

Assessing the effect of exercise intensity on cognitive task performance in an exercise video game

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Abstract

Exercise video games encourage people to be more physically active by combining entertainment and physical movement. On the other hand, conventional sedentary video games attract players with challenging mental tasks and puzzles. We address the question as to how performance on such tasks is effected by physical movement when they are placed in the context of an exercise video game.

Sports psychology research suggests a general improvement in cognitive task performance during and after physical activity. To assess if these findings can be replicated in the domain of exercise video games, we present an experiment in which we monitor the performance of game players on text comprehension, reaction time, and virtual target shooting tasks while cycling for several minutes on a recumbent bicycle. Our results suggest that the former two tasks are unaffected by exercise intensity, while the ability to perform the latter task is hampered under higher levels of exercise intensity.

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1. Introduction

The recent commercial successes of video games integrating physical movement, such as WiiSports and Dance Dance Revolution, have indicated a demand for games which are more active than sedentary video games. While such games have been shown to elicit a significantly greater energy expenditure when compared to playing sedentary video games, these games are still insufficient in contributing towards a healthy amount of exercise, especially for children and adolescents [6]. This presents a challenge for exercise video game developers, who must design games which provide players with a viable amount of physical activity while maintaining the attractive and entertaining features of sedentary video games.

Past research in computer-aided exercise and exercise-video games has shown that adherence to exercise programs is improved when players can feel immersed in a virtual environment, alleviating the sense of monotony experienced by conventional exercise (i.e. jogging on a treadmill) [19]. Adding elements from sedentary video game to an exercise activity, such as race checkpoints or reward systems, can provide a player with a sense of accomplishment, as well as the motivation to continue playing the games over multiple sessions [10]. Unfortunately, many such exercise games are still reported to be not as entertaining as conventional sedentary video games.

Sedentary video games are hardly "mindless entertainment", as they were once dubbed; they typically contain many forms of challenging mental puzzles and tasks, requiring a combination of cognitive faculties to formulate strategies and overcome obstacles. Aside from the obvious entertainment values of video games, frequent video game players report enjoying games which are pleasantly frustrating, and those that allow for players to master a set of skills [5]. It has yet to be shown if these aspects of sedentary video games can be integrated successfully into exercise video games, as this integration may render exercise video games more appealing and accessible.

A large body of sports psychology research has identified several cognitive processes which are facilitated by acute bouts of exercise, some processes which are unaffected by exercise, and other processes which exhibit an inverted-U pattern of ability dependent on exercise type, intensity, and duration [8]. Given that many of these processes are routinely called upon during conventional video game-play, these findings generally support the integration of conventional video game tasks into exercise video games.

In this paper, we examine the possibility of adding a subset of tasks commonly found in today's popular sedentary video games to an exercise video game environment. We have developed an environment in which players perform three types of cognitive tasks, including a text comprehension task, a reaction time task, and a virtual target-shooting task. These tasks are carried out while cycling under different levels of exercise intensity on a recumbent bicycle. We discovered that these tasks were generally unaffected by activity level for short durations of exercise.

The paper is organized as follows. We first survey existing exercise video games, examining strengths and weaknesses of several approaches. We then turn to cognitive psychology and sports psychology research to provide overviews of the effects of video games and physical activity on cognition. Finally, we present the results of an experiment using our exercise video game environment.

2. Related Work

In this section, we will provide a context for this work by reviewing exercise video games, the effects of conventional sedentary video games on cognitive ability, and the effects of exercise intensity and duration on cognitive ability.

2.1. Computer-Aided Exercise and Exercise Video Games

Conventional video games offer substantial entertainment value. This is accomplished partially by the experience of projecting oneself into the game space, to be immersed in a virtual world. Augmented reality games have been shown to provide this immersion with positive results [17].

Augmented reality has also been used in the field of computer-aided exercise to create a more immersive environment for exercise use [11]. While this approach has been shown to provide a user with a richer, less monotonous exercise environment for stationary cycling purposes, the experience is not very game-like, with participants reporting that it felt more like exercise than a video game.

