 2D Sudoku game</td>
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</tr>
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<td>N/A</td>
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