The feasibility and efficacy of using active video games to promote health enhancing physical activity

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Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of PhD is entirely my own work, and that I have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

S J Monedero

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Abstract

In the last 30 years, technological advances have altered occupational and recreational activities that have resulted in decreased daily physical activity. The resultant increase in physical inactivity and sedentary behaviour has been reported to be an independent risk factor for a number of chronic diseases. Any modality or strategy that results in increased physical activity levels and energy expenditure merits further investigation. **Aim:** to determine if active video games promote health enhancing physical activity in an asymptomatic adult population (18- 45 years of age). A secondary aim of the thesis is to examine affect states and psychological states associated with the use of active video games in an adult population since these factors are likely to have an effect on medium and long term adherence rates. Three studies were carried out to answer the research questions. **Methods:** Study 1 assessed the physiological responses to a sedentary video game, an active video game (Nintendo Wii Sports) and a modified version of the same active video game. Study 2 compared physiological and affect responses to stationary cycling and active video game cycling (GameBike). Finally, Study 3 compared the acute physiological and affect responses to two different types of active video games (fitness-themed and entertainment-themed), and also to two bouts of conventional exercise, an acute bout of moderate exercise intensity and a bout of self-selected intensity treadmill exercise that allowed for greater autonomy to research participants. **Results:** Study 1 showed that Wii Sports resulted in very light-to-light intensity exercise. A simple modification to play rules was enough to bring it to moderate intensity. Study 2 showed that participants were working at a higher metabolic and cardiovascular intensity during the GameBike session than during a matched workload conventional stationary cycling session. Active video game resulted in higher enjoyment ratings. Study 3 showed that the entertainment-themed video game was the best option to exercise at moderate intensity and maintain positive affect states, enhanced state of well-being and higher ratings of the state of flow. **Conclusion:** The findings of this research suggests that active video game results in very light-to-vigorous intensity exercise and therefore is a valid strategy to increase physical activity levels in a healthy adult population. This level of exercise is well within the current recommendations for physical activity. Active video game leads to significantly more positive affect states that conventional exercise and this may have important implications for public health since lack of enjoyment is a correlate in physical activity participation. Active video games may also play a positive role in reducing sedentary behaviour by reducing sitting time and increasing light-to-moderate intensity activities.

Publications

Papers

Monedero J., McDonnell A., Keoghan M., O'Gorman DOG. J. (2014) **Modified active videogame play results in moderate-intensity exercise.** Games for Health J. 3(4): 234-240.

Conference oral presentations

Can exergames be part of the solution to the physical inactivity challenge we face today? Monedero J., McDonnell A., Keoghan M., O'Gorman DOG. J Presented at the 11th International Diverse Conference, Dublin, June 2011.

Active video games have similar physiological responses but results in more positive psychological states when compared to a moderate intensity bout of exercise. Monedero J., O'Gorman DOG. J. Presented at the 19th Annual Congress of the European College of Sports Science, Amsterdam, The Netherlands, July 2014.

Active video game play blunts decreases in enjoyment during exercise and results in similar rates of energy expenditure than moderate intensity conventional exercise. Monedero J., O'Gorman DOG. J. Presented at the World Federation of Athletic Training and Therapy 11th Annual Scientific Conference, Dublin, September 2014.

Poster presentations

Physiological response to Wii Sports and Modified Wii Sports in young adults. Monedero J., McDonnell A., Keoghan M., O'Gorman DOG. J. Poster presented at the 16th Annual Congress of the European College of Sports Science, Liverpool, England, July 2011.

Physiological response, enjoyment and Rate of Perceived Exertion following a bout of interactive game cycling and conventional cycling in adults. Monedero J., Collins N., Torris L., O'Gorman DJ. Poster presented at the 17th Annual Congress of the European College of Sports Science, Bruges, Belgium, July 2012.

Abbreviations

ACSM: American College of Sports Medicine

AHA: American Heart Association

AVG: active video game

BMR: basal metabolic rate

BRFSS: Behavioural Risk Factor Surveillance System

CDC: Center for Disease Control and Prevention

CFSS: core flow state scale

CVD: cardiovascular disease

DDR: dance dance revolution

EE: energy expenditure

EPOC: excess post-exercise oxygen consumption

ESA: Entertainment Software Association

ETVG: entertainment-themed video game

FEO_2: fraction of expired Oxygen

FTVG: fitness-themed video game

FFM: fat-free mass

GPS: global positioning system

HDL-C: high density lipoprotein cholesterol

HEPA: health-enhancing physical activity

HR: heart rate

HRmax: maximal heart rate

HRR: hear rate reserve

IPAQ: International Physical Activity Questionnaire

$mL^{\cdot}kg^{-1\cdot}min^{-1}$: millilitre of oxygen per kilogram of body mass per minute

LDL: low density lipoprotein

LPTA: leisure time physical activity

MVPA: moderate-to-vigorous physical activity

NEAT: non-exercise activity thermogenesis

NCDs: non-communicable diseases

PA: physical activity

PACES: physical activity enjoyment scale

PAL: Physical activity level

PALA+: Presidential Active Lifestyle Award

PAR-Q: physical activity readiness questionnaire

PCFSN: President's Council on Fitness, Sports & Nutrition

PO: power output

POMS: profile of mood states

PPO: peak power output

PS: PlayStation

Rate of EE: rate of energy expenditure

RER: respiratory exchange ratio

RPE: rate of perceived exertion

RMR: resting metabolic rate

SDT: self-determination theory

SV: stroke volume

TEE: total energy expenditure

TG: triglycerides

$\dot{V}_E$: minute ventilation

VG: video game

$\dot{V}O_2$: oxygen uptake

$\dot{V}O_2max$: maximal aerobic power

$\dot{V}O_2peak$: peak oxygen uptake

$\dot{V}O_2R$: oxygen uptake reserve

VT: ventilatory threshold

WHO: World health organisation

Glossary of terms

Active video game (AVG): video game that uses technology that tracks body movement or reaction and that requires the player to stand up and move to be able to play.

Affect: the most basic or elementary characteristics component of all valenced (positive or negative, pleasant or unpleasant) responses, including, but not limited to, emotions and moods.

Affect response: a change in self-reported pleasure-displeasure

Energy expenditure (EE): the amount of energy an individual uses daily to complete all bodily activities, from breathing to digestion and including movement.

Enjoyment: a feeling of pleasure caused by doing or experiencing something the person likes.

Exercise: activity requiring physical effort, carried out especially to sustain or improve health and fitness.

Heart rate reserve (HRR): the difference between resting heart rate and maximum heart rate .

Maximal oxygen uptake ($\dot{V}O_2max$): maximum consumption of oxygen taken up during maximal exercise and measured at mouth level.

Oxygen uptake ($\dot{V}O_2$): oxygen taken up by bodily tissues and measured at mouth level.

Oxygen uptake reserve ($\dot{V}O_2R$): the difference between resting heart rate and maximum heart rate .

Physical activity: any bodily movement produced by the contraction of skeletal muscles that results in a substantial increase over resting EE.

Physical fitness: set of attributes that people have, or achieve, that refers to a physiologic state of well-being that allows one to meet the demands of daily living or that provides the basis for sports performance, or both.

State of flow: Flow is the optimal psychological state of mind that usually occurs when the challenge of a situation or an activity matches the skills the individual brings to the situation. It is characterised by supreme enjoyment and engagement in the task

Ventilatory threshold (VT): the point during progressive exercise where respiratory changes first occur. More specifically, when ventilation increases above and beyond the increase in oxygen uptake.

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CHAPTER I

INTRODUCTION

"Lack of activity destroys the good condition of every human being, while movement and methodical physical exercise save it and preserve it".
Plato

1.1 General Introduction

Physical activity (PA) is recognised as a critical determinant of healthy aging. The beneficial effects of an active lifestyle are widely accepted and include physiological adaptations (Åstrand, 1986; Blair *et al.*, 2001; Warburton *et al.*, 2006; Joyner & Nose, 2009; Ng & Popkin, 2012), positive psychological states (Kanning & Schlicht, 2010; Swan J, 2012), and a positive impact on emotions (Saklofske *et al.*, 2007). Despite these known benefits, PA levels have continued to decline over the past 30 years (Ng & Popkin, 2012). This reduction has had significant negative consequences on health. Physical inactivity was responsible for 3.2 million deaths and 2.8% of disability adjusted life years (DALYs) in 2010 and it was tenth on the list of global health risks and fifth in western Europe (Lim *et al.*, 2012).

Scientists and physicians in China and India recognised there was a link between PA and health more than 5000 years ago. Hippocrates, the father of preventive medicine, wrote in detail about the benefits of exercise for a variety of ailments, including mental illnesses. Paradoxically, in the beginning of the 20th century, after centuries of advancing human knowledge, PA was undervalued, underestimated and was even considered to be dangerous for health, as a study comparing the health of university sportsmen to that of intellectuals in Cambridge shows (Rook, 1954).

This negative perception of PA has dramatically changed in the course of the last few decades thanks to the contribution of modern PA epidemiology. Extensive and rigorous pieces of work support a role for PA in the prevention of chronic disease. The seminal work of Morris and colleagues (1953) was the first to examine the effects of occupational PA on workers' health. Morris and colleagues (1953) were the first scientists to demonstrate that the sedentary occupation of a bus driver led to a higher disease risk profile than that of the more active bus conductors.

In conclusion, it has taken considerable time to gather the evidence that supports the undeniable beneficial role of regular PA in promoting and maintaining health. In spite of the fact that physical inactivity is associated with increased risk of chronic disease and mortality rates, population PA levels are low and this presents a public health problem.

1.1.1. Statement of the problem

Life in the 21st century is radically different to that of our ancestors. Technological advances have led to a decrease in the amount of PA in different domains (leisure, occupation, transportation, home-based activities). Occupation-related daily energy expenditure (EE) in the US has decreased by 140 kcal for men and 124 kcal for women from 1968 to 2008. This reduction in EE could account for most of the adult body weight gain in the US over the last 50 years (Church *et al.*, 2011). Total PA in the US and UK in the 1960s was 235 and 216 MET $hr^{\cdot}wk^{-1}$ respectively, with occupational PA being the main contributor. It is estimated that total PA for both the US and the UK will have decreased to 126 and 140 MET $hr^{\cdot}wk^{-1}$ respectively by 2030 (Ng & Popkin, 2012).

There is a clear need to increase PA levels and reduce sedentary behaviour in the population to improve public health. Most PA interventions have had very limited success in attaining the participation levels recommended by health guidelines (Lewis *et al.*, 2002; Hillsdon *et al.*, 2004; Rhodes & Pfaeffli, 2010). It could be argued that engaging and enjoyable PA interventions that have a significant impact on health are urgently needed.

A new type of video game that combines play with physical exertion has emerged over the last number of years. Active video games (AVGs), such as those available in Nintendo Wii, Xbox Kinect and Sony Move and also referred to as exergames, exertainment or interactive video games are video games that require the player to get up from the couch and move in order to be able to play. Active video games use different peripherals that include balance boards, dance pads, gym equipment, cameras, remote controls with accelerometers, heart rate monitors, and other types of sensors and inputs that keep the player moving to play and win the game. There is robust scientific evidence that AVGs elicit significantly higher EE than traditional sedentary games (Lanningham-Foster *et al.*, 2006; Graves *et al.*, 2008a; Ridgers *et al.*, 2011). There is also some preliminary evidence that AVGs elicit light, moderate and vigorous exercise intensities in children and adults (Lanningham-Foster *et al.*, 2006; Graves *et al.*, 2008a; Graves *et al.*, 2008b; Lanningham-Foster *et al.*, 2009; Warburton *et al.*, 2009; Graves *et al.*, 2010a; Mellecker *et al.*, 2010; Lyons *et al.*, 2011; Mitre *et al.*, 2011; Worley *et al.*, 2011; Sanders *et al.*, 2012; Peng *et al.*, 2013; Sween *et al.*, 2013). Perhaps, one of the most promising reasons why this technology warrants further investigation as a modality to increase expenditure is the positive psychological and affective states that these games may bring about.

1.1.2. Significance of the study

The studies in this PhD thesis have been designed to gain a more in-depth understanding of the physiological response to different types of AVG play in adults. They also investigate ways of increasing the physiological stimulus that AVG play imposes on the body in order to make it more physiologically challenging and more likely to meet PA intensity guidelines. In addition to assessing physiological, psychological and affect responses to AVG play, these responses are compared to those of conventional exercise.

Active video game play is a way of increasing PA that might not comply with public guidelines for exercise in some cases, but that might induce benefits on health by diminishing sedentary behaviour and increasing light-to-vigorous intensity activities. The importance of this cannot be overestimated because sedentary behaviour competes directly with light intensity activities rather than with moderate-to-vigorous intensity activities (Healy *et al.*, 2008b; Wilmot *et al.*, 2012). It is of paramount importance to have a repertoire of enjoyable and attractive light intensity activities available to choose from, and AVGs could be part of this repertoire of activities. AVGs could be a useful means of minimising sedentary time and an effective strategy to increase population PA and therefore reduce physical inactivity levels.

1.2. Thesis overview: aims, objectives and hypothesis

1.2.1. Aims

The aim of this thesis is to determine if AVG play results in health enhancing physical activity in an adult population (18- 45 years of age). A secondary aim of the thesis is to examine affect and psychological responses associated with the use of AVGs in an adult population, since these factors are likely to affect medium and long term adherence rates.

1.2.2. Objectives

- To measure physiological, psychological and affect responses to different types of AVG play in adults and establish the exercise intensity while playing these.
- To measure the impact of modified AVG games on physiological response in adults.
- To compare the relationship between exercise intensity and affect measures during conventional exercise and different types of AVG play.

1.2.3. Thesis hypothesis

AVG play will result in moderate-to-vigorous intensity exercise that meets the public health recommendations for healthy adults. AVGs will also induce more positive affect states than conventional exercise.

This PhD thesis consists of three interrelated studies that were designed to provide a more in depth understanding of the physiological, psychological and affect response to different types of AVG play in adults. The first study investigates the physiological responses to a commercially available AVG and a modified version of the same video game. It also examines whether it is possible to comply with the PA guidelines by playing these AVGs. The following study expanded on results of study 1 by comparing physiological and affect responses to gaming and to a bout of traditional cycling exercise in the form of cycling. The final study in this thesis compared different types of commercially available AVGs to conventional exercise and measured more psychological variables to build a more detailed picture of the effect of AVG play.

1.2.4. Study 1: Cardiometabolic responses to Wii Sports and Modified Wii Sports in young adults.

Overview

Asymptomatic, physically active participants played (i) a traditional sedentary video game (PlayStation), (ii) an active video game (Wii Sports) and (iii) a modified active video game (Mod Wii Sports) in random order. Cardiometabolic responses to the three games were compared. The aim of the study was to determine if playing Wii Sports and modified Wii Sports would sufficiently increase energy expenditure (EE) to meet current PA recommendations for healthy adults.

Hypothesis

Wii Sports will result in exercise intensities lower than recommended for daily physical activity for the adult population and modified Wii will result in greater energy expenditure and cardiovascular response than regular Wii Sport games, and that the intensity of activity would meet the American College of Sports Medicine/American Heart Association recommendations.

1.2.5. Study 2: Energy expenditure and enjoyment during conventional stationary cycling and interactive video game cycling in sedentary adults

Overview

Asymptomatic, physically inactive participants performed two exercise trials at a matched workload. One of the trials was conventional cycling while the other was interactive video game cycling (GameBike). Oxygen uptake ($\dot{V}O_2$), percentage of maximal oxygen uptake (%$\dot{V}O_2$max), percentage of maximal oxygen uptake reserve ($\dot{V}O_2R$), heart rate (HR), heart rate reserve (HRR), percentage of maximal heart rate (%HRmax), percentage of ventilatory threshold (%VT), METs and EE values were measured during the gaming sessions. Rate of perceived exertion and rates of enjoyment were recorded every 10 min. The aim of this study was to do a direct comparison of physiologic and affect responses to stationary cycling and active video game cycling.

Hypothesis

Interactive video game cycling will result in higher exercise intensity levels measured by cardiovascular parameters and metabolic parameters than a bout of conventional stationary cycling at a matched workload. It is also hypothesised that the interactive video game cycling would result in lower or similar RPE ratings and higher enjoyment scores than the bout of conventional cycling.

1.2.6. Study 3: Flow, enjoyment and energy expenditure during conventional exercise and active video game play

Overview

Asymptomatic, physically inactive participants performed two exercise trials and two AVG trials. One exercise trial consisted of participants self-selecting exercise intensity, and the other exercise trial involved exercising on a treadmill at 55% of $\dot{V}O_2R$. The AVG conditions included a fitness-themed video game and an entertainment-themed video game. $\dot{V}O_2$, %$\dot{V}O_2$max, $\dot{V}O_2R$, HR, HRR, %HRmax, METs and EE values were measured during the trials. Psychological well-being, enjoyment, rate of perceived exertion and state of flow were also measured during and after the trials. The study aims were 1) to compare the acute physiological and affect responses to two different types of AVGs (fitness-themed and entertainment-themed), and 2) to compare these games to an acute bout of moderate exercise intensity that would results in health benefits if done regularly according to best scientific knowledge, and also to a bout of self-selected intensity that allowed for greater autonomy to research participants.

Hypothesis

Active video games will result in similar rates of energy expenditure (rate EE) and more positive affect states than the moderate exercise intensity activity recommended to achieve health benefits. Active video game play will also result in similar or higher ratings of enjoyment, psychological well-being and state of flow than the self-selected condition.

1.2.7. Delimitations

- Participants were restricted to asymptomatic participants aged 18-45 years.

1.2.8. Limitations

- Participation in the 3 research studies involved the participants playing games that were part of the research protocol, at a determined intensity level and for an externally imposed duration. This way, the whole setting was artificial and the inherent spontaneity of video game play was missing.
- Despite the familiarisation session in the testing protocol of each study, findings might have been affected by the different levels of ability and experience of the participants.

- The choice of the AVGs used in the studies might not necessarily reflect the most used and liked AVGs of the general population. Pilot studies were carried out before each study to select the AVG for the different studies. The selection criteria were intensity of exercise measured during the pilot study and feedback on enjoyment and overall interest from participants of the games.

Chapter II

Review of Literature

2.1 Introduction

This literature review discusses the evolution of population PA levels from the ancient hunter-gatherer to the 21st century humans. The determinants and correlates of PA participation are discussed to try to understand the reasons behind the high physical inactivity levels. It also discusses the scientific evidence surrounding the role of PA as a key component in the maintenance of human health, and the risks of adopting a physically inactive lifestyle and increasing sedentary behaviour. As well as this, it also reviews the literature on AVGs as a technology that combines play with PA in order to re-engineer PA and movement back into people's lives.

2.2. Physical activity, exercise and physical fitness

The terms physical activity, exercise and physical fitness are frequently used inter-changeably, but these terms are not synonymous. Physical activity refers to any bodily movement produced by the contraction of skeletal muscles that results in a substantial increase over resting EE (Caspersen *et al.*, 1985; Bouchard, 2007). Physical activity includes different domains such as leisure-time PA, exercise, sport, transportation, occupational work and chores. The resting EE refers to the EE at complete rest in a post-absorptive state, and therefore, any activity that requires more EE than that of complete rest qualifies as PA.

Exercise is a subset of PA that is planned, structured, and repetitive and has as a final, or an intermediate objective, the improvement or maintenance of physical fitness (Caspersen *et al.*, 1985). Finally, physical fitness can be defined as a set of attributes that people have, or achieve, that "refers to a physiologic state of well-being that allows one to meet the demands of daily living or that provides the basis for sports performance, or both"(Warburton *et al.*, 2006). The scientific literature supports the notion that physical fitness is a better predictor of cardiovascular, and all-cause mortality than PA (Blair *et al.*, 2001; Williams, 2001; Myers *et al.*, 2004). However, there is an undeniable link between PA and health. According to Blair *et al.*, (2001), population PA levels should be targeted rather than physical fitness levels for health benefits. If PA levels are increased in physically inactive people, it is likely that physical fitness would also be positively affected.

2.3. Physical activity as a major force in evolutionary history

It could be argued that PA has been a major factor in human evolution. Our ancestors from the late Palaeolithic Age had a lifestyle that required high levels of PA (Cordain *et al.*, 1998). Examples of this include walking while gathering, during persistence hunting and on visits to neighbouring campsites, running after wounded prey, carrying children, game meat, gathering plant foods or firewood and erecting shelters, to name a few. While it is challenging to accurately determine the importance of movement and PA in human evolution, it seems that they played important roles in shaping the evolution of the human genome (Eaton *et al.*, 1988; Cordain *et al.*, 1998; Eaton, 2003). It is remarkable that the genomic difference between Homo sapiens and closely related nonhuman primates is only of 2-5%. But this small percentage difference is sufficient to bring about significant functional improvements such as upright posture, bipedal locomotion, well-articulated thumbs, vertical head position facilitating visual scanning, and refined language capacity (Bouchard, 2007).