In order to improve upon these early findings, exercise video game development research has adopted several strategies to help motivate sedentary people to be more physically active, in addition to providing an immersive game environment. Providing more interaction with the virtual world using biometric feedback is one such approach, as is incorporating collaborative and competitive aspects from multiplayer games. Yim and Graham surveyed several features of exercise programs and conventional video games which may facilitate an increased motivation to start and maintain an exercise program using an exercise video game [20]. These include the integration of contextually-appropriate game music, the ability for users to set and achieve short and long-term goals, and the availability of leadership or instructional roles within the game to assist and motivate new players. This latter point is drawn from the fact that many successful conventional video games contain initial game levels which are really tutorials lessons [5], occasionally using a non-player character to guide the player. In the context of exercise video games, the presence of a virtual coach or trainer character can have encouraging effects on novices [3].

Simply being immersed in a game environment is not sufficient for generating a sense of accomplishment, especially if the exercise component is monotonous and heart rate is maintained at a set level. This sense of accomplishment is another key motivating factor in adhering to an exercise regime. This can be facilitated when the actions and biometric feedback from the player have more of an effect on the contents and speed of the game [10]. Masuko and Hoshino developed a boxing game that monitored the heart rate of the player, and actively adjusted the speed and difficulty of opponents in the game according to heart rate feedback. This feedback also allowed for alternating intensity levels

within the game, providing an exciting and unpredictable experience. This control can be adjusted to achieve an effective heart rate for the individual, thus providing an appropriate workout in addition to an immersive gaming session. Buttussi, Chiattro, Ranon, and Verona extended this model to a more general free-movement exercise game involving the control of a virtual avatar using coordinated knee bends and side-to-side jumps [3]. Their system also maintained an adaptation engine and a user model which could be updated over multiple exercise sessions, increasing the exercise intensity appropriately as a particular player improved, thus providing an incentive for the player to maintain an exercise program using the game.

Yim and Graham also recommended incorporating aspects of massive multiplayer online games to motivate players and facilitate the ability for friends to exercise together, even over a distance using a networked connection [20]. Aside from the enjoyment people experience when playing a game with other players, this feature can be particularly useful in the context of exercise video games, as it can allow for users of different fitness levels to play together, without the weaker player feeling a sense of inadequacy, or without a cost to the stronger player who may play at a lower intensity to accommodate the weaker player. This was successfully demonstrated between players of different fitness levels using a heart rate-scaling technique based on the user's age and fitness level to control the speed of a vehicle in a racing game [16]. Mueller, Stevens, Thorogood, O'Brien, and Wulf have also developed several prototypes for facilitating a multiplayer experience and social bonding within an exercise video game [12]. These include a version of the classic computer game "Breakout", in which opposing players kick a soccer ball against a wall of projected tiles in an attempt to break down a virtual wall dividing the players. Additional multiplayer exercise video games developed by this group included a virtual hang-gliding game, and a game using an exertion interface for pushing and pulling against an opponent. Each of these prototypes tested well with pilot users and allude to the potential popularity of similar shared-experience exercise games.

Using their set of exercise motivation requirements, Yim and Graham produced an exercise video game entitled *Life is a Village* [LIAV], which incorporated many aspects from conventional sedentary video games [20]. For instance, while cycling on a recumbent bicycle, a player must control an avatar to gather resources in order to build a virtual village, until resources are exhausted. Rare resources are harder to find and access, requiring more rigorous pedalling. The game also contains a quest system, in which players can encounter villager characters within the game and search for items sought after by the villagers. Completing these quests earns rewards in the form of items that can be added to the village. Future extensions of the game include linking these quests to exercise goals based on the player's capabilities. LIAV also has a cooperative play mode, in which one player cycles and navigates the avatar, while another player uses a Nintendo Wii controller to defend against damaging snowballs thrown by enemy characters. The latter task is accomplished using a backward or forward swatting motion. The two players have complimentary roles, meaning that players with different fitness levels can play together. In future extensions to the game, distributed players will be able to play together. By incorporating features and tasks found in many conventional video games, LIAV is very inviting for devoted gamers, and anecdotal evidence from pilot players suggests that the game is fun to play. Such a game may constitute exercise, but it may be entertaining enough to predominantly feel like one is playing a video game. It is also worth noting that LIAV incorporates several cognitive tasks often found in conventional video games, such as text comprehension, and reacting quickly to sudden threats (i.e. snowballs in cooperative mode). The ability to perform such tasks in the presence of different levels of exercise intensity are further explored in the experiment described in the next section.