The spread of agriculture and animal domestication created less nomadic communities, but physical exertion remained a constant element. Archaeological remains are proof of different leisure physical endeavours such as foot races, throwing contests wrestling, dances and hunting that took place in diverse cultures around 5,000 to 8,000 years ago (Bouchard, 2007). Around 3 millennia ago, activities requiring physical exertion, such as games, formed an important part of cultural society in ancient Greece. However, since the Industrial Revolution started in England around 1760, PA levels have been declining steadily. The technological advances made in the last 200 years have enabled people to reduce the amount of physical labour and free their time for other pursuits. As technological advances in transport, recreation, entertainment, and occupations have become more widespread, the requirement for PA and increased EE has diminished (Hallal *et al.*, 2012).

Eaton and colleagues (1988) proposed that the genetic makeup of humanity has changed little during the past 10,000 years, but that during the same period, ‘our culture has been transformed to the point that there is now a mismatch between our ancient, genetically controlled biology and certain important aspects of our daily lives. The consequences of these changes have been referred to as the “diseases of civilization” (Eaton *et al.*, 1988).

2.4. Physical activity patterns over time

2.4.1 Hunter-gatherer

The appearance of Homo sapiens approximately 2.4 million years ago (Hill *et al.*, 1992) has always been associated with a high volume of PA that often marked the difference between survival and death. The hunter-gatherers developed an instinct that compelled them to move when they had to, and rest when they could (Cordain *et al.*, 1997). Many of their waking hours were necessarily consumed with the tasks required of everyday life such as food and water procurement, social interaction, escape from predators, maintenance of shelter and clothing, running after wounded prey, carrying children, erecting shelters, making composite tools, digging for roots or tubers, dancing for simple recreation or as part of religious ceremonies and vigorous play to name a few (Eaton, 2003). Most estimates conclude that men walked or ran between 6 and 16 km per day to accomplish some of their daily tasks such as food and water provision (Cordain *et al.*, 1997; Cordain *et al.*, 1998). Days of heavy exertion were followed by recovery days. Women typically went out foraging to collect food every other or every third day, spent hours walking to and from sources of food, water and wood, and often carried their children until about age 4 years, covering over 4,800 km with the child in her arms over this period of time (Cordain *et al.*, 1997; Cordain *et al.*, 1998). The best available scientific estimates of EE from PA for humans (males and females averaged) living in the late Palaeolithic, 25 000 years ago, are of 1240 $\text{kcal}\cdot\text{day}^{-1}$ or near 21.8 $\text{kcal}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$

for a 57-kg composite individual (Eaton *et al.*, 1988; Cordain *et al.*, 1997; Cordain *et al.*, 1998). This was a critical factor in the hunter-gatherer achieving an estimated physical activity level (PAL) of 1.74, a value markedly higher than most humans in industrialised nations. A typical sedentary lifestyle that involves an office job is likely to yield a PAL of 1.55 for men and 1.56 for women respectively (Leonard, 2008).

2.4.2. Agricultural Revolution

Approximately 10,000 years ago, an agricultural revolution took place. A band of hunter-gatherers in the Middle Eastern region and six other areas around the globe made a transition to a lifestyle based around animal domestication and cultivation of plant crops. This transition to a less nomadic life resulted in the gradual decline of the hunter-gatherer lifestyle (Fenner, 2005; O'Keefe *et al.*, 2010). While the agriculturalist style of life also involved significant levels of physical exertion, the type of physical endeavours typical of agriculturalists were less endurance-based than that of the hunter-gatherer. There is evidence that current rural populations have similar or even higher PAL values than hunter-gatherers from ancestral times (Heini *et al.*, 1996) but there is no detailed scientific data of PA levels when the Agricultural revolution started.

2.4.3. Industrial Revolution

The industrial revolution started approximately around 1760 in England and spread through Western Europe and the United States. It marked the beginning of an accelerated pace of technological changes that have had a major negative impact on population PA levels in the long term. Initially, when the industrial revolution started, energetically demanding jobs were common, but changes in technology have made many workers’ jobs less strenuous over time (Lieberman, 2013). Many labour-saving devices have been progressively incorporated in factories and households. The increased usage of these devices has the direct effect of reducing the EE used to carry out tasks at home and at work. As it is the case with the Agricultural revolution, there is no detailed scientific data on population PA levels during the Industrial Revolution.

2.4.4. 20th and 21st Century

The acquisition of detailed PA data is a recent phenomenon that has been gradually increasing over the last 6 decades. PA occurs mainly in the leisure, occupation, transport and household domains. The SLOTH (sleep, leisure, occupation, transport, household) model (Cawley, 2004; Pratt *et al.*, 2004) has been used to conceptualise these domains in which PA occurs (Bauman *et al.*, 2012; Ng & Popkin, 2012). In the US, total adult PA for the four domains was 235 MET hr·wk^{-1} in 1965 and decreased to 160 MET hr·wk $^{-1}$ by the year 2009. Adult PA in the UK shows a similar trend with 216 MET hr·wk $^{-1}$ in 1961 and 173 MET hr·wk $^{-1}$ by the year 2005. Data for Brazil and China is available only for the last 2 decades. Total adult PA in China was 399 MET hr·wk $^{-1}$ in 1991 and dropped to 213 by 2009. Adult PA in Brazil was 229 MET hr·wk $^{-1}$ in 2002 and dropped to 214 MET hr·wk $^{-1}$ by the year 2008 (Ng & Popkin, 2012).

The leisure-time physical activity (LTPA) domain is the only one to show a stable or slight increase in the United States over the last 2 decades (Brownson *et al.*, 2005; Moore *et al.*, 2012). These results are consistent and are supported by studies from Canada (Juneau & Potvin, 2010), Spain (Palacios-Cena *et al.*, 2011), Sweden (Sjol *et al.*, 2003) and England (Stamatakis & Chaudhury, 2008). However, another recent study concluded that LPTA declined during the same period in the US (Ng & Popkin, 2012). On the basis of the Behavioural Risk Factor Surveillance System (BRFSS) from 2000, 26.2% of US adults achieved recommended levels of PA during recreation time as recommended by the CDC and the ACSM in 1993. Recommended PA was defined as 30 min of moderate intensity exercise at least 5 times per week or 20 consecutive min of vigorous activity at least 3 times per week, acquired during recreational or leisure-time activities (i.e., not work-related). Men were more likely to meet the ACSM and CDC recommendations than women during recreational pursuits. In the 10-year period between 1990 and 2000, men improved compliance with the ACSM and

CDC guidelines by 9.7% while women improved by 5.8% (Brownson *et al.*, 2005). This data is supported by another study that found a reduction in the number of people reporting zero-min of LTPA (29.8% in 1996 to 24.1% in 2004) (Moore *et al.*, 2012). This trend toward an increase in LTPA is not unique to the US as similar changes have been reported in the UK, Brazil, India and China (Ng & Popkin, 2012).

The occupation-related PA domain has shown a clear and profound decrease from the middle of the 20th century in the US (Brownson *et al.*, 2005; Church *et al.*, 2011; Ng & Popkin, 2012). The prevalence of agricultural and goods-manufacturing sectors has decreased over the last 5 decades while there has been an increase in service-oriented occupations (Church *et al.*, 2011). In addition, there has been an increase in occupations that are predominantly sedentary or require light intensity PA, and a reduction in the prevalence of moderate intensity PA jobs from 48% in 1960 to 20% in 2008 (Church *et al.*, 2011). One consequence of these changes is a decrease in occupation-related EE of 140 calories for men and 124 calories for women. According to Church *et al*. (2011), the reduction in occupational EE explains the reported increase in mean US body weight over the last 5 decades. The occupation-related PA domain is more prevalent in low-income and middle-income countries than in high-income countries (Bauman *et al.*, 2012). Therefore, population in these countries is more likely to reach higher levels of PA than that of high-income countries.

The transport-related PA domain also shows a negative trend during the same period in the US. The percentage of trips to work by car increased from 67% in 1960 to 88% in 2000, and walking to work decreased in the same period (Brownson *et al.*, 2005). Urban planning and sprawl requires people to travel from suburban areas to their workplace which makes active commuting difficult. There are obvious benefits to increasing transport-related PA, commonly known as active commuting, as countries with the highest prevalence have the lowest rates of obesity (Bassett *et al.*, 2008).

Finally, a negative trend has been observed in household-related PA. Technological advances have reduced or eliminated the physical exertion required to conduct most household tasks. Vacuum cleaners, washing-machines, food processors and microwaves are a few examples of technological advances that have reduced the amount of PA required (Lanningham-Foster *et al.*, 2003). From 1965 to 2010, there was a 12 hr·wk^{-1} decline in household PA time, which implies a considerable decrement in EE spent at home, and an increase in the amount of time spent in screen-based media use (8.3 hr·wk^{-1} in 1965 and 16.5 hr·wk^{-1}in 2010). In the same period, non-employed women experienced the largest decrease in EE during household tasks (10.5 Mj·wk^{-1}, 1.5 Mj·week^{-1}; 2518 kcal·wk^{-1}, 360 kcal·d^{-1} (Archer *et al.*, 2013). A recent study concluded that domestic PA accounts for between 11 and 73% of the reported moderate-to-vigorous physical activity (MVPA) for English adults that comply with current guidelines of 150 min of MVPA per week (Murphy *et al.*, 2013). There is a considerable variation between gender groups in the percentage contribution of domestic PA to MVPA. Domestic PA accounted for 34.9 and 19.8 of all reported MVPA for women and men respectively.

As a summary, it can be concluded that total PA in highly industrialised nations has considerably decreased in the last 5 decades. The occupational, household, and transport domains are the most common types of PA in low-income and middle-income countries (Macniven *et al.*, 2012). While there is not an agreement amongst the studies in the literature regarding how the leisure time PA has evolved over the last 2 decades, if this domain has had a slight increase, this improvement has not been enough to offset the decrease in PA that occurred in the occupational, transport and household domains.

2.4.5. Future trends

Ng and Popkin (2012) estimated the amount of PA in the different domains for the years 2020 and 2030 for the US, UK and China (see Table 2.1). In doing this estimation, they assumed that current trends of modernisation and time use would continue and that trends over time are linear. Best estimations are that occupational, and domestic PA domains will decrease while the active leisure domain will increase in the three countries. The travel domain is likely to decrease in the US, increase in the UK and remain practically unchanged in

China. Overall, there will be a decrease in the total PA when all domains are taken into account (Ng & Popkin, 2012).

Table 2.1 MET $hr^{\cdot}wk^{-1}$ forecast for 2020 and 2030.

	YEAR 2020	YEAR 2030
US	142	126
UK	153	140
Brazil	180	151
China	200	188

Forecast of MET $hr^{\cdot}wk^{-1}$ of all adult PA for the year 2020 and 2030 for the US, UK, Brazil and China (reproduced from Ng, 2012).

The technological advances that the Industrial Revolution started and facilitated have made human existence less dependent on physical exertion and have increased leisure time significantly. Given that it is unlikely this trend will change in the future, it is particularly important to promote activities that increase PA during leisure time. There is a clear need to increase the PA level of the general population in order to ward off chronic disease. There is strong evidence that PA plays a core role in disease prevention, but despite this, worldwide physical inactivity levels are high (Warburton *et al.*, 2007a). Activities that involve physical exertion, enjoyment and positive psychological states are attractive options in a world where leisure time is predicted to keep expanding.

2.5. Physical activity determinants

PA behaviour is influenced by a large number of psychological, sociological, economic, ecological and biological factors. Several frameworks have been formulated to organise and try and explain the relationship of all these factors with each other and with PA behaviour (Swinburn *et al.*, 1999; Booth *et al.*, 2001; Glass & McAtee, 2006; Bauman *et al.*, 2012). Some of these frameworks combine the perspectives from the natural and social sciences by including the biological system and the socio-ecological model in the framework. In these frameworks, the different levels of influence (micro, meso, macro, global) indicate the proximity of the determinants to the individual conducting the behaviour (Booth *et al.*, 2001; Glass & McAtee, 2006). The ANGELO-framework (Swinburn *et al.*, 1999) makes a distinction between the types of environmental influences that exerts an influence at each level (socio-cultural, physical, economic and political).

The PA determinants taxonomy presented in this thesis is based on the model presented by Bauman *et al*. (2012). This model is an integration of ideas from several theories into an ecological model that includes inter-relations between individuals and their social and physical environment.

The rationale for this approach is that knowledge about all types of influence can have a positive impact on the development of multilevel interventions to offer the best chance of success. Figure 2.1 shows a model of multiple level PA influences that guided the determinant classification presented by Bauman et al (2012).

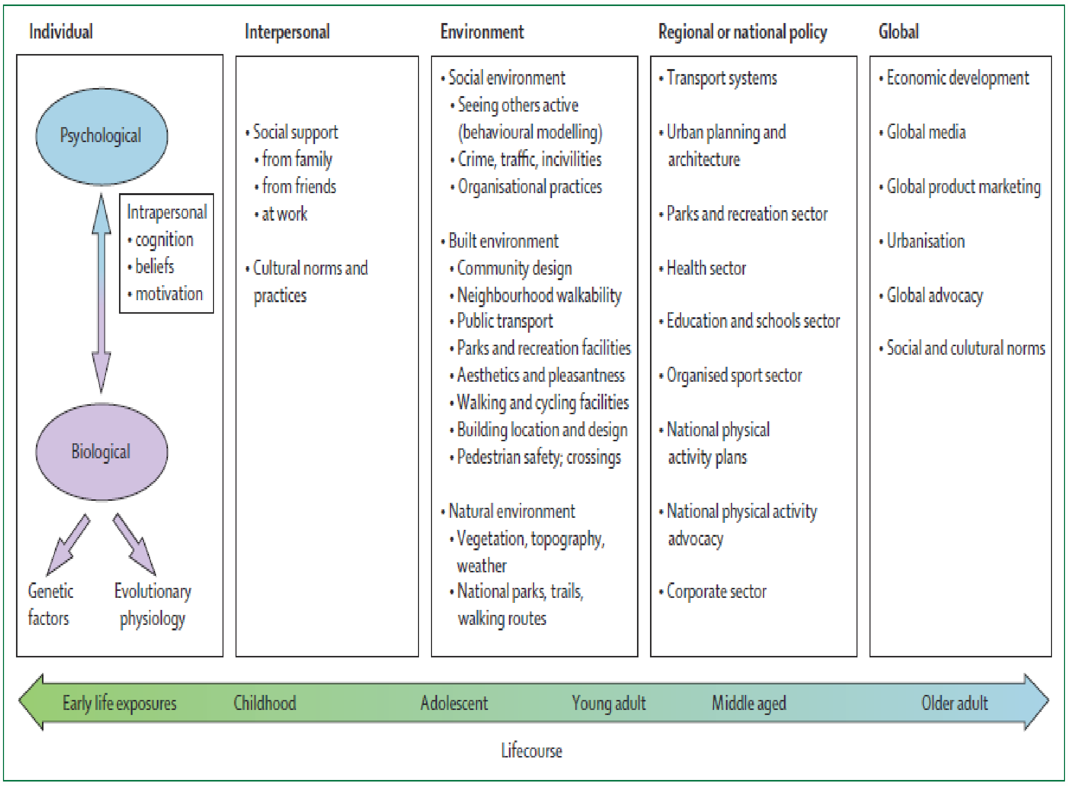


Figure 2.1*:* Adapted ecological model of the determinants of PA (reproduced from Bauman *et al*., 2012).

The different models presented above have some differences, but are broadly the same. There is not a definitive model and agreed set of determinants in the literature, and research efforts are on-going to try to better establish the determinants of adult PA. Bauman *et al.* (2012) makes a distinction between correlates of PA (factors associated with activity) and determinants (those with causal relationship). The PA determinants can be grouped in 1) demographic and biological factors, 2) psychological, cognitive, and emotional, 3) behavioural attributes, 4) social and cultural, and 5) physical environmental (Trost *et al.*, 2002). Bauman and colleagues include genetic and evolutionary factors as another set of determinants (2012). The determinants presented are examples of the most important PA ones and it is not a comprehensive review of them.

2.5.1 Demographic, biologic, psychological, cognitive, social and cultural factors

A number of studies have reported that health status and self-efficacy, an individual's confidence in his/her ability to be physically active on a regular basis, are the most important correlates of PA in adults (Rhodes *et al.*, 1999; Trost *et al.*, 2002; Plonczynski, 2003; van Stralen *et al.*, 2009). One review also found health status and self-efficacy to be determinants (van Stralen *et al.*, 2009). Age and gender are also strong correlates since several studies have shown that PA participation is higher in men than in women at different stages in life, and that PA participation is inversely associated with age (Burton *et al.*, 1999; Rhodes *et al.*, 1999; Booth *et al.*, 2000; Brownson *et al.*, 2000; King *et al.*, 2000; Trost *et al.*, 2002). Other reported PA correlates are enjoyment of exercise, income/socioeconomic status, ethnic origin (white), perceived effort (inversely), and social supports (Trost *et al.*, 2002; Plonczynski, 2003).

Another determinant that exerts negative influence in PA participation is overweight and obesity. In a study comprising 15 countries of the European Union, Martinez-Gonzalez and colleagues (1999) found that after controlling for 9 confounders, individuals in the highest quintile for leisure time PA were approximately 50% less likely than those in the lowest quintile to be classified as obese. Factors such as job strain, working hours, and overtime had inverse associations with leisure-time PA (Kirk & Rhodes, 2011). Finally, two longitudinal studies showed that stress is an inverse determinant and that physical and psychological outcome realisations are direct determinants of maintenance of PA, but action planning is a determinant of initiation of PA (Kirk & Rhodes, 2011; Koeneman *et al.*, 2011; Bauman *et al.*, 2012).

Personal history of PA during adulthood and intention to exercise are important behavioural attributes. There is evidence showing that both factors are correlates (Rhodes *et al.*, 1999; Trost *et al.*, 2002), and also determinants (van Stralen *et al.*, 2009). Dietary habits and smoking status are relevant PA determinants in this category. Positive associations with healthy diet have been reported and smoking is negatively associated with PA involvement (Brownson *et al.*, 2000; Salmon *et al.*, 2000; Trost *et al.*, 2002). A positive association between social support and PA has also been reported (Trost *et al.*, 2002).

2.5.2 Physical environments

Walkability and street connectivity (grid-like pattern of streets) have been identified as correlates of transport-related PA. Total PA was related to environmental variables in all five categories, most convincingly with recreation facilities and locations, transportation environment, and aesthetics (Bauman *et al.*, 2012). Another study found that enjoyable scenery while exercising and frequently observing others exercise were positively associated with PA participation (King *et al.*, 2000). In a different report, the Center for Disease Control and Prevention reported a significant positive association between perceived neighbourhood safety and PA (CDC, 1999). But generalisation should be avoided since another study found that for women older than 40 years of age, neighbourhood safety was the top barrier only for African American women and it was not that important for white or Hispanics (King *et al.*, 2000). Possibly, personal safety is a basic requirement that has to be met for adult PA to occur. Once this requirement is met, as can be the case in more affluent neighbourhoods, other barriers to PA (lack of time, caregiving duties, lack of energy, and lack of enjoyment) gain importance

2.5.3 Genetic and evolutionary factors

Physical activity behaviour may have a genetic determinant, something similar to other behaviours such as appetite (Bauman *et al.*, 2012). There is evidence that genetics and intrinsic biological processes play a role in PA behaviour (Bouchard *et al.*, 1990; Levine *et al.*, 1999), but clearly more research is needed in this area. Some of this evidence comes from animal studies (Tokunaga *et al.*, 1991; Klingberg & Klengel, 1993) and also from twin and family studies (Franks *et al.*, 2005; Fisher *et al.*, 2010) which suggest that central nervous system mechanisms play a regulatory role in daily PA. These have shown that genetic factors contribute to variation in reported daily PA levels.

Very interesting and thought provoking is also the large inter-individual variability regarding responses to routine exercise. While some subjects experience reward, others experience pain, fatigue and negative feelings (de Geus & de Moor, 2011). To try and explain these opposing responses, some research efforts have focused on genes that constitute the dopaminergic (Baik *et al.*, 1995; Kelly *et al.*, 1998) and melanocortinergic pathways (Ste Marie *et al.*, 2000; Butler *et al.*, 2001), but these studies have not reached any success in explaining inter-individual differences. So far, despite the evidence already mentioned, candidate gene and genome-wide studies have not yet identified genetic loci that have robust associations with daily PA. It is expected that large-scale genome-wide studies will identify new loci, and this might reveal biological mechanisms that explain differences in daily PA (Bauman *et al.*, 2012).

Finally, supporters of the evolutionary biology as a possible PA determinant suggest that adaptation of human species determines that PA is needed for normal function of biological systems. However, urbanised and technological society does not encourage natural levels of PA.

2.6. Health-enhancing physical activity and physical activity guidelines for health

Health-enhancing physical activity (HEPA) includes any form of PA that benefits health and functional capacity without undue harm or risk (WHO, 2005). The health benefits of PA are determined by the intensity, duration and frequency of the activity. Over the last 70 years our scientific knowledge of the benefits of PA for health has substantially increased. Several international organisations have developed PA guidelines to promote or maintain health (EU *et al.*, 2008; WHO, 2010; ACSM, 2014). The guidelines published by these organisations are quite similar but, for the purpose of this thesis, reference will be made to the American College of Sports Medicine (ACSM)/American Heart Association (AHA) guidelines (ACSM, 2014). These guidelines are as follows:

1) All adults aged 18 should participate in moderate intensity aerobic PA for a minimum of 30 min on 5 days a week or vigorous intensity aerobic activity for a minimum of 20 min on 3 days a week,

2) A combination of moderate and vigorous intensity exercise can be performed to meet this recommendation,

3) Moderate intensity aerobic activity can be accumulated to total the 30 min minimum by performing bouts each lasting ≥ 10 min,

4) Every adult should perform activities that maintain or increase muscular strength and endurance for a minimum of 2 days a week,

5) Individuals will gain more fitness benefits, reduce their risk for chronic disease and disability, and/or prevent unhealthy weight gain by exceeding the minimum recommended amounts of physical activity.

The ACSM/AHA PA recommendations have been formulated so that the whole population can understand clearly and easily minimum targets and intensities of exercise to promote and maintain health. Compliance with these guidelines might result in enhanced prevention of certain chronic diseases, but not all of them. The recommendations focus solely on the physiological stimulus of the exercise bouts without taking into account the affect and psychological states that these exercise bout leads to. While these are recommendations for the general public they have been questioned by other expert groups. In 2003, a panel of the Institute of Medicine (Saris *et al.*, 2003) recommended 60 min of moderate-intensity PA for weight maintenance. This contrasts with the 30 min recommended in the ACSM/AHA guidelines. Saris and colleagues also stated that while the current PA guidelines are of importance for limiting health risks for a number of chronic diseases including coronary heart disease and diabetes, it seems likely that moderate intensity activity of approximately 45 to 60 min per day, or 1.7 PAL is required to prevent the transition to overweight or obesity. There is compelling evidence that prevention of weight regain in formerly obese individuals requires 60-90 min of moderate intensity activity or lesser amounts of vigorous intensity activity (Saris *et al.*, 2003).

There have also been a number of studies concluding that significant health benefits are possible with lower doses of PA than those recommended in the PA guidelines (Lee *et al.*, 2001; Manson *et al.*, 2002; Sattelmair *et al.*, 2011; Woodcock *et al.*, 2011). Furthermore, there is evidence that lower doses of PA than those of the ACSM/AHA recommendations, lead to reduced rates of mortality (Schooling *et al.*, 2006; Warburton *et al.*, 2006; Leitzmann *et al.*, 2007; Wen *et al.*, 2011). In the study by *Wen et al.*, 1 in 9 deaths from cancer in individuals in the inactive groups could have been averted if they had exercised for 15 min daily. Authors concluded that 15 min a day exercise had a similar effect in the reduction of all-cause mortality in men and women across all age groups and that these results were similar after controlling for 13 confounders (Wen *et al.*, 2011).

Chronic disease was the cause of death of up to 63% of worldwide deaths in 2008 (Alwan *et al.*, 2010). Regular PA and exercise are modifiable risk factors in the fight against chronic disease (Kruk, 2007), have been linked with the effective prevention of up to 25 chronic conditions (Booth *et al.*, 2002; Warburton *et al.*, 2007a), have been termed the miracle drug (Pimlott, 2010) and there are numerous epidemiological studies and meta-analysis backing up the use of PA to reduce incidence of morbidity and mortality.

2.7. Physical inactivity

In PA epidemiological research, physical inactivity is defined as not meeting any of these three criteria: 30 min of moderate-intensity PA on at least 5 days every week, 20 min of vigorous-intensity PA on at least 3 days every week, or an equivalent combination achieving 600 metabolic equivalent (MET)-min·wk^{-1} (IPAQ, 2011; WHO, 2011). To have a true picture of population PA and inactivity levels, it is necessary to examine and accurately measure population PA in the different domains. The most common measures of PA found in the literature are standardised and validated self-questionnaires like the International Physical Activity Questionnaire (IPAQ) and relatively new technologies like accelerometry. Using accelerometers avoid some of the inherent limitations of self-reported instruments like recall bias, or a tendency to overestimate PA levels (Prince *et al.*, 2008). There is a significant difference in reported values when accelerometry and self-questionnaires are used. Accelerometry is the best available measure since it is a direct and objective measurement of the activity, but most studies use self-report questionnaires. Other methods used include PA diaries and PA logs, where information on all kind of activities is recorded each day, measurement of energy expenditure by doubly-labelled water or the use of cost-affordable pedometers. The pedometer counts the steps that a person takes, and is particularly useful for capturing walking behaviour (Tudor-Locke & Myers, 2001).

One of the most comprehensive studies in the recent literature compiled information of PA levels in 122 countries, covering 89% of the global population, by analysing the WHO global health observatory data repository (Hallal *et al.*, 2012). Hallal *et al.* (2012) reported that 31.1% of world population is physically inactive, more females (33.9%) are inactive than males (27.9%), inactivity levels increase with age and inactivity is more common in high income countries. These results contrast with those from a pooled analysis from three multi-centre studies (Dumith *et al.*, 2011). Worldwide prevalence of physical inactivity was 18.9% for males and 23.7% for females. After weighting for the total population of each country, worldwide prevalence of physical inactivity was 17% with values ranging from 2.6% in Comoros to 62.6% in Mauritania. Dumith *et al.* (2011) also reported that physical inactivity was more prevalent among wealthier and urban countries, and among women and elderly individuals. The differences in the physical inactivity percentage results from these two studies are difficult to explain since both studies used self-report questionnaires such as IPAQ. Some of the differences might be explained by the fact that the Hallal (2012) study covered 89% of the world population and included 15 years or older, while the Dumith *et al*. (2011) study covered 80% of the world population and included 18 years or older adults.

In spite of the outstanding health benefits associated with regular PA, most PA intervention initiatives have produced only modest changes to behaviour and often fail to impact PA at health guideline doses (Baranowski *et al.*, 1998; Lewis *et al.*, 2002; Rhodes & Pfaeffli, 2010). Dishman (1982) also noted that 50% of persons who start an exercise program will drop out within 6 months. The WHO has recognised physical inactivity as a serious worldwide health problem that has to be addressed urgently. Recently, the Global Burden of Disease study ranked physical inactivity as the fifth leading cause of disease burden in western Europe and 10th worldwide, and as one of the top modifiable risk factors along with smoking (Lim *et al.*, 2012). In 2009, physical inactivity accounted for more than 3 million preventable deaths (WHO, 2009). In addition to discussing physical inactivity, it is also necessary to review the role of sedentary behaviour and its relation with chronic disease.

2.8. Sedentary behaviour

Sedentary behaviour is defined as any waking behaviour characterized by an EE ≤1.5 METs while in a sitting or reclining posture (Sedentary Behaviour Research, 2012). Sedentary behaviour is different to physical inactivity in that it refers to behaviours characterised mainly by sitting and with activities that are associated with a very low level of metabolic EE (Owen *et al.*, 2011) and may account for 50–60% of time spent awake (Healy *et al.*, 2011).

One of the challenges is the accurate and objective measurement of sedentary behaviour. The main tools have been self-report measures and accelerometer devices, but these methods are limited in their ability to differentiate between sedentary pursuits (Tremblay *et al.*, 2010). There is strong evidence on the reliability of measures of TV viewing time; but there is a lot of uncertainty about the measurement of other sedentary activities (Clark *et al.*, 2009), including sitting time in the car, chair time, indoor time, and screen time (Tremblay *et al.*, 2010).

Two important considerations are that time spent in sedentary behaviour is associated positively with mortality (Koster *et al.*, 2012; Matthews *et al.*, 2012; Kim *et al.*, 2013) and associated inversely with time spent in 'light' physical activities (Healy *et al.*, 2008b). This implies that, on a population level, sedentary time competes with light-intensity PA during the daylight hours. Therefore, increasing light-intensity activities and standing may have beneficial effects on health by reducing the risk of chronic disease and mortality (Wilmot *et al.*, 2012). It is therefore paramount to have a repertoire of light intensity physical activities as part of a daily routine since this is likely to significantly reduce sedentary time. These might include simple activities such as walking to a work colleague's desk instead of e-mailing or phoning, using stairs instead of lifts, walking to shops, standing up for a few min every hour and playing AVGs. Some currently available AVGs result in light-intensity activities and positive affect states. These games could be used to increase time devoted to light exercise intensity activities and minimise sedentary time and reduce risk of chronic disease.

2.8.1. Health risks associated with sedentary behaviour

There is emerging evidence that sedentary behaviour has a deleterious effect on human metabolism, physical function, and health outcomes that is separate and different from the negative effect of physical inactivity (Hamilton *et al.*, 2004; Hamilton *et al.*, 2007; Healy *et al.*, 2008b; Owen *et al.*, 2010a). The detrimental effect of sedentary behaviour on metabolic health is purported to be partially mediated by changes in lipoprotein lipase (LPL) activity (Tremblay *et al.*, 2010). Lipoprotein lipase is a water soluble enzyme found bound to the surface of the capillary endothelium (especially in muscle and adipose tissue). It plays a role facilitating the uptake of free fatty acids into skeletal muscle and adipose tissue (Hamilton *et al.*, 2007). Rat immobilisation studies showed a marked decrease in postural-muscle LPL activity. This reduction in enzyme activity has important implications since it has been associated with blunted triacylglycerol uptake, reduced plasma HDL-cholesterol levels and cardiovascular disease (Hamilton, 2008). Compared to sedentary behaviour, moderate and vigorous PA have a small effect on LPL activity, which highlights the important contribution of postural muscle contraction (Bey & Hamilton, 2003; Hamilton, 2008).

A recent systematic review and meta-analysis of cross-sectional and prospective studies revealed that the greatest sedentary time compared with the lowest was associated with a 112% increase in risk of diabetes, 147% increase in risk of cardiovascular disease, 90% increase in risk of cardiovascular mortality and 49% increase in risk of all-cause mortality (Wilmot *et al.*, 2012). Sedentary behaviour is associated with increased plasma triglyceride levels, decreased levels of high-density lipoprotein (HDL) cholesterol, and decreased insulin sensitivity (Dunstan *et al.*, 2005; Hamilton, 2008; Owen *et al.*, 2010a; Owen *et al.*, 2010b; Thorp *et al.*, 2010; Tremblay *et al.*, 2010; Thorp *et al.*, 2011). All the reported associations were found to be independent of amount of PA, which provides further evidence that the deleterious effect of sedentary behaviour is not mediated by decreases in PA (Wilmot *et al.*, 2012) or MVPA (Koster *et al.*, 2012; Matthews *et al.*, 2012). This has important implications for chronic disease prevention and improving population health. It is possible to be physically active and even exceed the PA recommendations whilst also being at a higher risk of suffering chronic disease if sedentary behaviour is high.

2.8.3. Sedentary behaviour determinants

The identification of determinants of sedentary behaviour is essential in order to design effective behavioural strategies to reduce this behaviour. This is an emerging area of research and there is a clear need for investigation in this field.

This is likely to occur in the short-term given the negative impact that sedentary behaviour is recognised to have on health. Recently, the development of a taxonomy of sedentary behaviour started which will lay the foundations for solid research in this area (Chastin *et al.*, 2013). At present, most of the available evidence on sedentary behaviour determinants comes from cross-sectional studies. This is not ideal, as cross-sectional studies are likely to identify behavioural correlates, rather than determinants (Owen *et al.*, 2011). It is also likely that the different sedentary behaviours (e.g. sitting in car, watching TV, sitting at work) will have distinct determinants (Owen *et al.*, 2000), therefore it is paramount to establish the determinants for sedentary behaviour that takes place in different settings.

2.9. Physiological and psychological benefits of physical activity on health

2.9.1. Physiological response to an acute bout of exercise and health gains

The physiological response to an acute bout of exercise has been well documented by many laboratory studies. The intensity, duration and the environmental conditions determine the physiological response to acute exercise. In the transition from rest to exercise, the cardiovascular, respiratory, metabolic, nervous and endocrinology systems respond rapidly to the increased demand for oxygen and substrate that the increased muscle work contraction is imposing.

The cardiovascular response includes an increase in stroke volume (SV) and heart rate (HR) and therefore cardiac output (CO). The time to reach a levelling off in CO depends on the nature of the exercise. This increased preload has the effect of stretching the myocardium and causes it to contract more forcibly. There is also an activation of the sympathetic nervous system during exercise, which leads to an increase in the contractility of the myocardium. The HR increases as result of a parasympathetic nervous inhibition and a sympathetic nervous activation (Rowell, 1986; Plowman & Smith, 2013). A redistribution of the cardiac output takes places and skeletal muscle tissue goes from getting 21% of cardiac output at rest to 47% during moderate exercise. Vital organs like the brain receive the same volume in absolute terms (750 mL) but decreases in relative terms (Plowman & Smith, 2013).

The respiratory system responds rapidly to the onset of exercise by increasing tidal volume (TV) and respiratory rate (RR) therefore ventilation ($\dot{V}_E$) within the first respiratory cycle. This initial rise in $\dot{V}_E$ is followed by a more gradual rise that will reach a steady-state generally within 2-3 min of low to moderate-intensity exercise (Plowman & Smith, 2013).

The metabolic responses to acute exercise involve the participation of diverse energy-producing pathways to cover the extra demand for ATP regeneration that results from exercise. During exercise, ATP is regenerated at a faster rate than at rest. One of the consequences of the increased usage is an increase in the EE or caloric cost of the task. The relative contribution of ATP and PC, muscle glycogen, liver glycogen and free fatty acids depends on the complex interplay of exercise intensity and duration. In all cases, there is an energetic continuum which means that all energy producing pathways are involved in ATP regeneration.

Finally, the nervous system (through the autonomic nervous system) and the endocrine system exert a synergistic control of body responses to face the imposed challenges of exercise. The sympathetic nervous system innervates multiple organs and its stimulation also leads to the release of catecholamines (adrenaline and noradrenaline) from the adrenal medulla. These events play a regulatory role in redistributing blood flow during exercise and maintaining blood pressure. This important function is accomplished by inducing vasoconstriction in arterioles of visceral organs, skin and non-active tissues, and vasodilation in active tissues. Another important aspect of the neural response to exercise is the parasympathetic system inhibition that results in an initial increase in HR.

Thompson *et al*. (2001) stressed the important role that an acute bout of exercise can exert on diverse physiological parameters. The strength of the evidence presented by these authors was category A in most cases. Examples of these beneficial effects include a reduction in triglycerides seen after 18–24 h of exercise which can last for up to 72 hr, increases of 4-43% in HDL-C, 5–8% reductions of LDL-C in hyper-cholesterolemic men with acute exercise (Crouse *et al.*, 1995; Crouse *et al.*, 1997; Ferguson *et al.*, 1998), maximal decreases in systolic blood pressure of 18–20 mm Hg and diastolic blood pressure of 7–9 mm Hg as reported among subjects with Stage I hypertension (Kenney & Seals, 1993; Hagberg & Brown, 1995), enhanced glucose control and reduced insulin resistance (Thompson *et* al*.*, 2001).

2.9.2. Psychological and affect responses to an acute bout of exercise

Affect is defined as "the most basic or elementary characteristic component of all valenced (positive or negative, pleasant or unpleasant) responses, including, but not limited to, emotions and moods" (Ekkekakis & Petruzzello, 2000). While there are subtle differences between mood and affect, these terms have been used interchangeably in the scientific literature and that is the way how they are used in the present thesis.

A large number of studies have found at least some degree of improved mood on a wide variety of measures following an acute bout of exercise, despite a diversity of exercise modes, durations and intensities. Exercise is also a useful short-term strategy for alleviating psychological distress. In general, the positive effects of exercise on mood occur irrespective of gender or age, and most forms of aerobic exercise, weightlifting and yoga seem to result in a reduction in negative mood states (Yeung, 1996). The minimum exercise duration required to induce positive benefits on psychological variables is not clear, but one study concluded that 10 min of brisk walk might be sufficient to enhance energy and reduce tension (Thayer *et al.*, 1993). Different mechanisms have been proposed to explain the positive effects of exercise on mood. One of these proposed mechanisms is the exercise-induced increase in blood circulation to the brain, and also, an influence on the hypothalamic-pituitary-adrenal (HPA) axis and, thus, on the physiologic reactivity to stress (Guszkowska, 2004). This physiologic influence might be mediated by the communication of the HPA axis with other regions of the brain such as the limbic system, which controls motivation and mood; the amygdala, which generates fear in response to stress; and the hippocampus, which plays an important part in memory formation as well as in mood and motivation (Sharma *et al.*, 2006). Other potential mechanisms to explain the beneficial effects of exercise on mental health include distraction, self-efficacy, and social interaction (Peluso & Guerra de Andrade, 2005).

There are also conflicting results in the literature on the effect of exercise intensity on mood states. Some studies conclude that only moderate and high intensity exercise resulted in enhanced mood states (Farrell *et al.*, 1987), while others reported improved mood states only after moderate intensity exercise (Steptoe & Bolton, 1988; Steptoe & Cox, 1988). The literature also includes reports in which self-selected exercise resulted in the best improvements in the profile of mood states (POMS) (Zervas *et al.*, 1993). This result might be partly explained by the “flow theory”, which states that “flow” (supreme enjoyment and engagement in the task) can only be achieved when an individuals’ competencies are matched against the challenges of the task at hand (Csikszentmihalyi, 1990). When the participants have the freedom to self-select the exercise intensity, they might choose an intensity that presents a better challenge than if the exercise intensity were imposed externally which may be too demanding or too easy. Finally, research indicates that the positive effects exerted by exercise on mood states last for 3 to 4 hr post-exercise (Raglin & Morgan, 1987), but certain aspects like anger and total mood disturbance can be improved for up to 24 hr (Maroulakis & Zervas, 1993).

2.9.3. Physiological responses to regular exercise and health gains

Regular exercise participation induces a number of physiological adaptations. Some of the most important are cardiovascular, and metabolic adaptations, all of which have a beneficial effect on health (U.S. Department of

Health and Human Services & Center for Chronic Disease Prevention and Health Promotion, 1996).

Significant cardiorespiratory adaptations occur as result of regular aerobic exercise. These adaptations include a reduction in cardiac output at the same relative exercise intensities and up to a 30% increase in maximal cardiac output (Saltin & Rowell, 1980). Resting and submaximal HR decrease while HRmax remains unchanged or slightly lower (Saltin, 1969; Plowman & Smith, 2013). Some important muscle adaptations take place, for example, aerobic training induces an increase in cross-sectional areas of slow-twitch fibres and an increase in capillaries in trained skeletal muscle which leads to an enhanced capacity for blood flow in the active muscle (Terjung, 1995). There are also a series of metabolic adaptations that take place in the skeletal muscle as result of endurance training. These adaptations include an increase in the size and number of mitochondria, an increase in the activity of oxidative enzymes (mitochondrial marker cytochrome C) and an increase in the amount of oxygen stored in the muscle fibre as result of an increment in the myoglobin content in the muscle fibre (Hickson, 1981). Aerobic training also leads to an enhanced ability to mobilise free-fatty acids from fat depots along with an improved capacity to oxidise fat (Hawley *et al.*, 1998).