With the inclusion of attractive and entertaining aspects of conventional video games, it is likely that more people will be motivated to use games such as LIAV for exercise purposes. Warburton, Bredin, Horita, Zbogar, Scott, Esch, and Rhodes have shown that exercise training programs which link an interactive video game experience to exercise will have greater adherence levels than similar

programs without the interactive gaming experience [19]. Exercise video games have been shown to help people maintain an exercise plan, and as a result lead to lower risk factors for chronic disease, improved aerobic fitness levels, improved cardiorespiratory response, as well as musculoskeletal improvements.

Conventional sedentary video games are popular not only for the reasons cited above, but also because they allow players to engage in challenging cognitive tasks, often simultaneously during gameplay. It is possible that if such tasks are deployed in exercise video games, such games may be perceived as more entertaining and rewarding, and result in an increased motivation to use them as a form of regular physical activity. In the next two sections, we will examine such tasks in the context of conventional video games, and subsequently how cognitive task performance is affected during and after physical activity.

2. 2. Video Games and Cognitive Ability

Many gamers enjoy the process of mastering a challenging video game, which provides a sense of accomplishment and a motivation to continue playing [5]. As many large game studios move to developing games for casual players, publishing shorter and easier games, hardcore gamers may feel alienated, as such games no longer pose a long-term challenge [21]. Thus if exercise video games include challenging mental tasks and long-term skill development, devoted gamers may have more of an incentive to play them. A cycle of expertise may also attract players familiar with massive multiplayer online games, requiring players to master new sets of skills incrementally throughout the game.

There exists a substantial body of research devoted to studying the cognitive benefits of playing video games. Improvements in mental task performance often coincides with achievements within a game, such as defeating a level boss or setting speed records. There are two explanations for these improvements, which are mutually supportive. First, games provide strong motivational factors to

improve, especially as difficulty increases or when competition with other players is a factor. Second, practising a task repetitively in games such as Tetris leads to a general improvement of ability, even after a small number of game-playing sessions. It has been noted that games such as Tetris or Block-Out (a 3D version of Tetris) improve spatial visualization and mental rotation skills [13, 4]. Green and Bavelier have also shown how playing action games can dramatically increase the visual attentional capacity of a player, both in spatial and temporal resolution [7]. While the benefits of action games, and specifically first-person-shooter (FPS) games, have been disputed in the past, such games have been shown to improve multi-tasking skills in simulated work environments [9]. Multi-tasking and hand-eye coordination are especially important in such games, as a player must constantly scan their surroundings for allies and enemies, be aware of their objective, reload their weapons, and monitor their health, ammunition, and position on the game map. Should an exercise video game demand multi-tasking and provide the opportunity for players to create and refine their own strategies, devoted gamers may be more interested in playing.

2. 3. Exercise and Cognitive Ability

Integrating the challenging cognitive tasks of conventional video games into exercise video games may attract devoted gamers, and may make the game feel less like exercise. But this approach may be problematic if the physical component of an exercise video game has adverse effects on cognitive task performance. A substantial number of research findings in the field of sports psychology suggests otherwise, indicating that acute bouts of exercise generally improve cognitive abilities, dependent upon exercise intensity and duration.