The biological mechanisms responsible for the health benefits that lead to reduced risk of chronic disease and reduced mortality have been thoroughly studied and documented in the literature. Regular PA exerts a positive effect on cardiovascular risk factors through reduction of plate aggregation (Wang *et al.*, 1995), improvement of cardiac function, increase of blood flow and oxygen delivery to skeletal muscle, improvement of cardio-respiratory fitness, reduction of body mass (Åstrand, 1986), lowering of blood pressure (Paffenbarger *et al.*, 1983; Blair *et al.*, 1984) improved glucose homeostasis an increase in insulin sensitivity (Borghouts & Keizer, 2000; Warburton *et al.*, 2001a; Warburton *et al.*, 2001b) and increased urinary sodium extraction (Hambrecht *et al.*, 2000; Charkoudian & Joyner, 2004). Exercise also leads to an enhanced lipid lipoprotein profile by decreasing TG levels, increasing HDL and decreasing the

LDL-to-HDL ratio (Brenes *et al.*, 1986; Berg *et al.*, 1997; Warburton *et al.*, 2001a; Warburton *et al.*, 2001b).

One of the most beneficial roles of PA and exercise on human health is reduced inflammation and enhanced endothelial function (Kasapis & Thompson, 2005). Chronic inflammation, as measured by circulating levels of inflammatory mediator C-reactive protein, is associated with a host of chronic diseases (Kruk, 2007). Kasapis and Thompson (2005) concluded that regular PA may reduce resting C-reactive protein.

Another protective role of regular PA or exercise is that it increases the levels of antioxidant enzymes which is of paramount importance to counterbalance the oxidative stress caused by reactive oxygen species (Powers *et al.*, 2010). Oxygen free radicals are known to react rapidly with proteins, lipids, carbohydrates and nucleic acids (e.g. DNA). Moderate physical exercise can, theoretically, reduce DNA damage and increase DNA-repair activity through up-regulating the activities of antioxidant defence systems responsible for removing reactive oxygen species.

2.9.4. Psychological and affect responses to regular exercise and health gains

While physiological research has produced undeniable evidence of the positive physiological effects of regular exercise, the equivalent psychological research has resulted in more controversial evidence. Part of the reason for this controversial evidence has been numerous weak research designs and low statistical power in many studies. It is noteworthy, however, that all psychological variables studied are positively impacted by regular exercise.

Numerous research studies have examined the relationship between exercise and affect states. The results from some experimental trials lead us to conclude that the intensity of exercise is important in determining the effect of exercise on affect states (Ekkekakis *et al.*, 2008). At least three studies have shown that moderate intensity exercise had a mood enhancing effect, while high intensity exercise did not have this desired effect (Steptoe & Bolton, 1988; Steptoe & Cox, 1988; Moses *et al.*, 1989). Also, fitness level is important since trials have shown that trained individuals have greater positive affect than untrained participants (Boutcher *et al.*, 1997). Relevant evidence comes also from population surveys like those by Stephens (1988). Stephens (1988) concluded that PA was positively associated with positive mood general well-being and relatively infrequent symptoms of anxiety and depression. This relationship is stronger for women and people aged 40 or older.

Another affective construct/measure that may have important implications for health promotion and exercise adherence is enjoyment. Enjoyment is a positive affective state that reflects feelings of pleasure, liking and fun (Berger *et al.*, 2002). Individuals that enjoy exercise are more likely to adhere to it than if they feel neutral towards the activity or even dislike it (Motl *et al.*, 2001; Salmon *et al.*, 2003). A related concept to the enjoyment construct is the state of "flow". Flow is the optimal psychological state of mind that usually occurs when the challenge of a situation or an activity matches the skills the individual brings to the situation. Flow is characterised by supreme enjoyment and engagement in the task (Biddle & Mutrie, 2001). Flow is a well-documented phenomenon in experienced athletes, but anybody can experience it. Since it is a positive affective state, an increased flow state might be a desired outcome in terms of increasing exercise adherence.

Regular exercise participation has been linked to other positive outcomes that include small-to-moderate positive effect on vigour, small-to-moderate negative effect for fatigue and confusion, positive changes in self-esteem and physical self-perception, less anxiety, a small reduction in non-clinical depression and small significantly positive effects in cognitive function (Biddle & Mutrie, 2001).

2.9.5. Physical activity and energy expenditure

Total EE is the sum of several components that vary amongst different individuals. Firstly, energy is required in the human body to accomplish vital bodily functions in the waking state. This component of EE is called basal metabolic rate (BMR) and refers to the amount of energy required by the body at complete rest. The basal metabolic rate is the minimum energy required to sustain tissue function, and therefore life, and accounts for 60% of total daily EE in sedentary individuals (Levine, 2002). .

Secondly, energy is expended in response to a meal and is associated with digestion, absorption and fuel storage (Donahoo *et al.*, 2004). The thermic effect of food accounts for approximately 10% of total daily EE of which there is relatively little inter-individual variability (Levine, 2007).

The third component of total EE is activity thermogenesis, which comprises all of the EE from exercise and other daily activities. The energy cost of exercise is relatively easy to measure or predict but other daily activities account for activity thermogenesis for most people. Quantifying and categorising non-exercise EE is and has been referred to as incidental movement (Tremblay *et al.*, 2007), occupational PA (Probert *et al.*, 2008), spontaneous PA (Westerterp, 1998) and non-exercise activity thermogenesis (NEAT) (Levine, 2002, 2003).

2.9.5.1. Energy expenditure measurement

Energy expenditure can be measured through different methods that include indirect calorimetry, direct calorimetry and a number of non-calorimetry based techniques (Levine, 2005; Plowman & Smith, 2013). In Indirect calorimetry, measurement of steady-state $\dot{V}O_2$, $\dot{V}CO_2$ and respiratory quotient (RQ) are used to estimate EE using different formulas (Weir, 1949; Consolazio C, 1963; Elia & Livesey, 1992). During exercise, portable metabolic analysers such as that used for studies 1 and 3 in this thesis (Cosmed, K4B2) are a useful and valid way of estimating EE. Direct calorimetry involves the subject remaining inside a chamber with walls specifically designed to absorb and measure the heat produced (Åstrand, 1986). This method is expensive, technically challenging and only a few laboratories avail of these facilities.

The non-calorimetry based techniques include doubly-labelled water (DLW), pedometers, accelerometers and heart rate telemetry. The doubly-labelled water uses the natural occurring stable isotopes of water (D_2O and $H_2{}^{18}O$) to assess EE, body composition and water flux. The basis of the DLW method is to follow the decline in enrichment of the stable isotopes of oxygen (oxygen-18,^{18}O) and hydrogen (deuterium,^{2}H) in body water after initial labelling of the body water pool. As ^{18}O is lost from the body in the form of water and CO_2, whereas deuterium is lost only as water, the difference in loss from the body reflects the CO_2 production during the period. The CO_2 production is the result of fat, carbohydrate and protein oxidation and is also an index of energy expenditure (Montoye, 1996). For a more affordable and technically simpler way of estimating EE, the pedometer is a good option that is particularly suited to measure walking (Tudor-Locke & Myers, 2001). The accelerometers are more sophisticated devices that are capable of storing multi-dimensional data for subsequent analysis. Finally, EE can be estimated from heart rate data. This estimation is based on the robust linear relationship between $\dot{V}O_2$ and HR.

2.9.5.2. Exercise activity thermogenesis

The energy cost of an acute bout of exercise comprises the resting component and the energy required to carry out the exercise itself. The resting component is the energy required to sustain all body activities at rest, awake and in a supine position. The resting component remains unchanged during exercise. It is the increased level of activity inherent to the exercise that results in an elevation in $\dot{V}O_2$ and EE. Throughout this thesis, the terms metabolic equivalent of the task (MET) and kilocalories have been used to describe the EE associated with the different protocols (exercise and AVGs) tested. One MET is the mean energy cost of an adult while sitting and equals 3.5 mL·kg^{-1}·min^{-1} of oxygen or 1 kcal·kg-1·hr^{-1}. The METs during an activity is also used as an index of exercise intensity (ACSM, 2014).

In addition to the energy cost of the exercise bout there is an increased rate of energy expenditure (rate of EE) in the post-exercise period (Speakman & Selman, 2003). The magnitude of this excess post-exercise oxygen consumption (EPOC) depends on the intensity and duration of the exercise. This elevated metabolism during recovery is thought to be caused by the restoration of ATP-PC and oxygen stores, an elevated cardiovascular-respiratory function, elevated hormonal levels, elevated body temperature and lactate removal (Plowman & Smith, 2013). It is, however, unlikely that an acute bout of exercise results in any long-term changes in RMR (Horton, 1986; Bingham *et al.*, 1989; Melby *et al.*, 1993; Stiegler & Cunliffe, 2006).

2.9.5.3. Non-exercise activity thermogenesis (NEAT)

Levine coined the term non-exercise activity thermogenesis (NEAT)(Levine *et al.*, 1999; Levine *et al.*, 2000; Levine & Kotz, 2005; Levine *et al.*, 2006). NEAT refers to the energy expended other than from sleeping, eating or sports-like exercise. It includes the energy expended in tasks such as walking to work, typing, performing yard work, undertaking agricultural tasks and fidgeting (Levine, 2003). Levine highlights the vast potential of NEAT to have a significant impact on total EE rates of the population. This potential surpasses that of organised exercise and sports, according to Levine. Any activity or strategy that is likely to result in higher NEAT is worth exploring since it has the potential to result in health benefits.

Promoting PA is a target of public health given the proven beneficial effects of PA. However, it is important to recognise as well, that exercise adherence rates are poor amongst new exercisers. NEAT offers a significant potential to increase EE without resorting to exercise, and therefore has the potential to produce health benefits. Technology has been part of the problem of reduced PA levels, especially in the 20th century. Despite this, technology can be part of the solution to bring population PA levels up again. AVGs may play a role in using technology to increase PA level.

2.10. The potential for play and technology to increase population physical activity levels

According to the French philosopher Roger Caillois, play is a voluntary activity and a source of joy and amusement. When somebody is force to play a game, then it ceases being play (Caillois, 1958). The French philosopher Roger Caillois goes on to say that play is an occasion of pure waste: waste of time, energy, ingenuity, skill, and often of money. It is also an essential element of human social and spiritual development". Caillois refers to the fact that enjoyment and pleasure derived from playing games may appear to be the only product of playing. While a lot of people tend to devalue play and see it as a trivial waste of time (Fink, 1979), play fulfils an important role in social and spiritual domains, areas that are difficult to measure.

Psychologists and educators have recognised the value of play in the development and education of children, but it is rarely acknowledged as a determinant of healthy aging for adults. Individuals play for fun, for the stimulation of meeting challenges and for the social interaction. It is interesting to note that some of these reasons to play are also reasons behind the participation in sports (Guttmann, 1988). Sometimes, individuals do not try to meet a goal other than having a good time.

Play is a powerful vehicle to increase PA level in the adult population through the use of technology. In the US, 58% of the adult population play video games. In addition to this, the largest segment of gamers (36%) are age 36 or older, the mean age of the most frequent purchaser is 35 years old and 51% of US-households own a dedicated game console (ESA & USA, 2013). Recent advances in technology have led to the development of computer games that required interaction with, and movement from, the player. The market for these games has grown rapidly and has resulted in the development of an Active Video Game (AVG) industry.

The term 'exergame' is widespread in the literature and the media but some feel it might be too focused and give the impression of fitness based activity rather than play based PA. As Oh and Yang (2010) have pointed out, the first part of the word “exergame”, exer, refers to exercise, while playing AVGs is not always done with the intention of improving or maintaining physical fitness in a repetitive manner. For these reasons, the term “active video games” has been used during this thesis dissertation.

2.11. Active video game technology to fight physical inactivity.

There is a considerable body of evidence to suggest that long term video games play can be potentially harmful for health (Anderson & Bushman, 2001; Primack *et al.*, 2012). Amongst others, these games can be associated with more aggressive behaviours, desensitization to violence and decreases in pro-social behaviour. Relatively less attention has been paid to the long periods of time that individuals are inactive while playing games, and the fact that video game play has become one of the most prominent sedentary activities.

The development of AVGs has the potential to counteract the sedentary behaviour components while maintaining, or enhancing, the enjoyment. There is strong evidence that AVGs result in higher HRs, oxygen consumption and EE in adults and children (Ridley & Olds, 2001; Tan *et al.*, 2002; Unnithan *et al.*, 2006; Maddison *et al.*, 2007; Straker & Abbott, 2007; Graves *et al.*, 2008b; Mellecker & McManus, 2008; Sell *et al.*, 2008; Barkley & Penko, 2009; Haddock *et al.*, 2009; Lanningham-Foster *et al.*, 2009; Siegel *et al.*, 2009; Willems & Bond, 2009a; Fawkner *et al.*, 2010; Penko & Barkley, 2010). A growing number of studies have shown that AVGs elicit light-to-vigorous intensity exercise and some have suggested that they could be a contributor to health enhancing PA (Warburton *et al.*, 2009; Willems & Bond, 2009b; Guderian *et al.*, 2010; Lyons *et al.*, 2011; Mullins *et al.*, 2012; O'Donovan *et al.*, 2012; O'Donovan & Hussey, 2012; Lyons *et al.*, 2013; Soltani, 2013). While the evidence to support these claims is equivocal, the studies have been conducted on the first generation of these games. Gaming technology is evolving at a fast pace and the opportunities for increasing PA needs to be developed within the gaming industry.

Peng *et al*. (2011) published a meta-analysis of EE in AVGs. They reported that AVG did not significantly increase HR when compared with conventional traditional moderate intensity physical activities (running, cycling). They also found that AVG play resulted in small, but non-significant, effects on $\dot{V}O_2$ and on EE.

There have been some studies examining the effect of AVGs on diverse psychological and well-being parameters. While there is a scarcity of data in this area, the evidence seems to point to a positive affect state as result of engaging in AVG play (Barkley & Penko, 2009; Graves *et al.*, 2010a; Garn *et al.*, 2012; Lyons *et al.*, 2013). The psychological states and affect responses may be important factors in modelling the adherence rates to physically active lifestyles. There is some preliminary evidence that AVG programmes result in higher adherence rates than traditional PA programmes (Warburton *et al.*, 2007b; Rhodes *et al.*, 2009; Keats *et al.*, 2011).

2.11.1. Types of active video games

Currently, there are four genres of AVG available (Lieberman *et al.*, 2011) The first are screen-based programs such as Dance Dance Revolution, Wii games, Xbox Kinect games, Sony Move games, and GameBike. These are generally played on consoles and are most commonly played in the home environment. Secondly, light-sensor–based games such as Makoto, a 3-column–with-lights system that combines speed and fun with aerobic exercise, or the Cybex Trazer, a machine that offers lots of games as well as being used for rehabilitation. The third type of games is not digitally-based, use light sensors and examples of this type of games are Rock Climbing and Frisbee golf. The fourth genre is the newest of all and includes mobile games such as smart phones, handheld GPS hardware, and other devices that combine the virtual world with the real world via some sort of online game. An example of this is the popular smartphone game Zombies Run. As AVG technology has expanded, so has the number of input devices that have been used with it to detect player’s motion and interaction. These include accelerometers and gyroscopes, vision based devices, ergometers, pressure and touch sensors (pads and mats), and special purpose devices (Stach *et al.*, 2009; Brehmer *et al.*, 2010).

2.12. Video game and active video game usage

In 2012, in the United States alone, consumers spent 20.77 billion dollars on the video games industry (including portable and console hardware, software and accessories) (ESA & USA, 2013). While there is a decline in general video game industry sales in 2011 and 2012, a recently published report by the President's Council on Fitness, Sports & Nutrition and the Entertainment Software Association (ESA, 2012) reveals that the AVG market grew sharply from 2002 to 2011, and will likely continue to expand through to 2015. The report titled "Active games market analysis" found that 20% of all games released in 2011 were AVGs, up from 5% between 2002 and 2007. AVG sales resulted in estimated revenues of US$750 million in 2012. The report also predicts that AVG sales will be a continued revenue driver for the video game industry at least until 2015.

In the USA, 58% of the population play video games, and the majority of these (68%) are adults with an average age of 30 years and a relatively equal gender distribution (55% male, 45% female)(ISFE, 2012; ESA & USA, 2013). In Europe, 25% of the population of 16 European countries play video games at least once a week (ISFE, 2012). AVGs have become mainstream recreational activities, and their popularity is predicted to continue (ESA & USA, 2013).

There seems to be a degree of official support in the US for the use of AVG technology to increase PA in the population, despite a lack of conclusive data. On April 30th 2012, the US Department of Health and Human Services Secretary, Kathleen Sebelius, and the President's Council on Fitness, Sports & Nutrition (PCFSN) launched the Active Play PALA+ Challenge (Presidential Active Lifestyle Award), to highlight AVGs as one way to help Americans lead more active lives. The state of West Virginia committed to install the AVG "Dance Dance Revolution" in all 765 of its public schools by 2008. While this official support is present, there is still inconclusive evidence regarding the health effects of AVG play.

2.13. Physiological responses to active video games and physical activity

There has been an increased interest in the effects of active video game technology on health and wellness, as the growing number of publication shows. Overall, more research efforts have focused on the use of AVGs in children (Ridley & Olds, 2001; Goran & Reynolds, 2005; Lanningham-Foster *et al.*, 2006; Unnithan *et al.*, 2006; Epstein *et al.*, 2007; Maddison *et al.*, 2007) than in adults (Graves *et al.*, 2010a; Lyons *et al.*, 2011; Monedero *et al.*, 2014). This literature review has gathered the available scientific literature on physiological responses to AVGs in adults and includes two different types of studies. The first type measures specific physiological responses (e.g. EE, HR, oxygen consumption) during AVG play, to determine if the exercise intensity was high enough to meet PA guidelines for the general population. The second type includes intervention studies that have used active video gaming to increase PA or to improve some physiological parameter.

2.13.1. Indexes of exercise intensity

There are different methods to measure and report exercise intensity. The main methods are percentage of HRmax (% HRmax), HR reserve (HRR), percentage of maximal oxygen uptake (% $\dot{V}O_2$max), oxygen uptake reserve ($\dot{V}O_2R$), rate of perceived exertion (RPE) and metabolic equivalent (MET). Other methods include the affective scale and the OMNI scale. The indexes of a physiological nature ($\dot{V}O_2R$ and HRR) and RPE are the main methods used during this thesis to report exercise intensity. The reason for this choice is that $\dot{V}O_2R$ and HRR reflect the rate of EE during PA more accurately than any of the other prescription methods (Swain & Leutholtz, 1997), and RPE is a validated index of perceptual responses during exercise (Borg, 1982; Noble *et al.*, 1983). In some cases, the studies reviewed did not report HRmax values, $\dot{V}O_2$max values, resting

HR and O_2 values, or relative values for HR and $\dot{V}O_2$. When $\dot{V}O_2R$ or HRR were not reported by the authors, relative HR values were estimated using the formula by Gellish *et al*. (2007) and resting HR. This was done to obtain objective indexes of exercise intensity as well as being able to compare results to those of other studies.

$$\text{HRmax} = 206.9 - (0.67 \times \text{age}) \quad \text{Gellish et al (2007) formula}$$

The classification of PA intensity adopted by the American College of Sports Medicine (table 2.2) has been used to determine exercise intensity reached during the different protocols.

Table 2.2 Classification of physical activity intensity.

INTENSITY	**$\dot{V}O_2R$ (%)/HRR (%)**	**HRmax**
Very light	<20	<50
Light	20-39	50-63
Moderate	40-59	64-76
Vigorous	60-84	77-93
Very hard	≥85	≥94
Maximum	100	100

Classification of PA intensity (reproduced from ACSM's Guidelines for exercise testing and prescription, 2014).

2.14. Acute studies on active video games

The following sections of this review of literature present the most relevant research studies that have assessed physiological and psychological responses to AVGs. There is considerable variation in the design and execution of individual AVGs making direct comparison between the games difficult. In addition to this, there are also significant methodological differences amongst the research studies that make reaching definitive conclusions difficult or challenging. For clarity, the physiological responses to each game will be presented separately.

2.14.1. Dance Dance Revolution studies

The first published research papers examining exercise intensity during AVG play tested the Dance Dance Revolution (DDR), a dance pad game released in October 1998 by Konami Corporation. Six studies provided valuable scientific evidence on the exercise intensity reached while playing this AVG. Tan *et al.* (2002) assessed cardio-metabolic parameters in 40 young adults while playing 10 min of a self-selected level of difficulty. One shortcoming of this study is that the authors did not evaluate the effect of participants' experience on exercise intensity during play. The game resulted in 70% HRmax and 53% of HRR, 44% $\dot{V}O_2R$, and 7.0 MET$_{S.}$ In this study, DDR resulted in exercise intensities that only just met the minimum ACSM guidelines, since DDR qualified as moderate exercise intensity based on HR and $\dot{V}O_2$ results. Dance-players would need to play for extended periods to improve or maintain cardiorespiratory fitness or to lose weight.