Tomporowski reported that acute bouts of exercise of up to 60 minutes in duration can selectively facilitate cognitive processes, and under some conditions, enhance reaction time and response accuracy on simple and complex decision tasks [18]. The size of the effect can depend on the type and duration of exercise, although positive effects have generally been reported for a variety of

tasks during and following medium-intensity aerobic activity. Exercise can improve one's ability to block out irrelevant information and respond more efficiently to task-relevant information. Motor response and the capacity to plan movement patterns also shows improvement following bouts of steady-state aerobic exercise. Intense anaerobic exercise has not been shown to impair cognitive functioning either, however sub-maximal aerobic exercise leading to dehydration and fatigue has been known to compromise memory functions and information processing. Of course, any positive effect may also vary depending on the level of experience or fitness level of the individual. For instance, professional soccer players exhibit an exercise-induced facilitation of enhanced visual attention, with the ability to "zoom-out" their focus of attention between local and global contexts to a greater degree than a soccer novice [14]. Individual differences have also been examined by Sibley and Beilock, who observed that the positive effects of exercise on working memory performance is not uniform across all individuals [15]. In an experiment which tested working memory following 30 minutes of moderate-intensity treadmill exercise, the greatest improvements in working memory were observed in individuals with poor working memory capacity to begin with, as it is known that this capacity can vary between individuals.

Kamijo, Nishihira, Higashiura, and Kuroiwa continued to explore the effect exercise intensity on task difficulty [8]. They identified an inverted-U shaped function of cognitive processing following exercise at various intensities. They observed that reaction times for an Eriksen flanker task following exercise are shorter when compared to the baseline sedentary condition. Cognitive processes in this task involve an organization of action, interference control, error monitoring, complex discrimination, response selection and inhibition. It was determined that physical activity selectively improves cognitive processing for tasks involving greater amounts of executive control. As well, while some processes showed improvement following light and moderate bouts of exercise, high-intensity exercise adversely affected some processes, such as response inhibition.

Benefits for perceptual and decisional tasks have been shown to appear after 20 minutes of moderate exercise between 40 and 80% of the individual's VO₂ max (or maximum heart rate) [1]. It is possible that an increase in arousal level related to physical exertion leads to increased decisional performance. This may be a product of motivational factors related to exercise, in which a reallocation of resources occurs in the brain, wherein if the energy demand is greater, more resources are devoted to executive functioning and planning movements, which spreads activation to the brain's decision centres. Budde, Voelckner-Rehage, Pietraßyk-Kendziorra, Ribiero, and Tidow also explored the possibility of bilateral coordinated exercise spreading activation of coordination to cognition in the cerebellum and prefrontal regions [2]. Concentrative capacity and visual perceptual-attentional ability in adolescents showed improvement on a stimulus-distractor selection task after a bout of coordinated exercise. The effect was greater for these individuals than others who performed exercise without requiring bilateral coordination.

In general, the aforementioned findings regarding exercise and cognitive performance indicate a general improvement of cognitive ability during and following bouts of moderate-intensity exercise. However, depending on individual differences such as working memory capacity and domain expertise, performance may not be affected by physical activity at all. On the other hand, cognitive performance may be hampered after dehydration or fatigue sets in, which may only occur after an hour of moderate-intensity aerobic exercise [18]. These results are promising for exercise video game developers, as they may be able to justifiably integrate challenging cognitive tasks into exercise video games without having to compensate for the exercise component of the game, such as by dumbing the tasks down. In the next section, we present an experiment which assesses if several challenging cognitive tasks, each of which found in conventional video games, can be performed while exercising at light and moderate intensities without a drop in performance.

3. Experiment

To assess the effect of physical activity on cognitive task performance in an exercise video game, we have developed a game-like environment which presents three types of conventional video game tasks to a participant. These comprise of a text comprehension task, a reaction time task, and a pointing and shooting task.

3. 1. Method

We carried out a study to investigate this hypothesis.

3. 1. i. Participants

Participants were selected on their ability to operate a recumbent bicycle and use a wireless Nintendo Wii game controller. A total of 18 participants (5 female) were recruited from the university community. Participants' ages ranged from 18 to 27 with a mean age of 21.6. On average participants reported spending 2-3 hours every week exercising, and 1-2 hours per week playing video games.

3. 1. ii. Equipment

Participants used a Tunturi E6R recumbent bicycle. A wireless Nintendo Wiimote controller was used for the reaction time and target shooting tasks. The game environment was projected onto a large (6' x 8') screen (see Figure 3.1).