The study by Sell *et al.* (2008) is an important addition to the scientific literature. These authors investigated the effects of player experience on EE while playing DDR. Twelve experienced male players and 7 inexperienced male players played 30 min of DDR. While Sell *et al*. (2008) did not report % HRmax or % HRR values, these parameters have been estimated using the prediction equation 206.9-(0.67-age) (Gellish *et al.*, 2007) to be able to make comparisons with other studies and interprete results. In Sell *et al*. (2008) study, experienced players had values of 83% of HRmax, 47.7% $\dot{V}O_2R$ and 315.5 kcal$^{\cdot}$30min^{-1}. The $\dot{V}O_2R$ values of experienced players (47.7%) in Sell's study (2008) were slightly higher than those reported in Tan *et al.* (2002) study (44%$^{)}$ for all subjects Also, HR values for experienced players in Sell study (2008) (83% of HRmax) was significantly higher than for all participants in Tan's study (2002)(70% of HRmax). The reason for this may be that Tan *et al.* (2002) reported values for all participants (experienced and inexperienced) while Sell et al (2008) reported values for experienced and novice players separately. Inexperienced players had values of 51% HRmax, 18% $\dot{V}O_2R$ and 144 kcal$^{\cdot}$30min^{-1}. This means that experienced players were working at moderate exercise intensity, compared to inexperienced players that were working at very light exercise intensity. The experienced players' higher exercise intensity might be explained by the capacity to play at higher difficulty levels, and higher on-task and continuous play compared to inexperienced player.

The $\dot{V}O_2$ values during DDR reported in *Tan et al.* (2002) and Sell *et al.* (2008) are in contrast with those of Leininger *et al.* (2010). In this study, enjoyment and rate of perceived exertion ratings were compared between two 30 min isocaloric bouts of DDR and treadmill exercise. Eighteen participants with no experience or very limited experience in DDR took part in the study. Mean $\dot{V}O_2$ values for DDR were 11.88 $mL\cdot kg^{-1}\cdot min^{-1}$, compared to 12.14 $mL\cdot kg^{-1}\cdot min^{-1}$ for treadmill walking. These $\dot{V}O_2$ results are markedly lower than those reported in the two previous studies. Mean enjoyment rating values were significantly higher for DDR (6.83) than for treadmill walking (3.08). There were no significant differences in RPE values. The analysis of enjoyment and perception of effort data from the study by Leininger *et al.* (2010) study offers some support for the use of AVG play as a means of increasing PA. Participants perceived both treadmill and DDR play equally hard, but they enjoyed DDR significantly more than the treadmill exercise.

The available scientific literature includes studies in which AVGs were utilised to produce a stimulus similar to that of high intensity training. Noah *et al.* (2011) aimed to do this by examining whether DDR play resulted in vigorous exercise intensity in 12 participants. Participants had 20 hr experience playing a similar game to DDR prior to taking part in the study. Authors tried to replicate the stimulus of an interval training session with the protocol used in this study. The goal was to provide a vigorous workout that allowed for a 90 s recovery time between the bouts of intense activity. Participants played 2 slow songs, 2 medium and 2 fast songs with progressively shorter breaks (45s, 30 s and 15 s). The mean values attained were 8 METs, 157 $beats\cdot min^{-1}$, 28.5 $mL\cdot kg^{-1}\cdot min^{-1}$ $\dot{V}O_2$ and 9 $kcal\cdot min^{-1}$ rate of EE. These results show clearly that experienced DDR players can reach vigorous exercise intensities by playing DDR. However, DDR play requires an advanced degree of motor skill and motor control, and it is unlikely that inexperience players would reach this high intensity exercise as data from other studies show (Sell *et al.*, 2008)

Lyons *et al.* (2011) compared METs during DDR and three other video games in one of the best statistically powered AVG studies found in the scientific literature. One hundred young adults (30 overweight males; 20 normal weight males; 25 overweight females and 25 normal weight females), played a shooter game (with traditional controllers), band simulation (guitar or drum controller), DDR, and Wii fit for 10 min each. They found that both DDR and the fitness games yielded significantly higher EE than the more sedentary games, but they were not as enjoyable as the band simulation games. The authors also reported EE values 298% above baseline for dance simulation and 322% for the Wii fit, compared to 23% for the shooter and 73% for band simulation. The fitness AVG was the only video game that qualified as moderate intensity (3.10 METs). DDR resulted in values of 2.91 METs, which means that this activity was only of light exercise intensity. Another important finding of this study is that while overweight participants enjoyed all games more than normal weight participants, the EE of overweight participants was lower than that of normal weight when corrected for body mass. Lyons *et al*. (2011) could not explain the reasons for this finding, and argued that lesser enjoyment in overweight participants was not the likely cause, since these participants enjoyed all games more than the normal weight participants. It is likely that the differences in EE might have been non-significant if the EE had been corrected for fat-free mass (FFM) rather than for body mass. The fat-free mass tissue (skeletal muscle and organs) use up considerably more oxygen than fat tissue (Elia, 1991). Skeletal tissue, in particular, can have more than a 100-fold increase in energy turnover during exercise (Sahlin *et al.*, 1998). The authors argued that while AVGs may be more enjoyable than traditional PA for some populations, they might not be reinforcing enough to replace sedentary gaming in young adults. They also highlighted the potential health benefit of games with lower activity levels (such as the band simulation) to replace sedentary time with periods of light intensity activity. Evidence is starting to appear that replacing sedentary time with bouts of light activity results in health benefits (Healy *et al.*, 2008a; Duvivier *et al.*, 2013). Lyons *et al*. (2011) also argued that if these enjoyable but not physiologically demanding games were designed so that players exercise a bit harder (around ≥ 0.22 METs increase), the public health impact may be more beneficial. Finally and more recently, Lyons *et al.* (2013) investigated how different psychological predictors such as perceptions of competence, control, and engagement, may be associated with the enjoyment of playing a game, which has in turn been hypothesized to predict energy expended during play. Lyons *et al.* (2013) found that enjoyment mediated the relationship between engagement and EE, but this was not the case for the other psychological predictors tested in this study. They concluded that enjoyable and engaging games may produce a higher intensity of exercise and game developers should take this into consideration when designing new games.

In conclusion, playing Dance Dance Revolution results in exercise intensities that range from very light-to-vigorous intensity exercise. The reason for this wide variation might be that DDR play is an AVG that requires a high level of motor skills. Experienced players can reach higher intensities of exercise because they have the ability to meet the challenge of high difficulty levels in the game, compared to novice players that are still challenged from a motor learning perspective, but not so much physiologically. DDR appear to results in higher enjoyment ratings than more conventional forms of exercise, e.g. treadmill walking. DDR play has the potential to meet the PA recommendation for health adults to improve and maintain health.

2.14.2. Nintendo Wii studies

Nintendo Wii Sports, Wii Fit and Wii Fit plus games are the most widely used video games in AVG research protocols. Nintendo Wii was the first motion controlled AVG released by one of the three leading corporations in this industry (Nintendo, Microsoft Xbox, and Sony PlayStation).

Most research studies assessing Wii Sports, Wii Fit and Wii Fit$^+$ games have focused on physiological outcome measures and only a small number have included psychological outcome measures. Comparing results obtained in the different studies is sometimes complicated by the fact that researchers have used protocols of varying duration, participants with different fitness levels, and different ways to report the measured parameters, e.g. some studies report absolute HR and $\dot{V}O_2$ values, while others have reported relative values (HRR, $\dot{V}O_2R$, % HRmax, % $\dot{V}O_2max$). Heart rate, $\dot{V}O_2$ and EE are the most widely available outcome measures. While HRR and $\dot{V}O_2R$ are superior indexes to prescribe exercise intensity and to classify activities based on intensity of exercise, very few studies have used them to report intensity of exercise during AVG play.

2.14.2.1. Nintendo Wii Sports

The methodology used in most Wii Sports studies includes participants playing and/or exercising for between 8 and 30 min, with 10 min being the most common duration. Table 2.3 summarises the main measures and results from the Wii Sport, Wii Fit and Wii Fit+ studies included in this literature review. A number of studies have reported that playing Wii Sports results in moderate intensity exercise in adults (Bausch *et al.*, 2008; Jordan *et al.*, 2010; Leatherdale *et al.*, 2010; Miyachi *et al.*, 2010; Bosch *et al.*, 2012; Naugle & Wikstrom, 2013). The first published study, though a simple study in design, provided useful data on the physiological response to Wii sports in adults. Participants played Wii boxing and Wii tennis during 10 min with 3 min rest in between (Bausch *et al.*, 2008). The % $\dot{V}O_2R$ was 41.7 and 23.9 % for Wii boxing and Wii tennis respectively. The % HRR was 48.1 and 28.1 % for Wii boxing and Wii tennis respectively, and METs values were 5.2 and 3.2 for Wii Boxing and Wii Tennis respectively. Based on these results, both Wii boxing and Wii tennis play led to moderate intensity exercise.

Jordan *et al.* (2010) reported similar values for Wii sports boxing. Six different modalities (see table 2.3) were tested to assess if they were capable of generating exercise intensities high enough to develop and maintain cardiorespiratory fitness according to ACSM guidelines (1998). These authors assessed one condition consisting of playing a computer game controlled by lower limb activity (PS2limb) using a modified console. Wii boxing resulted in 65.5% HRmax, 41%$\dot{V}O_2$ peak and EE of between 19.6 and 23.0 $kJ\cdot h^{-1}\cdot kg^{-1}$. They also reported that playing the PS2limb equated to cycling at 120 W and the physiological cost of these two activities was significantly greater than for walking, Wii boxing or PS2hand. The cardiovascular intensity reported in this study for Wii Sports (65.5% HRmax) is that of moderate intensity exercise, and therefore would meet the guidelines for PA for health.

The study by Miyachi *et al.* (2010) was an important contribution to the research literature since it was the first study in which EE during active video game play was measured by open-circuit indirect metabolic chamber. These authors reported METs values of 4.2 for Wii sports boxing, which correspond to moderate exercise intensity. The same authors also reported values of 2.0, 2.7, 3, and 3.0 METs for Wii sports golf, bowling, baseball and tennis respectively. Miyachi *et al.* (2010) highlighted that these values were markedly lower than values obtained playing the real sports. The MET values for Wii Sports tennis reported by Miyachi *et al.* (2010) contrasts with those reported by Leatherdale *et al.* (2010) of 5.4 METs. The main difference between the two studies was the equipment used to estimate EE. Miyachi *et al.* (2010) used an open-circuit indirect metabolic chamber, a criterion measure to assess EE that is reported to be accurate to within 2% of EE measurements of doubly-labelled water (Montoye, 1996), and Leatherdale *et al.* (2010) used a SenseWear armband. While there are mixed reports about the accuracy of the SenseWear armband (Fruin & Rankin, 2004; King *et al.*, 2004), it seems more suited for measurements of EE during long periods of activity, and inaccurate in acute periods of activity (Fruin & Rankin, 2004; Zanetti *et al.*, 2013).

The following table summarises the main measures and results from the Wii Sport, Wii Fit and Wii Fit+ studies included in this literature review.

Table 2.3. Methodology and results of Nintendo Wii Sports, Wii Fit and Wii Fit+ studies.

First author	Year	Study design	Population (n)	Age group	Intervention	Measure	Results
Barkley, JE	2009	Cross sectional	12, M=6, F=6	31.5 y	4 x 10 min conditions, 5 between Rest, treadmill walking at 2.5m/h, sed VG and Wii sports	HR, $\dot{V}O_2$, RPE, liking (visual analogue scale)	Wii sports resulted in moderate PA (MPA) and the highest RPE and liking ratings.
Bausch, L	2008	Cross sectional	12, M=4, F=8	22.1y	2 x 10 min Wii boxing and tennis, 3 min rest in between	$\dot{V}O_2R$, %HRR, METs, total EE	Wii boxing resulted in MPA, Wii tennis in light PA (LPA)
Bosch, PR	2012	Cross sectional	20, M=11, F=9	25.4y	30 min Wii boxing	HR, %HRmax	Vigorous PA (VPA)
Douris, PC	2012	Cross sectional	21 , M=9, F=12	23.2 y	30 min brisk walk 30 min Wii free run	HR, Rate pressure product, $\dot{V}_E$	Wii free run resulted in MPA.
Garn AC	2012	Cross sectional	30, M=7, F=23	20.5y	5 x 10 min Wii fit AVG (basic step, basic run, table tilt, balance bubble, ski slalom)	Accelerometry, enjoyment, future intentions to be physically active	Wii fit basic run resulted in highest step count. AVG yielded the highest intention to exercise
Graves LEF	2010	Cross sectional	14, M=10, F=4 15, M=7, F=8 13, M=10, F=3	15.8y 28.2y 57.6y	10 min, Sed video game, Wii Fit, brisk walking, treadmill running	$\dot{V}O_2$, EE, HR, MET's.	Wii aerobics resulted in LPA and the highest enjoyment ratings.
Guderian, B	2010	Cross sectional	20, M=10, F=10	58.1y	3min each activity, Wii Fit (jogging, soccer, hula, ski, step, penguin)	HR, HRR%, METs, EE	Wii Fit jog resulted in VPA, Wii soccer and hula in MVA. Wii Ski, step and penguin in LPA.

First author	Year	Study design	Population (n)	Age group	Intervention	Measure	Results
Jordan *et al.*	2011	Cross sectional	15 M	29 y	6 x 12 min of:1) PS2 hand, 2) Wii boxing, 3) walk at 5.6 km/h, 4)cycle at 120W, 5)PS2 lower limb controlled 6) run at 9.6km/h	EE, HR,, %HRmax, % $\dot{V}O_2$peak	Wii Sports and modified PS2 resulted in MPA
Lanningham-Foster *et al.*	2009	Cross sectional	20, M=10, F=10 BMI = 27.7 22, M=11, F=11 BMI=20.2	33.5 y, 12.1y	One visit: Rate EE+ EE while sitting & standing, + 13 min sed video game + 13 min Wii boxing	EE, PA (inclinometers, triaxial accelerometer)	Sed video game resulted in 23% EE above rest. AVG resulted in 214% EE above rest.
Leatherdale *et al.*	2010	Cross sectional	51, M=30, F=21 M BMI=24.3, F BMI=22.5	18.9y	2 x 30 min trial, 5 min rest: sed video game: Mario Power Tennis for Nintendo Cube, AVG: Wii Sports tennis	EE, and SenseWear armband	Significant differences between SenseWear and HRM. Wii tennis resulted in > EE than Mario Power Tennis
Lyons *et al.*	2011 2012	Cross sectional	100,M=50,F=50 MOW=30, MNW=20, FOW=25, FNW-25	23.76y, 25y 22.8 y 25y 22y	2 Wii fit AVGs: aerobic and balance games, 10 min each game	EE, enjoyment	Aerobic games yield 2.70 $kcal^{.}kg^{-1.}h^{-1}$ > than balance games. Enjoyment predicted EE in aerobic games.
Miyachi *et al.*	2010	Cross sectional	12, M=7, F=5	34y	3 visits: Sitting, Wii Fit Plus and Wii Sports, 8 min each activity	METs	All average Wii Sports = 3.0 MET Wii boxing = 4.2 Wii tennis = 3.0
Mullins *et al.*	2012	Cross sectional	10, M=5, F=5 10, M=5, F=5,	21.4y 58 y	4 x 15 min Wii Fit (yoga, balance, aerobics, strength)	HR, %HRR, $\dot{V}O_2$, EE, RPE, enjoyment, step count data	Wii fit yoga, balance and strength = LPA. Wii aerobics = MPA.

First author	Year	Study design	Population (n)	Age group	Intervention	Measure	Results
Naugle & Wikstrom	2013	Cross sectional	22, M=7, F=15 11 high int exer (HIE), M=3, F=8 11 low int exercisers (LIE), M=4, F=7	HIE: 20.2 LIE: 20.7	Treadmill walk, cycle, Wii tennis, Wii boxing, Wii Fit's Island Cycling, Aerobic step. 20 min each	HRR, RPE, PANAS, enjoyment (visual analogue scale)	LIE reached > ex int than HIE during AVGs. PANAS increased after Wii tennis and boxing and decreased after waking/running.
O'Donovan & Hussey	2012	Cross sectional	28, M=18, F=10 Wii sports, n=12 Wii fit, n=16	Wii Sports: 23y, Wii fit: 22y	15min Wii boxing, Wii tennis, Wii Baseball and Wii Fit Jogging with 5 min recovery	HR, $\dot{V}O_2$, EE	Wii Fit free jogging = MPA Wii boxing = LPA Wii tennis = VLPA
O'Donovan *et al*.	2012	Cross sectional	14, M=13, F=1	20.8 y	10 min of Kinect Adv. Reflex ridge and Wii Sports boxing in single and multiplayer modes	EE, METs, HR, $\dot{V}O_2$	LPA. Kinect Adv resulted in > EE than Wii Sports. Multiplayer mode led to higher EE than single mode.
Sanders *et al*.	2012	Cross sectional	24, M=13, F=11	21.8y	10min Wii boxing, Wii Madden, PS2 Madden	$\dot{V}O_2$, HR, RPE, Liking, Relative reinforcing value (motivation)	Wii boxing resulted in LPA, >r RPE and higher enjoyment. .
Stroud *et al*.	2010	Cross sectional	19, M=12, F=7	M=30.2y, F=29.1y	3 x 10 min (sed video game, Wii baseball, Mario and Sonic @ Olympic games)	$\dot{V}O_2$, $\dot{V}O_2$R, HR, %HRR, $\dot{V}_E$	Wii baseball resulted in VLPA. Mario and Sonic resulted in LPA.
Willems & Bond	2009	Cross sectional	10, M=7, F=3,	21 y	10 min, self-selected walk, Wii tennis, baseball, boxing	$\dot{V}O_2$, HR, EE, RER, CHOg, FATg	Self-selected and Wii boxing = MPA. Wii tennis = LPA
Worley *et al*.	2011	Cross sectional	8 F	21.8	2 games (beg &interm) Wii fit aerobic step and Wii fit Hula games	%$\dot{V}O_2$max,EE(kcal$\cdot$min^{-1}), RER	LPA

Naugle *et al.* (2013) reported light and moderate exercise intensity during Wii Sports boxing for two different groups of subjects. They compared the physiological, emotional and enjoyment responses in participants who regularly exercise at a high intensity (HI), and participants who regularly exercise at a low intensity (LI). Participants completed six 20 min conditions that included treadmill walking, stationary cycling, and Wii Tennis, Boxing, Cycling, and Step. Participants were asked to exercise on the treadmill and the cycle ergometer at an intensity of 11-13 in the 15-point Borg scale. Participants in the HI group reached moderate-to-vigorous exercise intensity during the treadmill and bike test, while participants in the LI group reached moderate intensity exercise in these two conditions. Interestingly, the former group reached only light intensity exercise (% HRR values 21-39%) while the latter group reached a more desirable moderate intensity exercise (% HRR 35-54%) during Wii boxing. Wii Sports tennis and Wii cycling resulted in light exercise intensities in both the HI and LI groups. Enjoyment ratings were significantly higher for Wii tennis and Wii boxing than treadmill and cycling. Finally, the positive affect score decreased after treadmill and cycling conditions, while it increased after playing Wii tennis and Wii boxing. Therefore, Wii Sports boxing was the most successful game in this study, since it led to light-to-moderate exercise intensities and led to the highest enjoyment and most positive emotional response.

A number of studies have reported light intensity exercise for adults playing Wii sports games (Willems & Bond, 2009b, a; Stroud *et al.*, 2010; O'Donovan *et al.*, 2012; O'Donovan & Hussey, 2012; Sanders *et al.*, 2012). O’Donovan and Hussey (2012) reported different findings to those of Sell *et al.* (2008) regarding the effect of gaming experience. Participants played Wii boxing, Wii tennis, Wii Baseball and Wii Fit Jogging for 15 min each with 5 min seated rest in between. There were five experienced participants in each group. Participants reached HR values of 58% HRmax for Wii Sports Boxing, 42 % HRmax for Wii Sports tennis, 42% HRmax for Wii Sports Baseball, and 71% HRmax for Wii Fit Free Jogging. Based on these figures, all participants were exercising at light exercise intensity while playing all Wii sports games tested in this study (boxing, tennis, baseball). The authors did not find a relationship between gaming experience and the energy cost of playing. O'Donovan *et al.* (2012) compared Wii Sports boxing to one of the most popular Kinect games, Reflex Ridge, and also examined the cardiometabolic differences as a result of playing single and multiplayer modes. Playing the Xbox Kinect game resulted in significantly higher EE than playing the Wii, but there were no differences in HR between consoles. Playing games in multiplayer mode led to significantly higher EE and HR values than playing the games in single player mode. According to the classification of exercise intensity based on METs that takes into account the participant's age (Garber *et al.*, 2011), participants were working at light intensity exercise (METs from 3.14 for single player Wii sports boxing to 4.51 for multiplayer Xbox Kinect Reflex Ridge.