Each participant wore a Polar heart rate strap around his/her torso. The strap wirelessly transmitted the participant's heart rate to the recumbent bicycle, which was programmed to adjust the resistance of the pedals in order to maintain a target heart rate zone (based on the age and weight of the participant). Once a participant reached their target heart rate, the rate would be maintained by the bicycle for the length of each experimental condition (approx. 6-7 minutes).

3. 1. iii. Procedure

Three banks of tasks with unique task orderings and text comprehension tasks were prepared. Participants performed 15 tasks in each of the 3 exercise conditions (moderate intensity cardiovascular exercise, light intensity fat-burning exercise, and sedentary). Each type of task appeared 5 times in each condition as part of a shuffled order of tasks, with a brief pause between tasks. The ordering of exercise

conditions and task banks were counterbalanced across all participants. In both exercise conditions, approximately two minutes of pedalling was performed as a warm-up before the experiment began. This allowed a participant to reach their target heart rate zone by the time the tasks were presented. Following each exercise condition, sufficient rest time was given to allow for the participant's heart rate to return to a resting level.

The text comprehension task consisted of a game instruction in the form of a quest text. The text is displayed for 8 seconds, followed by a brief pause, then a multiple choice question pertaining to the contents of the text appeared for an additional 8 seconds (see Figure 3.2). Multiple choice questions contained four options, and always pertained to the identity of characters or locations having appeared in the quest text. Quest texts were restricted to contain 3 characters and/or locations. Participants were instructed to give an oral response to the multiple choice question, which was recorded by an experimenter.

The reaction time task also began with a quest text of the same format as those mentioned above. Participants were unaware as to whether the quest text would be followed by multiple choice question or if it would be interrupted by a reaction time task. In the latter case, the quest text is interrupted by a threatening bomb icon and a flashing warning label. Participants were instructed to react to the bomb as quickly as possible by pressing a button, at which point his/her reaction time was recorded.

The target shooting task presented a circular target appearing in a random location on the screen. Participants were given 5 seconds to move the the cursor and shoot (via a button press) using the Wiimote, at which point the distance from the cursor to the centre of the target was recorded.

Before the three experimental conditions, participants familiarized themselves with several trial instances of the target shooting and reaction time tasks. They were encouraged to do so while pedalling until they felt comfortable and confident. To facilitate target shooting, participants were instructed to

slow or stop pedalling whenever a target appears, and to resume pedalling after shooting. Participants were then given a training bank of tasks to complete, which was performed without pedalling.

Following the experiment, participants completed a brief questionnaire and a semi-structured interview was carried out to gather qualitative comparisons of the three conditions.

3. 2. Results

Our results address the hypothesis mentioned above.

3. 2. i. Text Comprehension

A one-way within-subjects ANOVA was conducted with the factor being the level of exercise intensity and the dependent variable being the number of correct responses. The means and standard deviations of question responses are presented in Table 3.1. The results for the ANOVA did not indicate a significant exercise intensity effect, Wilks's $\Lambda = 0.915$, $F(2,16) = 0.743$, $p = .49$, multivariate $\eta^2 = .09$. Post-hoc power analysis reveals that power was low (0.18).

3. 2. ii. Reaction Time

A one-way within-subjects ANOVA was conducted with the factor being the level of exercise intensity and the dependent variable being the reaction time of the button press from the onset of the bomb icon. The means and standard deviations of question responses are presented in Table 3.2. The results for the ANOVA did not indicate a significant exercise intensity effect, Wilks's $\Lambda = 0.919$, $F(2,16) = 0.701$, $p = .51$, multivariate $\eta^2 = .08$. Post-hoc power analysis reveals that power was low (0.15).

3. 2. iii. Target Accuracy

A one-way within-subjects ANOVA was conducted with the factor being the level of exercise intensity and the dependent variable being the distance of the cursor to the centre of the target. On several occasions participants reported accidentally pressing the button prematurely, or mistook the target for a bomb icon; these instances were discarded. The means and standard deviations of question responses are presented in Table 3.3. The results for the ANOVA did indicate a significant exercise

intensity effect, Wilks's $\Lambda = 0.627$, $F(2,16) = 4.77$, $p = .02$, multivariate $\eta^2 = .37$.

Follow-up polynomial contrasts indicated a significant linear effect with means increasing with an increase in exercise intensity, $F(1,17) = 10.120$, $p < .01$, partial $\eta^2 = .37$. Higher-order polynomial contrasts were non-significant. Significant differences were found between the moderate exercise condition and the two other conditions, but not between the sedentary and light exercise conditions. These results suggest that light intensity exercise in one's fat-burning zone does not negatively affect one's ability to shoot a virtual target accurately, but moderate intensity aerobic exercise does.

3. 3. *Analysis*

It was expected that increasing levels of exercise intensity would have an observable effect on cognitive ability for the types of tasks presented in this experiment. While subjects consistently reported having difficulties concentrating on the tasks in the moderate exercise condition, the overall results do not support our hypothesis nor the observations of the participants. No significant differences in the number of correct question responses were found between exercise conditions. Similarly, no significant differences in the mean reaction times were found between exercise conditions. As for the target-shooting task, significant differences were found between the moderate exercise condition and the two other conditions, but not between the sedentary and light exercise conditions. These results suggest that an increased heart rate due to a more rigorous level of exercise renders it difficult for one to control a motor response requiring accuracy in a target-shooting task.

In general, exercise intensity did not have a noticeable effect on cognitive ability for text comprehension or reaction time tasks. No significant differences were found, and power was low, indicating the possibility of a type II error. Post-hoc power analysis indicated that up to 100 participants may have been required to detect any significant differences in task performance between conditions.

3. 3. *i. Limitations*

Our subjects were drawn from the university population. They were for the most part young and

fit. Our recruiting poster and mailings indicated that the experiment would involve performing exercise, which likely biased the sample towards people who are more active. If we drew from a more heterogeneous population, we would have seen a greater diversity in task performance.

In our experiment, we calculated target heart rate based on a person's resting heart rate. Traditionally, maximum heart rate has been estimated using the formula $220 - \text{age}$. It is known that this formula can be inaccurate by as much as 10 to 12 bpm [16]. Using this formula, we approximated a participant's target heart rate for moderate-intensity cardiovascular or aerobic exercise by multiplying the result of $220 - \text{age}$ by 0.8; the aerobic exercise zone is typically defined as being between 70 % and 80% of one's maximum heart rate. Likewise, we approximated a participant's target heart rate for light-intensity or fat-burning exercise by multiplying by 0.65; the fat-burning exercise zone is typically defined as being between 60 % and 70% of one's maximum heart rate. In addition, the resting heart rate prior to beginning the experiment rate may have varied between participants based on what they had done prior to the experiment (e.g. previous physical activity, consuming caffeine). However, despite the potential inaccuracies in our calculated heart rates, subjects reported a noticeable difference in exercise intensity between the light and moderate exercise conditions. We also noticed a difference in the number of calories burned between exercise conditions, with a mean of 29.86 kcal (SD = 12.35) for the light exercise condition, and 46.50 kcal (SD = 10.77) for moderate exercise.

In terms of the quest texts and associated multiple choice questions, emphasis was placed on uniformity of difficulty during the design of the experiment. Pilot experiments were conducted to remove or modify texts and questions that were either too difficult or too easy. Despite efforts to maintain the difficulty of the quest texts throughout the experiment, some subjects claimed that the texts were not uniformly difficult, and were sometimes able to predict whether a text would be followed by a multiple choice question or interrupted by a bomb icon for the reaction time task. In one instance, a subject reported that "questions with reaction time component seemed, on average, more complicated/convoluted, possibly allowing [participants] to foresee the reaction component and

[decrease] reaction time". While this observation did not materialize in the overall results, future experiments may benefit by going to greater lengths to ensure uniform text comprehension task difficulty.

Several participants reported that the Wii controller was too sensitive and difficult to stabilize on the target, regardless of the experimental condition. It is possible that the Wii controller is not suitable for quick pointing and shooting tasks requiring the degree of accuracy imposed by this experiment. Alternative Wii controller calibration techniques or interfaces such as a gamepad controller may resolve this issue in future experiments.