Two studies (Willems & Bond, 2009a, b) also reported that Wii Sports play (tennis, baseball and boxing) resulted in light exercise intensity, similar to self-selected treadmill walking. The results revealed that Wii sports boxing yielded similar % HRmax values (56%) and $\dot{V}O_2$ values (16.3 $mL \cdot kg^{-1} \cdot min^{-1}$) to treadmill walking (56% HRmax and 19.9 $mL \cdot kg^{-1} \cdot min^{-1}$). Based on MET values, both Wii sports boxing and Wii sports tennis qualified as moderate intensity exercise and Wii sports baseball as light intensity exercise. Stroud *et al.* (2010) compared a sedentary control video game (Super Mario Brothers), with a "low activity" video game (Wii sports bowling) and "high activity" video game (Mario Sonic at the Olympic Games) with 5 min rest between conditions. Neither the "low activity" nor the "high activity" video game resulted in exercise intensities high enough to qualify as moderate exercise intensity.

Finally, Lanningham-Foster *et al.* (2009) compared Wii sports games with sedentary games in children and adults, but it was not possible to establish the relative exercise intensity of the AVGs. Lanningham-Foster *et al.* (2009) reported significant increases in EE over resting EE for standing playing the sedentary video game, and playing Nintendo Wii ($P < 0.001$). EE was significantly higher during Wii boxing than during all other activities. The children had higher rates of EE compared to adults, but there were no differences within each group relative to age, sex, or BMI status. Movement at the back, trunk and thighs was significantly higher during Wii Sports than during the other conditions. Lanninghan-Foster *et al.* (2009) argued that AVGs have the potential to increase non-exercise activity thermogenesis (NEAT) by converting sedentary video gaming to activity-promoting video gaming.

In conclusion, playing Nintendo Wii Sports results in exercise intensities that range from light-to-moderate intensity exercise. Wii Sports boxing yields the highest intensity of exercise of all Wii Sports games as measured by EE, HR and $\dot{V}O_2$. The reason for this is that Wii boxing encourages the use of both the dominant and non-dominant arm, while Wii tennis and Wii bowling play requires the use of just the dominant arm. In addition to this, total body movement during Wii boxing has been shown to be more than double than during Wii tennis and Wii bowling (Graves *et al.*, 2008b). Wii Sports results in higher enjoyment ratings than more conventional forms of exercise such as running or cycling.

2.14.2.2. Nintendo Wii Fit and Wii Fit$^+$

The methodology used in most Wii Fit and Wii Fit$^+$ studies include participants playing and/or exercising for between 6 and 30 min, with 10 min being the most common duration. Most studies have assessed differences between aerobic games and balance games in the Wii Fit suite, and some have measured exercise intensity during strength games and other activities like yoga, and step.

A number of studies have reported moderate exercise intensities while playing Wii Fit games (Guderian *et al.*, 2010; Miyachi *et al.*, 2010; Lyons *et al.*, 2011; Lyons *et al.*, 2012; O'Donovan & Hussey, 2012). One of the first published studies was that of Guderian *et al.* (2010) in which cardiovascular and metabolic responses were measured for Wii fit walk/jog for 6 min, beginner soccer game, beginner hula hoop, beginner ski game, beginner step and beginner penguin game. Values obtained ranged from 33.4% HRR and 2.2 METs for Wii Fit Penguin to 64.4% HRR and 5.7 METs for Wii walk/jog. Overall, average HR was 108.1 beats·min^{-1} or 43.4 % HRR. Average values for METs and EE for the 20 min session were 3.5 and 116.2 kcal respectively. The Wii fit session qualified as moderate exercise intensity, but some participants were working at light exercise intensity. These results are in partial agreement with those of Miyachi *et al.* (2010). These authors reported MET values of 2.1, 2, 3.2 and 3.4 for yoga, balance exercises, resistance exercises and aerobic exercises, respectively. This means that according to the MET intensity criterion, resistance and aerobic exercises were the only activities that resulted in moderate exercise intensity. Lyons *et al*. (2012) also reported similar findings in a study that assessed EE and enjoyment during an exercise-themed and a game-themed active video game. The aerobic games were hula hoop (10 min version) and jogging (free run) and the balance games were skiing (initial difficulty level) and penguin slide. Participants had a significantly higher EE during aerobic games (4.45 METs) than during balance games (1.75 METs). The balance games were rated as more enjoyable than the aerobic games. Lyons *et al.* (2012) reported that enjoyment predicted the EE in the aerobic games, but not in the balance games. The authors concluded that future fitness AVGs might include more game-like elements and reduce the exercise elements to make them more appealing and enjoyable. The use of Wii Fit aerobic activities (Wii Fit jogging) to reach moderate intensity exercise received further support by results obtained by O'Donovan and Hussey (2012). Participants reached 71% HRmax while playing Wii Fit Free Jogging.

A number of studies have concluded that Wii Fit games and activities result in only light intensity exercise (Graves *et al.*, 2010a; Worley *et al.*, 2011; Mullins *et al.*, 2012). Graves *et al.* (2010a) assessed the effect of age on cardiorespiratory and enjoyment ratings during AVG play, sedentary video game play and conventional exercise. Adolescents, young adults and older adults played sedentary video games, Wii Fit activities (yoga, muscle conditioning, balance, aerobics), and did brisk treadmill walking and jogging. Treadmill walking and jogging resulted in the highest $\dot{V}O_2$, HR and EE values, followed by Wii Fit and sedentary video gaming. All activities tested were of light intensity, except Wii aerobics and brisk treadmill walking that were moderate intensity exercise and treadmill jogging that was of vigorous intensity exercise. Wii aerobics was the only AVG activity that qualified as moderate intensity exercise based on MET values (3.2, 3.6 and 3.2 for adolescents, young adults and older adults respectively). However, playing Wii aerobics did not result in HRs high enough to meet the PA guidelines (estimates 51%, 51% and 57 %HRmax for adolescents, young adults and older adults respectively). Worley *et al*. (2011) reported similar exercise intensities for adults playing Wii fit aerobic step and Wii fit Hula games at two different levels. The AVGs were light PA with $\dot{V}O_2$ values ranging from 31% $\dot{V}O_2$max for the beginners step level to 39% $\dot{V}O_2$max for intermediate hula.

Mullins *et al.* (2012) provided more evidence to support that adult Wii Fit play results in light intensity of exercise. These authors reported light intensity exercise for young and older adults playing four Wii Fit activities (yoga, balance, aerobics, strength). Aerobic and strength activities resulted in significantly higher % HRR values (29%, 28%, 40% and 40% HRR for yoga, balance, aerobics and strength respectively) and $\dot{V}O_2$ values (4.79 $mL^{\cdot}kg^{-1\cdot}min^{-1}$, 4.64 $mL^{\cdot}kg^{-1\cdot}min^{-1}$, 8.44 $mL^{\cdot}kg^{-1\cdot}min^{-1}$and 7.21 $mL^{\cdot}kg^{-1\cdot}min^{-1}$ for yoga, balance, aerobics and strength respectively) than yoga and balance activities. While METs were higher during aerobic activities, all activities reached only light intensity exercise (1.37 METs, 1.33 METs, 2.41 METs and 2.06 METs for yoga, balance, aerobics and strength respectively). Participants rated the balance and aerobic activities as the most enjoyable.

Two studies have examined the physiological and psychological responses to Wii fit video games. Garn *et al.* (2012) measured PA using GT1M accelerometers, enjoyment and future intentions to be physically active while playing five common Wii Fit activities from the aerobics (Basic Run, Basic Step) and balance (Ski Slalom, Balance Bubble, Table Tilt) games. The Wii fit aerobics activities resulted in the most efficient conditions in accumulating PA as the counts per min shows, 7347.40 and 729.36 for Wii Fit Run and Wii Fit Step respectively. Analysis of enjoyment ratings revealed that only obese participants reported higher levels of enjoyment during the AVGs than in generic physical activities. Future intentions to play AVGs were significantly higher than future intentions to participate in generic PA for all weight categories.

Finally, Douris *et al.* (2012) assessed the physiological and psychological responses to 30 min of brisk walking exercise on a treadmill and 30 min playing Nintendo Wii Fit ʻʻFree Runʼʼ program. The brisk walk consisted of walking on a treadmill at 3.5 miles·hr^{-1} for 30 min, while participants self-selected the intensity during Nintendo Wii Fit condition. The Wii Fit condition resulted in higher HR values (142 vs 123 beats·min^{-1}), rate pressure product (19,843.1 vs 16,865.3) and RPE (12.7 vs 10.1) than brisk treadmill walking. The rate pressure product is the HR times the systolic blood pressure and is an indication of the energy demand of the heart (Brooks *et al.*). No significant differences were reported for psychological distress and fatigue between the groups. Interestingly, psychological well-being scores decreased when playing Wii Fit from pre-exercise values to post-exercise values. A reverse trend was found for psychological well-being values in the brisk walk condition, as expected.

2.14.3. Other active video games

A few studies in the literature have examined other AVGs. *Siegel et al.* (2009) assessed if 13 young adults with access to three different AVGs would burn enough EE to meet ACSM PA recommendations for health (Haskell *et al.*, 2007). Participants were allowed to play any of the three games (moving and striking lighted pads, riding a bike to increase the pace of a race car, and boxing against a video simulated opponent) and change games at free will. The authors did not give more details of the games tested in this study. Siegel *et al.* (2009) reported that total EE for the 30 min session was 226 kcal and males had a higher rate of

EE than women (9.10 $kcal{\cdot}min^{-1}$, and 6.20 $kcal{\cdot}min^{-1}$ for males and women respectively, $P < 0.05$). No significant differences were found between the three video games for HR, relative EE and total EE. The most played video game was boxing. Authors concluded that AVG technology is a viable option to reach the 150-400 $kcal{\cdot}day^{-1}$ from exercise that ACSM recommends.

The GameBike is an interactive video cycling game that has also received some attention by health research scientists. Playing this video game involves pedalling a cycle ergometer to cause a vehicle (car or motorbike) to move forward, and steering the handlebars to control the direction the vehicle is moving around the race track. Warburton *et al.* (2009) compared the cardiometabolic response and rate of perceived exertion to three different matched workloads during GameBike cycling and during conventional stationary cycling. Fourteen young and relatively aerobically fit adults performed three 5-min constant workloads of 25%, 50%, and 75% of maximal power output separated by 5 min rest, of GameBike cycling and of stationary cycling on separate days. The results showed that interactive video game cycling resulted in significantly higher HR, $\dot{V}O_2$ and EE at 25% and 50% of peak power output. There were no differences in the ratings of perceived exertion between interactive cycling and conventional stationary cycling.

In another study comparing AVG play with conventional exercise, Perron *et al*. (2012) assessed cardiovascular and affect responses in 30 healthy adults. Participants completed 30 min of brisk walking on a treadmill and approximately 40 min playing ''Island Cardio Blast'' on ''EA Sports Active.'' Participants had a higher average HR, RPE and enjoyment ratings during EA Sports Active than during brisk walking (147.5 vs. 126.4 $beats{\cdot}min^{-1}$), (13.1 RPE vs. 11.6) and 99.7 vs. 84.0 respectively). The authors concluded that EA Sports Active is a valid method of reaching moderate intensity exercise.

Bonetti *et al.* (2010) investigated the cardiovascular and perceptual response to a bout of isometric full body exercise during single vs. opponent-based play. Thirty two male participants completed 2-30 min bouts of the video game Fuzion Frenzy (Blitz Games, Leamington Spa, United Kingdom) both alone and against an opponent. Participants were assigned to an experienced group using Exerstation, a full-body isometric game controller, while the control group used a conventional Xbox hand controller. Significantly higher $\dot{V}O_2$ and EE values were reported for the experienced group than the control group, both for single and competitive mode. No differences were reported for HR and RPE. No significant differences were reported between solo and competitive play within each group.

2.15. Active video games intervention studies

2.15.1. Interactive video game cycling intervention studies

Studies examining the effect of medium and long term AVG play are scarce compared to those assessing acute responses. Most of these studies have chosen interactive video game cycling as the AVG used in comparison with some form of conventional mode of exercise (Annesi & Mazas, 1997; Ekkekakis & Petruzzello, 1999; Warburton *et al.*, 2007b; Rhodes *et al.*, 2009; Keats *et al.*, 2011). The studies by Annesi and Mazas (1997) and Warburton *et al.* (2007a*)* provided scientific evidence of the usefulness of AVG play in improving exercise adherence.. In the study by Annesi and Mazas (1997), thirty nine participants took part in a 14-wk exercise program that involved one of the following conditions: 1) upright exercise bicycle, 2) recumbent exercise bicycle and 3) virtual-reality exercise bicycle (participant sat in a recumbent bike, screen in front gave the participants the opportunity to race, explore, and compete in different settings). The authors reported that adherence was significantly higher in the virtual reality group (83.33%) than in the upright exercise bicycle group (57.14%) and the recumbent exercise bike group (61.54%). No differences were reported between sexes for the different parameters measured in this study.

Warburton *et al.* (2007b) also compared the exercise adherence during a programme of interactive cycling and conventional stationary cycling in addition to health-related fitness parameters. Fourteen participants were asked to exercise for 30 min, 3 times a week, for 6 weeks at 60-75% HRR. Warburton *et al.* (2007b) reported that adherence was 30% higher in the interactive group (78 ± 18) compared to the conventional cycling group (48 ± 29). Maximal oxygen uptake increased significantly in interactive cycling (11%), but not in conventional cycling group (3%). Systolic blood pressure was significantly reduced after the interactive condition (132 vs. 123 mmHg), but that was not the case in conventional cycling (131 vs. 128). Body composition was unaffected by both programmes.

In a similar study, *Keats et al.* (2011) compared adherence rates, enjoyment and fitness outcomes following participation in an interactive cycling programme or a programme of cycling with a DVD playing. The DVD condition involved cycling with the guidance of an instructive DVD containing video footage from on-bike cameras. Participants completed 30 min sessions, twice a week for 6 weeks, of either the interactive or the conventional cycling programme. Analysis of results showed that adherence was significantly higher in the interactive gaming group (93%) compared to the conventional cycling group (73%). Maximal oxygen uptake significantly increased with the AVG intervention (from 38.2 to 44.1 $\text{mL}^{\cdot}\text{kg}^{-1\cdot}\text{min}^{-1}$), but did not improve in the DVD cycling group. Finally, while both groups had similar perceptual ratings, the AVG group was working at a higher intensity (150.8 vs. 139.2 for AVG group and DVD cycling group respectively).

Finally, Rhodes *et al.* (2009) carried out a study to evaluate the effects of interactive cycling on the constructs of the theory of planned behaviour. This study examined adherence to the interactive condition in comparison to a cycling condition where participants listen to self-selected music, and used the extended theory of planned behaviour as the social cognitive framework (Rhodes *et al.*, 2006). Twenty nine inactive young men took part in the study in either an interactive cycling programme (n=16), or a conventional cycling programme with self-selected music (n=13). The details of the training programme were similar to those described for Warburton *et al*. (2007b). Rhodes *et al*. (2009) reported that the interactive cycling condition resulted in more positive affect states than the cycling with music condition. This study provided some evidence that interactive cycling might lead to higher adherence rates because of the positive affect states induced by interactive cycling.

2.15.2. Dance Dance Revolution intervention studies

There are two studies in the literature that assessed DDR's efficacy as a PA programme. Trout & Zamora (2008) examined body composition, EE and enjoyment levels in twenty six young adults (12 M, 14 F). Participants took part in a DDR programme consisting of 20 min sessions, 3 times a week over eight weeks. All participants attended 24 sessions since missed appointments were rescheduled. Trout & Zamora (2008) reported that body mass and percentage body fat significantly decreased after the DDR programme. The authors stated that these results were the likely result of the DDR programme rather than changes in diet, PA or medications since participants were asked not to alter these. Enjoyment ratings were markedly and consistently high over the 8 weeks and the most active subjects prior to the study had significantly lower enjoyment ratings.

Mejia-Downs *et al.* (2011) carried out a study to assess the effects of a 6-week interactive video dance game program on adult participants' cardiorespiratory status and body mass index (BMI). Twenty-seven asymtomatic adults, age 49 ± 6 yr, completed 30 min sessions, 3 times for 6 weeks. Mejia-Downs *et al*. (2011) reported significant changes after the interactive video dance game programme in BMI, resting HR, peak $\dot{V}O_2$ and estimated $\dot{V}O_2$max.

2.15.3. Other video game intervention studies

Two studies have investigated the effectiveness of AVG programmes using games other than interactive cycling and dance game pads. Owens *et al*. (2011) assessed PA changes (5 days of accelerometry) and fitness variables after a 3-

month home-programme of Wii Fit in 8 families. Participants included 21 subjects, 9 adults and 12 children. Each family was given the Nintendo Wii Fit consoles and were free to play whenever they wanted during the 3-month duration of the study. Owens *et al*. reported that of all parameters tested, only $\dot{V}O_2$max increased significantly in children (34.3 vs. 38.4 $mL\cdot kg^{-1}\cdot min^{-1}$ for pre- and post-intervention respectively). Another important finding is that daily home use of Wii Fit decreased by 82% from the start to the end of the intervention (from 21.5 $min\cdot day^{-1}$ to 3.9 $min\cdot day^{-1}$). Owens *et al*.(2011) argued that the low daily usage of the Wii Fit in this study (12 $min\cdot day^{-1}$) and the fact that participants were already meeting the national recommendation for children and adults for aerobic fitness explain that most parameters measured were unchanged.

Finally, Nitz *et al.* (2010) had a different approach to assess AVGs. These authors investigated the feasibility of Wii Fit to improve balance, strength, flexibility and fitness for ten healthy women. Participants completed a 30 min session, twice weekly for 10 weeks. The programme included activities from yoga, balance, aerobic and strength options of the Wii Fit programme. Nitz *et al.* (2010) included measures of fitness, balance, flexibility, lower limb strength and somatosensation. Of all measures, only balance (unilateral stance with eyes open) and lower body strength showed significant improvements. Cardiovascular endurance, mobility, weight change, activity level and well-being changes were not significant.

2.16 Active video games in other populations

There are numerous studies assessing the effect of AVGs on different health components and diverse behavioural indicators in children and youth (Lanningham-Foster *et al.*, 2006; Widman *et al.*, 2006; Epstein *et al.*, 2007; Maddison *et al.*, 2007; Madsen *et al.*, 2007; Straker & Abbott, 2007; Graves *et al.*, 2008a; Graves *et al.*, 2008b; Maloney *et al.*, 2008; Mellecker & McManus, 2008;

Ni Mhurchu *et al.*, 2008; Graf *et al.*, 2009; Lanningham-Foster *et al.*, 2009; Murphy *et al.*, 2009; Adamo *et al.*, 2010; Fawkner *et al.*, 2010; Fogel *et al.*, 2010; Graves *et al.*, 2010a; Graves *et al.*, 2010b; Mellecker *et al.*, 2010; Penko & Barkley, 2010; Bailey & McInnis, 2011; Duncan *et al.*, 2011; Maddison *et al.*, 2011; Owens *et al.*, 2011; White *et al.*, 2011; Baranowski *et al.*, 2012; Maddison *et al.*, 2012; Maloney *et al.*, 2012; Smallwood *et al.*, 2012). Overall, the evidence suggests that AVGs have a greater impact on children than adults when assessing EE (Peng *et al.*, 2011). LeBlanc *et al.* (2013) stated that while AVGs may increase light to moderate intensity PA by reducing some sedentary behaviours, the gathered evidence suggest that AVGs do not make a significant contribution to enable children and youth to meet guidelines of 60 min of moderate-to vigorous-intensity PA on a daily basis. But this paper has been widely criticised among the scientific community because the conclusion are not based on the evidence or the numerous papers and systematic reviews than concluded that AVG play is a viable way to meet the guidelines for children.

Research on AVGs in older adults (above 55 years of age) is also present in the scientific literature. Studies have mainly focused on AVGs and effects on balance and fall reduction (Fitzgerald *et al.*, 2010; Pigford & Andrews, 2010; Agmon *et al.*, 2011; Kosse *et al.*, 2011; Lamoth *et al.*, 2011; Schoene *et al.*, 2011; Szturm *et al.*, 2011; Young *et al.*, 2011; Garcia *et al.*, 2012; Lamoth *et al.*, 2012; Janssen S, 2013; Schoene *et al.*, 2013), cognitive function (Lange *et al.*, 2010; Studenski *et al.*, 2010; Maillot *et al.*, 2011; Anderson-Hanley *et al.*, 2012), on acute response of physiological parameters (EE, HR, VO_2 response) (Graves *et al.*, 2010a; Guderian *et al.*, 2010; Wollersheim *et al.*, 2010; Mullins *et al.*, 2012) and increasing PA levels (Shubert, 2010; Studenski *et al.*, 2010; Brox *et al.*, 2011; Taylor *et al.*, 2012; Keogh *et al.*, 2013). Scientific evidence points to the fact that older adults spend less EE during active video game play than children and younger adults (Graves *et al.*, 2010a; Guderian *et al.*, 2010). Graves *et al.*(2010a) reported that older adults enjoyed the lower activity AVGs used in this study (Wii Fit) more than the younger participants. However, in a different study, older adults rated Wii Fit lower than younger participants (Guderian *et al.*, 2010). Researchers have also suggested that the light-to-moderate intensity of AVGs is more suited for the older adults than for children to meet PA recommendations.

2.17. Summary

Regular PA exerts multiple positive health benefits. However, population PA levels have been decreasing over the last 200 years while chronic disease and mortality have increased. Physical activity is a complex behaviour that is determined by multiple determinants and correlates. Sedentary behaviour is an independent risk factor for chronic disease and is linked to increased mortality. Best available evidence indicates that increasing PA levels and reducing sedentary time are two aims that should be pursued to improve health. There is potential to use technological advances to increase PA levels and to reduce sedentary time by the use of AVGs. Active video games combine PA, technology, present in many areas of modern life, and the natural and spontaneous tendency to play. There is a great variety of AVGs and it is not possible to make a generalisation regarding the physiological and psychological responses to these games. The available research studies have also employed different protocols and methodologies that make even more difficult to reach a definitive conclusion. The best available evidence suggests that AVGs result in light-to-vigorous PA. There is a great variability amongst different subjects, and experience playing this type of games has an effect in terms of exercise intensity reached. There is some evidence that these games result in more positive psychological and affect states than conventional exercise. While valuable knowledge on the effects of AVGs have resulted from research studies over the last number of years, there are still gaps on the knowledge we have of the effects of these games to improve health. Therefore, the purpose of this research is to determine if AVG play results in health enhancing physical activity in an adult population (18-45 years of age), and to examine affect and psychological responses associated with the use of AVGs in an adult population, since these factors are likely to affect medium and long term adherence rates.

CHAPTER III

Study 1: Cardiometabolic responses to Wii Sports and Modified Wii Sports in young adults

3.1. Introduction

Regular PA plays a key role in preventing chronic disease and maintaining health (Warburton *et al.*, 2006; Warburton *et al.*, 2007a; Booth *et al.*, 2008; Bryan & Katzmarzyk, 2011). However, worldwide adult physical inactivity levels remain high at 31% (Hallal *et al.*, 2012) and the percentage of the adult population meeting PA guidelines decreases as the population grows older (Haskell *et al.*, 2007). During the past 20 to 30 years, active leisure time has increased in high income countries (Knuth & Hallal, 2009). However, sedentary time has also increased and this is associated with negative health outcomes (Ng & Popkin, 2012). Objective measures indicate that the average adult spends 50-60% of their day involved in sedentary pursuits (Healy *et al.*, 2011). One of the most prevalent sedentary activities in the adult population, TV watching, is positively associated with the risk of obesity and type 2 diabetes in both men and women (Hu *et al.*, 2001; Hu *et al.*, 2003).

The ACSM and the AHA recommends that healthy adults should engage at least in 30 min five $d^{\cdot}wk^{-1}$ of moderate-intensity aerobic activity, at least 20 min three $d^{\cdot}wk^{-1}$ of vigorous-intensity aerobic PA, or a combination of moderate and vigorous intensity aerobic activity (ACSM, 2014). These guidelines are set out as the minimum volume and intensity of aerobic PA necessary to gain health benefits for adults. Guidelines for sedentary behaviour have been recently published (Australia, 2014; Canada, 2014) and is expected that more health organisations and agencies will publish their own guidelines.

In this context, innovative and enjoyable forms of daily PA and ways to reduce sedentary time for adults should be explored. The fact that the average video-game player in Canada and the US in 2013 was aged 31 and 30 years respectively (ESA & Canada, 2013; ESA & USA, 2013) and that home exercise was placed third amongst the top five physical recreation activities of Canadian adults in 1998/1999 (Warburton *et al.*, 2007a) make active video games a viable option for increasing recreational PA and reducing sedentary time.

Active video games have become popular in recent years but it is not clear if they provide a sufficient stimulus for health enhancing benefits. Research studies focused on the benefits of these games in children initially (Daley, 2009; Barnett *et al.*, 2011) and more recently on adults (Warburton *et al.*, 2009; Graves *et al.*, 2010a; Guderian *et al.*, 2010; Miyachi *et al.*, 2010; Lyons *et al.*, 2011). The limited data available suggest that AVGs increase oxygen consumption and EE but may not be sufficient to meet the ACSM/AHA PA recommendations (Guderian *et al.*, 2010; Leatherdale *et al.*, 2010). Therefore, the purpose of this study was to determine the exercise intensity during a bout of Wii Sports play and to assess if a modification to the movement pattern of an existing AVG would be sufficient to significantly increase EE and increase the possibilities of meeting the ACSM/AHA PA recommendations. A longer bout of gaming than PA guidelines recommends for exercise was used in an effort to mimic the duration of a typical fitness class or workout. The effect of a whole gaming session rather that the effect of playing games for short periods of time was assessed. The hypothesis was that the increased movement, while playing a modified Wii Sports, would result in a significantly greater EE and cardiovascular response than regular Wii Sport games, and that the intensity of activity would meet the ACSM/AHA recommendations.

3.2. Methods

3.2.1. Participants

The participants who volunteered (n=13, 8 females/5 males) were young, lean and active (Table 3.1). All participants completed a Physical Activity Readiness Questionnaire (PAR-Q) and a general health questionnaire. Body mass index was calculated from height, measured to the nearest 0.1 cm, and weight, to the nearest 0.1 kg (Seca Ltd, model 778, Germany). This study complied with the Declaration of Helsinki and was approved by the Dublin City

University Research Ethics Committee. All participants provided written informed consent prior to participation.

3.2.2. Procedures

Participants attended the laboratories at the School of Health and Human Performance on 5 separate days, (Figure 3.1). Participants performed a $\dot{V}O_2$ max test, a familiarisation session and three gaming sessions in a randomised order, for 46 min, (i) a sedentary game, PlayStation 2 "Burnout 3" racing car game, (SED), (ii) a boxing and tennis game, Nintendo Wii Sports (ACT) and (iii) a modified version of the Nintendo Wii Sports tennis and boxing games (Mod-ACT). The familiarisation session lasted 30 min and subjects spent 10 min in each game. In some cases, participants needed more than 10 min to learn how to play the Mod-Act game.

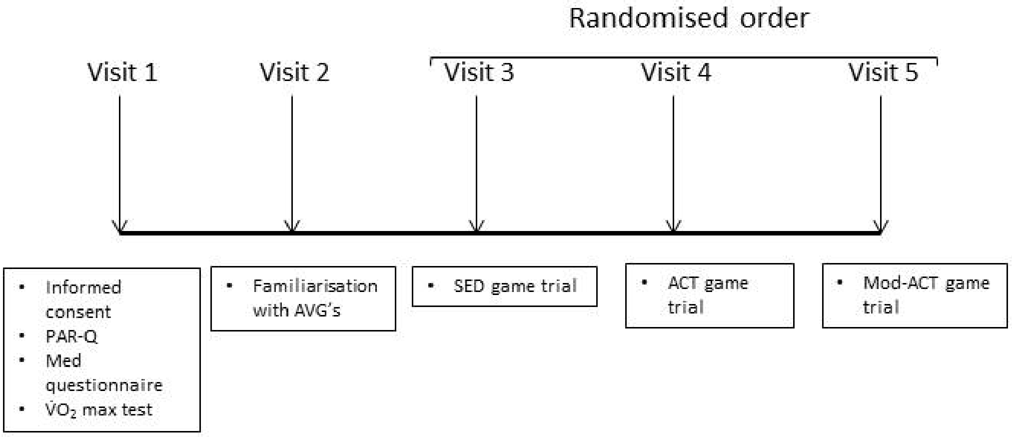


Figure 3.1. Schematic of study 1 protocol. All visits were interspersed by at least 48 hr.

A period of at least 72 hr separated each of the gaming sessions, which were performed at the same time of day with similar preparation for each session. These AVGs were chosen, as they elicit the highest EE of all Wii Sport games (unpublished observations from our laboratory).

3.2.3. Maximal aerobic capacity

An incremental treadmill test was used to determine maximal $\dot{V}O_2$ max using open-circuit spirometry (Cosmed $K4b^2$ portable metabolic system, Cosmed, Italy). Figure 3.2 shows a research participant wearing the Cosmed K4B2 system and playing one of the AVGs. Prior to each test, the $K4b^2$ was volumetrically calibrated using a 3L Hans Rudolph syringe, the O_2 and CO_2 analyzers were calibrated using a standard gas (16% O_2, 4% CO_2) and room air. Baseline data collection was performed for 3-min while participants were standing on the treadmill, followed by a 2 min incremental protocol until volitional exhaustion to determine maximal aerobic capacity. The initial speed and speed increments were selected for the test to last 8–12 min, a duration considered to be optimal for measuring $\dot{V}O_2$ max during a continuous incremental protocol (Buchfuhrer *et al.*, 1983; McConnell & Clark, 1988; Astorino *et al.*, 2004). Oxygen uptake was considered to have peaked if two of the following criteria were met: (i) a levelling off of $\dot{V}O_2$ with increasing treadmill speed (increase of less than 2 $mL{\cdot}kg^{-1}.min^{-1}$), (ii) a HR within 10 beats of the age predicted HRmax (220 $beats{\cdot}min^{-1}$ – age in years), (iii) a RER greater than 1.10. Expired gases (O_2 and CO_2) and ventilatory parameters were averaged every 20 s and the average of the three highest consecutive 20 s values was taken as the $\dot{V}O_2max$. Cardiorespiratory responses during the incremental maximal treadmill test are shown in Table 3.1.

3.2.4. Sedentary (SED), Nintendo Wii Sports (ACT) and Modified-Active game (Mod-ACT)

Each game was projected onto a large screen (1.8 x 1.5 m) by LCD projector, the playing surface was a non-slippery vinyl floor and participants were positioned 2.4m from the screen. Participants were seated while playing the sedentary game and standing while playing the active games. A familiarization session was provided on a different day, as some, but not all, of the participants had previous experience playing AVGs. In addition, a detailed explanation of the rules for Mod-ACT was required. Following the explanation and demonstration of the games, participants were allocated 30 min to practice the games.

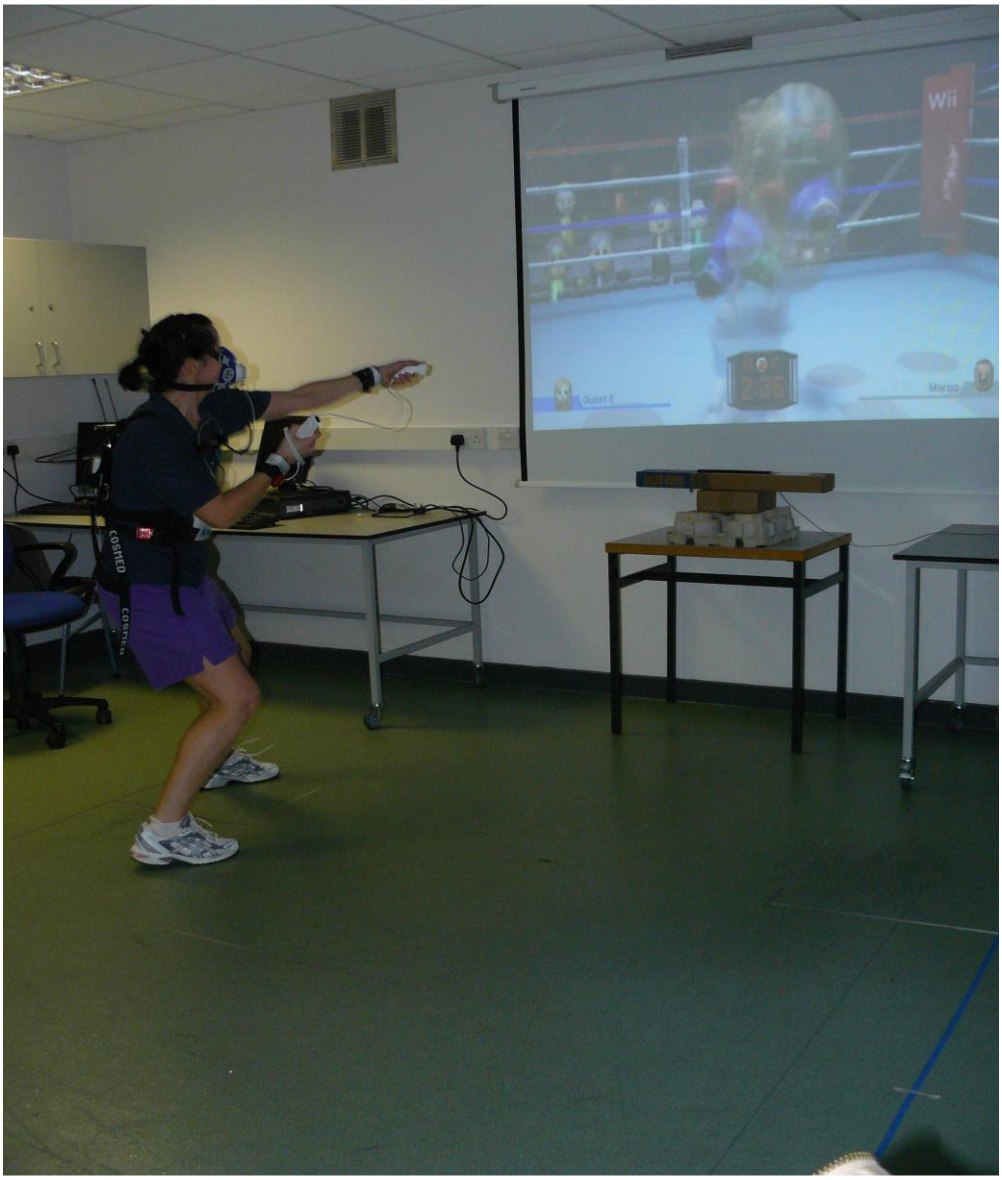


Figure 3.2. Research participant wearing the Cosmed K4B2 and playing one of the AVGs.

The four gaming modes for the ACT and Mod-ACT games were tennis target practice (TTP), tennis game (TG), boxing training (BT) and boxing fight (BF). In TTP, the participant has to hit a tennis ball against a wall and try to hit a moving aim in the wall to win points. In BT, the participant has to punch a punch bag for 1 min and receives bonus points for successful punches. Each participant used the guest mode to play all games. The AVG sessions consisted of 5-min TTP, 17-min TG, 5-min BT and 17-min BF. The total transition time between the different active video games was 2 min. This time was included in the analysis of the overall total time. Participants played the same Wii Sports games in ACT and Mod-ACT trials, but in Mod-ACT the subjects were required to move forward, backward and to the side, depending on the game. This was achieved by placing markings in front of the projection screen on the floor (Figure 3.3 and 3.4).

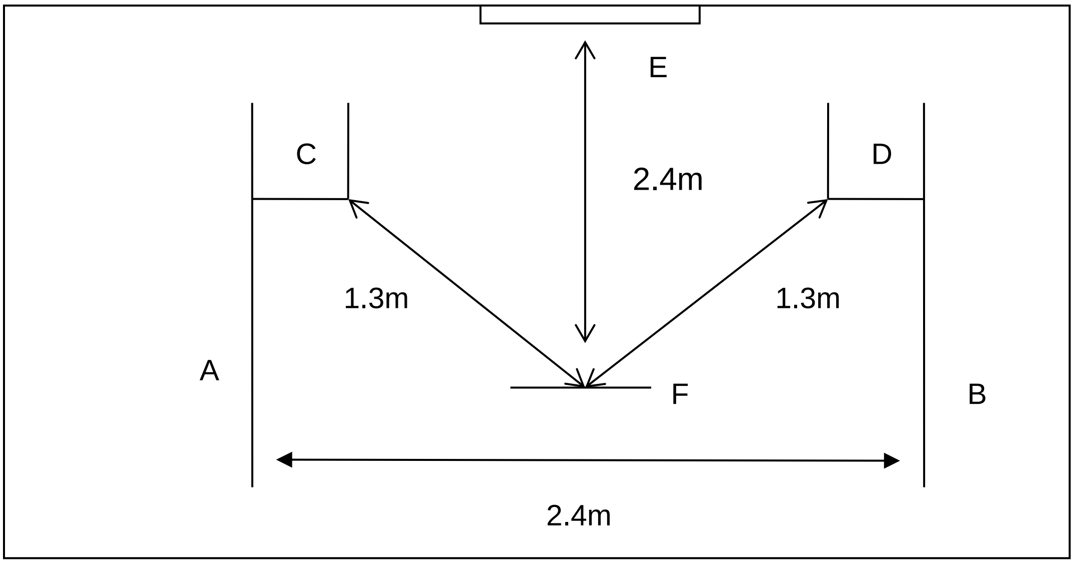


Figure 3.3 Mod-ACT playing area layout. The layout of the markings on the floor used for the PlayStation, Wii Sports and Mod Wii Sports trial. A: Left hand line; B: Right hand line; C: Top left hand box; D: Top right hand box; E: Projection screen; F: Line participants were seated at during Play trial and standing during Wii Sports and Mod Wii Sports trial.

During Mod-ACT tennis, participants were required to step laterally from the centerline 1.2m during each tennis stroke. When the participant (if right handed) made a forehand stroke they were required to place their right foot outside the right hand line (marked B in figure 3.3). When they attempted a backhand stroke, the participant was required to move their left foot outside the left hand line (marked A in figure 3.3). Similarly, during Mod-ACT boxing, the participants were required to step 1.3m diagonally forward or backward (Figure

3.3). The participants were then required to place their left foot into the top left hand box (marked C in Figure 3.3) when they punched with their left hand. There was a corresponding response for the right foot (marked D in Figure 3.3). After any movement participants were required to move back to the centre point between the lines or boxes, ready for the next stroke or punch.

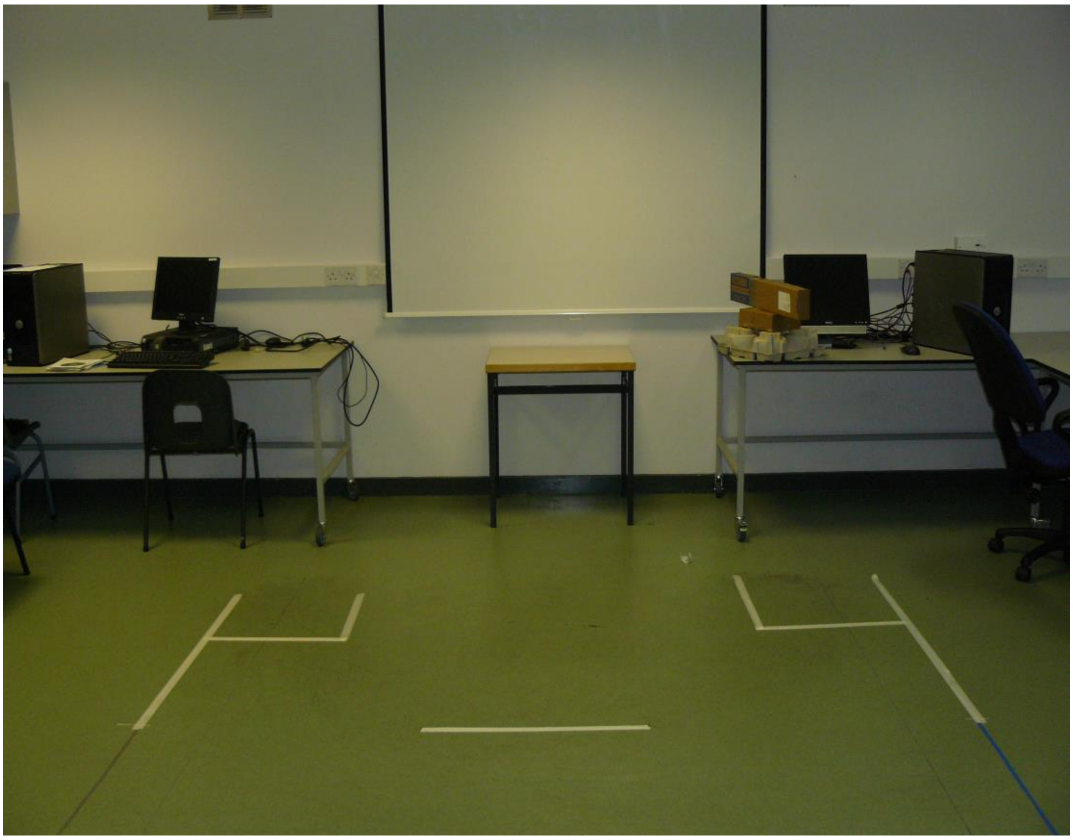


Figure 3.4. Mod-ACT playing area.