4. Discussion

The experiment described above suggests that, at least in the context of an exercise video game environment, short bouts of increased physical activity intensity does not effect performance on cognitive abilities such as text comprehension or reacting to sudden obstacles; no significant differences in ability between three levels of activity were detected for these two tasks. The results of the target-shooting component of the experiment indicate that a more rigourous level of physical activity corresponds with a drop in performance. A 49% drop in accuracy was observed between sedentary and moderate exercise conditions, while a 26% drop in accuracy was observed between the light and moderate exercise conditions. No significant drop in accuracy was observed between the sedentary and light exercise conditions. While this drop in performance may be attributed to the equipment used, it could also signify a diminished ability to plan and perform accurate motor movements in a moderate exercise state, which was not predicted by the findings of previous studies [\[18\]](#).

The goal of this experiment was to assess whether performance on cognitive-intensive tasks is affected by increased levels of physical activity in an exercise video game. In terms of the development of future exercise video games, our findings suggest that games involving text comprehension and reaction-time oriented tasks do not need to accommodate for different levels of physical activity. More

importantly, such games may be used by players different levels of physical fitness and exercise regimes. However, further experiments are required to determine if our results can be replicated with a more heterogeneous population, and for longer durations of exercise.

Our results also suggest that for exercise video games involving a target-shooting component, a more rigorous level of exercise may not be ideal for accurate pointing and shooting. Further experiments are required to verify if similar difficulties for target-shooting tasks exist for other interaction devices.

The approach taken in this experiment had several limitations and shortcomings that we hope can be addressed by further research. As indicated by the sports psychology findings mentioned above, it is likely that differences in task performance would only become apparent after longer exercise durations; the total time spent pedalling in the two exercise conditions did not exceed 7 minutes, including a 2 minute warm-up period. For longer-duration physical activities, a change in performance on cognitive tasks may not be evident during the first 7 minutes, but rather after 20-30 minutes of moderate-intensity aerobic exercise [[1](#), [15](#), [18](#)].

5. Conclusion

Exercise video games provide incentive for adolescents and adults with sedentary lifestyles to increase their physical activity level while doing an activity they enjoy. We have investigated whether exercise video games can contain challenging cognitive tasks found in conventional video games, and if a game's exercise component has an effect on the performance of such tasks.

We implemented a game-like environment using a recumbent bicycle and a projected display. Participants took part in a series of tasks involving text comprehension, reacting quickly to obstacles or sudden threats, and shooting a virtual target with three levels of exercise intensity on a recumbent bicycle. In each condition, the cycling resistance was controlled so a participant could maintain a target heart rate based on their age and weight. We found that text comprehension and reaction time activities were unaffected by different levels of exercise intensity. As per the accuracy task, we found that

performance may be hampered at a moderate-intensity cardiovascular or aerobic activity level, but not at a lighter intensity levels. Developers of exercise video games should consider our results, which indicate that some cognitive tasks, especially those commonly found in conventional video games, do not appear to be affected by a range of exercise intensity levels for short durations of activity, and can justifiably be integrated into exercise video games for the purpose of attracting and motivating new players.

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Figures and Tables

Table 3.1 - Means and standard deviations for question responses

<i>Exercise Condition</i>	<i>M (score)</i>	<i>SD (score)</i>
Sedentary	4.00	1.03
Light Exercise	4.17	0.86
Moderate Exercise	3.72	1.32

Table 3.2 - Means and standard deviations for reaction time

<i>Exercise Condition</i>	<i>M (ms)</i>	<i>SD (ms)</i>
Sedentary	420.67	80.64
Light Exercise	414.78	49.77
Moderate Exercise	441.36	92.88

Table 3.3 - Means and standard deviations for distance to target centre in shooting task

<i>Exercise Condition</i>	<i>M (pixels)</i>	<i>SD (pixels)</i>
Sedentary	12.15	7.21
Light Exercise	14.27	6.34
Moderate Exercise	18.04	8.42

Figure 3.1 – Equipment used in the experiment



Figure 3.2 – Example of a quest text game instruction its associated multiple choice question