3.2.5. Physiological response to the gaming sessions

Participants' baseline responses were measured during 10 min of seated activity. Participants were asked to not engage in vigorous intensity exercise the day before the trials, and to refrain from drinking coffee and tea for at least 3 hr before the trials. Also, participants were asked to follow the same diet the day before each trial and each trial day. After this, participants stood up and started playing the video games as directed by the testers. Expired gases were continuously analysed during each of the gaming sessions by open-circuit spirometry (Cosmed K4b^2 portable metabolic system, Cosmed, Italy). The Cosmed K4B2 provides an acceptable way for measuring oxygen uptake over a wide range of exercise intensities (McLaughlin *et al.*, 2001). Heart rate was monitored by radiotelemetry (Polar Electro, Kempele, Finland). Oxygen uptake and HR were analysed breath-by-breath, and averaged over 20 sec epochs. Minutes 7 to 9 were averaged to determine baseline $\dot{V}O_2$ and HR. Our primary outcome, the rate of EE, was estimated by the Weir equation (Weir, 1949):

$$EE = \dot{V}E\ (1.046 - (0.05 * FEO_2))$$

where $\dot{V}E$ = Ventilation ($L{\cdot}min^{-1}$) and FEO_2 = Fraction of expired Oxygen.

The EE at rest over 46 min (73.5±9.8) was calculated using the rates EE during the 10 min baseline before gaming. After this, the EE above baseline in 46 min during was calculated for each trial.

The percentage HR reserve (% HRR) was calculated by using a derivation of the Karvonen *et al*. formula(1957):

$$HRR = HRmax - RHR \text{ (Karvonen } et\ al. \text{ formula);}$$

$$\% HRR = (HRtrial - RHR)/(HRmax - RHR)*100$$

where HRtrial = average HR during the trial, RHR = resting HR and HRmax = heart rate max (as determined during a $\dot{V}O_2$ max test test). This formula allows us to calculate precisely the percentage of HR reserve participants were exercising at.

The $\dot{V}O_2$ reserve ($\dot{V}O_2R$) was calculated by using a derivation of the Karvonen *et al*. formula with $\dot{V}O_2$ data:

$\dot{V}O_2R = \dot{V}O_2max - \dot{V}O_2rest$ (Karvonen *et al*. formula with $\dot{V}O_2$ data)

$\dot{V}O_2R = (\dot{V}O_2trial - \dot{V}O_2rest)/(\dot{V}O_2max - \dot{V}O_2rest)*100$

where $\dot{V}O_2trial$ = average $\dot{V}O_2$ during the trial, $\dot{V}O_2rest$ = average resting $\dot{V}O_2$ as determined during baseline measurements prior to each trial and $\dot{V}O_2max$ = maximal oxygen uptake attained during an incremental maximal test.

3.2.6. Statistical analysis

The data were analysed using SigmaPlot statistical package v.12 and are presented as mean ± SD. Variables that were not normally distributed were log transformed prior to analysis. A one way repeated measures ANOVA was used to detect significant differences across the three different video games. Post-hoc analysis of significance was investigated using the Bonferroni test when significance differences were detected. Statistical significance was set at $P < 0.016$. Effect sizes were calculated for the outcome variables and partial eta squared values were reported. A post-hoc power analysis of our primary outcome, the rate of EE, resulted in $\pi > 0.90$.

3.3. Results

3.3.1. Participant charactaristics

There are some differences between the males and females that took part in this study. Males were significantly taller, heavier and had a higher $\dot{V}O_2$max compared to the females. There were no significant differences in the age, body mass index and HRmax between the two groups. There were no significant differences in the physiological responses of both males and females to SED and both AVGs with the exception of rates of EE that was higher in men as expected.

3.3.2. Gaming sessions

Participants took part in each gaming session for a similar length of time (46±0.2, 46.6±0.2, and 46.5±0.3 min for SED, ACT and Mod-ACT games, respectively). The gaming time excluded the 10 min baseline measurement during which the participants were seated, but included all the transition times between the games and the time used to reset the games. The time spent playing the games was 44 min and the transitions between games took 2 min.

Table 3.1 Physical characteristics and cardiorespiratory responses during maximal treadmill exercise.

	Male	**Female**	**Mean**
Age (yr)	25 ± 4	23 ± 3	24 ± 3
Body mass (kg)	74.9 ± 3.8*	61.2 ± 9.4	66.5 ± 9.8
BMI ($kg^{.}m^{-2}$)	23.1 ± 0.8	22.2 ± 2.5	22.5 ± 1.9
$\dot{V}O_2max$ ($mL^{.}kg^{-1}.min^{-1}$)	69.5 ± 6.8*	51.9 ± 5.9	58.7 ± 10.3
HRmax ($beats^{.}min^{-1}$)	194.4 ± 4	196.8 ± 3.1	195 ± 3.4

Data are presented as mean ± SD. HRmax: maximal heart rate, $\dot{V}O_2max(mL^{.}kg^{-1.}min^{-1})$: rate of maximal oxygen uptake. * significantly different from female ($P < 0.05$).

3.3.3. Physiological responses

The physiological responses to the gaming sessions are presented in Table 3.2. The HR and $\dot{V}O_2$ responses prior to the three gaming trials were similar. There was a significant effect for trial on HRR, (Wilks'Lambda = 0.090, F(2,11) = 55.29, $P < 0.001$, multivariate partial $\eta^2 = 0.91$ and $\dot{V}O_2R$ (Wilks' Lambda = 0.096, F(2,11) = 51.76, $P < 0.001$, multivariate partial $\eta^2 = 0.90$). Post-hoc tests revealed that during the ACT and Mod-ACT trials, the mean HRR and $\dot{V}O_2R$ were significantly greater than during the SED trial ($P < 0.001$). The Mod-ACT trial also resulted in a significantly larger response than for the ACT trial ($P < 0.001$). A similar pattern was observed for average HR, HRmax, $\dot{V}O_2$, and % $\dot{V}O_2max$ ($P < 0.001$).

3.3.4. Energy expenditure

There was a significant effect for trial (Wilks'Lambda = 0.14, F(2,11) = 33.48, $P < 0.001$, multivariate partial $\eta^2 = 0.86$). Post-hoc tests revealed that the mean rate of EE was significantly higher during Mod-ACT (8.40 ±3 $kcal^{.}min^{-1}$) than during both ACT (4.11±1.60 $kcal^{.}min^{-1}$) and SED trials (1.84 ± 0.32), ($P < 0.001$) and EE was significantly higher during ACT than during SED ($P < 0.016$). The total EE for each of the gaming trials is presented in Figure 3.5. and, as expected, is consistent with the rates EE. The baseline rate of EE across the 46 min gaming period would correspond to 73.5±9.8 kcal. Table 3.2. shows the EE above baseline for the different trials.

Table 3.2. Physiological responses at rest and during the gaming trials

	SED	ACT	Mod-ACT
Resting HR (beats·min^{-1})	60.1±8.2	58.2±5.4	55.9±6.2
Mean gaming HR (bpm)	62.0±7.4	85.0±15.9*	117.0±17.2**
% time spent above 60%HRmax	0.0%	12.2±14.9*	43.9±20.0**
Gaming HRR (%)	5.4±4.5	22.4±10.4*	46.6±13.6**
Gaming %HRmax	33.1±3.8	45.0±8.7*	62.2±9.9**
Resting $\dot{V}O_2$(mL^{-1}·kg^{-1}·min^{-1})	4.55±0.8	4.25±0.7	4.28±0.7
Average gaming $\dot{V}O_2$(mL^{-1}·kg^{-1}·min^{-1})	5.03±0.7	11.51±3.6*	24.21±6.1**
% time spent above 60% $\dot{V}O_2$	0.0	0.0	11.0±17.2
%$\dot{V}O_2$max playing games	8.6±2.4	18.9±9.6*	41.2±9.7**
$\dot{V}O_2$R (%)	2.4±5.1	14.6±9.3*	37.5±10.3**
METs (gaming)	1.4±0.2	3.3±1.0*	6.9±1.7**
Resting rate of EE (kcal/min)	1.64±0.26	1.56±0.25	1.58±0.30
EE above baseline in 46 min(kcal)	11.8±9.8	118.0±64.4*	314.9±125**
% increase EE over baseline	16.0±13.0	160.0±91.7*	426.0±138.8**

Data presented as mean ± SD. * significantly different from SED (*P* <0.016); ** significantly different from SED and ACT (*P* <0.05). EE: Energy expenditure (kcal), HR: heart rate (in beats per min), %HRmax : percentage of maximal heart rate, HRR (%): percentage of heart rate reserve, $\dot{V}O_2$: rate of oxygen uptake (mL^{-1}.kg^{-1}.min^{-1}), $\dot{V}O_2$R (%): percentage of oxygen uptake reserve.

METs: A significant effect for game played was found, Wilks' Lambda = 0.083, F(2,11) = 60.67, *P* < 0.001, multivariate η^2 = 0.92. Mean METs were significantly higher during Mod-ACT than during ACT and SED trials and they were significantly higher during ACT than during SED game. MET values are shown in

Table 3.2. There were no differences between Bonferroni corrected and uncorrected results for any of the outcome measures.

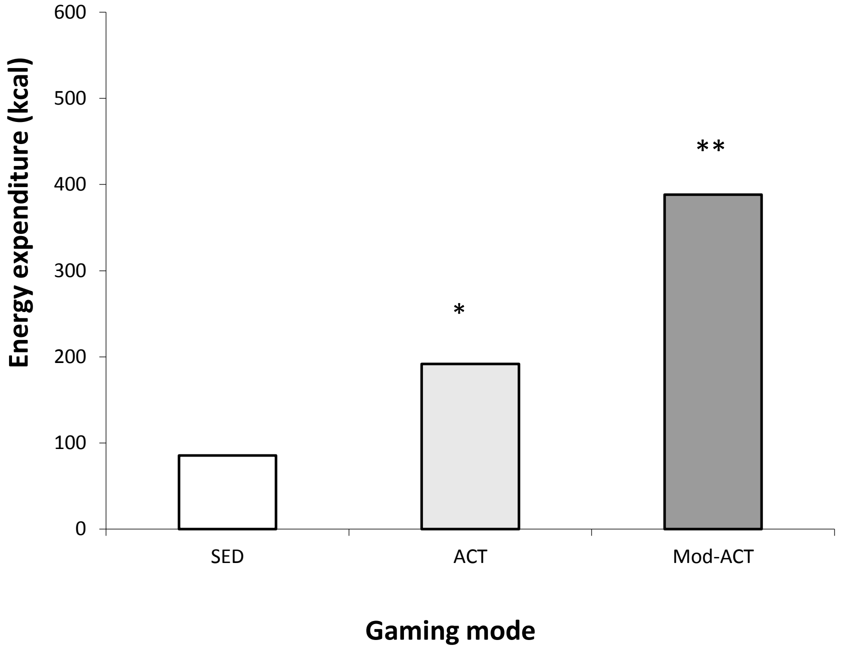


Figure 3.5 Total energy expenditure during SED, ACT and Mod-ACT trials. Data presented as mean ± SD. Total energy expenditure in kcal during SED (85.3 ± 14.4), ACT (191.6 ± 71.7) and Mod-ACT (388.4 ± 129.8). * significantly different from SED ($P < 0.05$). ** significantly different from SED and ACT ($P < 0.05$).

3.4. Discussion

The main finding from the present study is that the use of AVG play to attain the recommended levels of PA is possible. However, it is noted that existing games require certain modifications to the movement pattern in order to induce a moderate-vigorous stimulus. The ACT and Mod-ACT sessions significantly increased HR, $\dot{V}O_2$ and EE in comparison to the SED game; however, the use of Mod-ACT movement pattern increased the exercise intensity from light to moderate according to the ACSM (2014).

In order to maintain health and prevent chronic disease, innovative approaches are required to address the societal challenge of physical inactivity.

Traditional forms of recreational activity such as walking, running and cycling have proven physiological benefits (Marti, 1991; Bucksch & Schlicht, 2006; Warburton *et al.*, 2006; Kitchen *et al.*, 2011; Oja *et al.*, 2011). In addition, structured exercise sessions have not resulted in population wide increases in PA (Berger *et al.*, 2002; Matsumoto & Tekenaka, 2004). In certain instances the advancement in technology is cited as a possible reason for lower occupational and recreational PA (Lakdawalla & Philipson, 2002) However, embracing technology may also be a major part of the solution. The development of AVG technology has provided an opportunity for recreational gaming to contribute to daily PA although there is still a paucity of data available detailing the physiological responses in adults.

In this study the gaming sessions were 46-min in duration and the analysis included the transition times as it is more reflective of the discontinuous nature of playing games. Although the HR response to ACT game was significantly greater than to SED, the %HRmax (45 ± 8.7% HRmax) and %HRR (22.4 ± 10.4%HRR) would classify the ACT game as a very light activity . Willems and Bond (2009a) reported a similar result following 10 min of Wii tennis (46 ± 9% HR max), but higher values have been reported following 10 min (56 ± 9% HRmax) and 12-min (65.5% HRmax) of Wii boxing (Willems & Bond, 2009a; Jordan *et al.*, 2010). These differences may reflect the duration of the gaming session with a shorter duration eliciting a greater self-selected intensity. The combination of the Wii tennis and Wii boxing as well as the transition times might also partly explain a lower overall response in the present study. Other factors that might explain these discrepancies are differences in motivation, fitness and familiarity with the games. Guderian *et al*. (2010) conducted a 20-min continuous gaming session using six different Nintendo Wii Fit games in middle-aged and older adults, with most games being played for 3-min. Guderian *et al.* (2010) reported values ranging from 33% HRR (Wii Fit Penguin) to 64% HRR (Wii Fit Jogging) . The Mod-ACT trial developed for this study increased the activity level during each of the games such that there were significant increases in average HR, percentage of time spent with the HR above 60% HRmax and HRR. Furthermore, the increase in HRR observed during the Mod-ACT trial permitted an alteration of the intensity classification from 'Light' for the ACT game to 'Moderate' for Mod-ACT.

A similar pattern was evident for the $\dot{V}O_2$ and $\dot{V}O_2R$ data during the exercise trials. The rate of oxygen consumption or % $\dot{V}O_2$ max in this trial is comparable to that of most (Willems & Bond, 2009a, b; Sanders *et al.*, 2012) but not all studies (Jordan *et al.*, 2010) using Wii Sport. The results presented by Jordan et al. (2010) for Wii boxing are consistently higher than other studies and this may be due to the study design (12 min gaming). Whole body active games are likely to elicit the highest response in $\dot{V}O_2$ but the experience of the participant is also a factor. Sell *et al*. (2008) found that experienced users of the dance game had significantly higher rates of oxygen consumption compared to those with less experience. When $\dot{V}O_2R$ data is considered, ACT would be classified as 'very light' intensity, while Mod-ACT would be at the upper end of 'light' but below the moderate classification. Therefore, according to our observations the HRR and $\dot{V}O_2R$ data offer different classifications for exercise intensity. It is accepted in the literature that % HRR and % $\dot{V}O_2R$ values are closely aligned across the entire range of fitness levels (ACSM, 2010). The relationship between HR and $\dot{V}O_2$ data in the present study is similar to the HR-$\dot{V}O_2$relationship described in the literature (Swain *et* al., 1994). However, %HRR values were more closely aligned with % $\dot{V}O_2$ max than with % $\dot{V}O_2R$ in the present study.

A limited number of studies have measured EE in adults while playing Wii Sports (Lanningham-Foster *et al.*, 2009; Willems & Bond, 2009a; Jordan *et al.*, 2010). The net EE above baseline, while playing Wii Sports (ACT trial) in this study was 118.1 ± 64.4. This rate of EE is similar to that reported in other studies (Lanningham-Foster *et al.*, 2009; Willems & Bond, 2009b, a) despite differences in the duration of play. The net EE above baseline while playing Mod-ACT was significantly higher, (314.9 ± 125 kcal) and is comparable to jogging (Ainsworth *et* *al.*, 2000). While we did not measure the exact contribution of lower body in the Mod-ACT trial compared to the ACT trial, this extra lower body activation explains the substantial increments in EE compared to the ACT trial. This is in agreement with the fact that AVGs in which the lower body contribution is high, e.g. Dance Dance Revolution, result in higher EE values than AVGs in which lower body is not so activated (Lyons *et al.*, 2011).

When METs are considered, the SED game had a slightly lower intensity (1.4±0.2METs) than sitting as an spectator at a sporting event (1.5 METs) (Ainsworth *et al.*, 2000). The MET value for the ACT game observed in the present study (3.3±1) is comparable to walking at 3 mph on a firm level surface (Ainsworth *et al.*, 2000). Furthermore, Mod-ACT (6.9±1.7) is just below the intensity equivalent to jogging, tennis or a casual game of soccer (Ainsworth *et al.*, 2000). Similar values have been reported in other studies that have investigated Wii Sports (Willems & Bond, 2009b; Miyachi *et al.*, 2010; Sanders *et al.*, 2012), the Wii Fit (Lyons *et al.*, 2011) and a dance game (Lyons *et al.*, 2011). Leatherdale et al. (2010) reported a higher MET value than other reported studies but METs were calculated from a SenseWear armband rather than oxygen consumption. Based on the MET values obtained in this study, an average adult would need to play the ACT game (Wii Sports) for approximately 30-60 min, 5 $d \cdot wk^{-1}$ in order to reach the 500-1000 $MET \cdot min \cdot wk^{-1}$ recommended by ACSM (Garber *et al.*, 2011) while the same adult would need to play the Mod-ACT game for 15-29 min, 5 $d \cdot wk^{-1}$ to meet the same guidelines.

The present study has a few limitations. The nature of video game play implies spontaneity and a will to play for enjoyment or fun. This is not the case in a laboratory study where the participants are asked to play certain games for a particular length of time, reducing transition times between games to a minimum and in a non-familiar setting. Also, participants in the present study are active and the findings may not apply to sedentary or low-active individuals that are more representative of the general population. However, it is also possible that the exercise intensity and health benefits be greater in the general population since these games are likely to elicit higher relative exercise intensities than in the lean and fit participants that took part in this study. Finally, the comparison made between the trials used in this study and the other activities (spectator, walking, tennis game and soccer game) was based on normative data for the whole population rather than from the same subjects. It would have been better to have used data from the same subjects for the above mentioned activities. Affect variables such as enjoyment were not measured in this study and there is scientific evidence (Sorensen, 2005; Williams *et al.*, 2008) that affect responses to exercise are important factors in determining exercise adherence. The Mod-ACT trial resulted in the highest exercise intensity, but we did not measure how participants felt during this or any of the other trials. Chapter 4 and 5 expands on findings from study 1 by measuring affect responses and also by assessing how exercise intensity impacted on affect responses during AVG play and during conventional exercise.

3.5. Conclusion

Data from the present study suggest that active gaming may have a valuable role in increasing PA levels and reducing sedentary time. Factors such as the duration of the gaming session, the movement of the participant, the fitness level and experience playing the game will influence the physiological response and effectiveness of the activity session. When lower body activation is increased, as was the purpose of the present study, it is possible to achieve a significant increment in EE and to exceed the current PA guidelines. This is valuable information that video game designers should take into account to design enjoyable physiologically challenging AVGs. More research studies should also investigate the effects of modifying AVGs at a physiological and affective level in the adult population. Based on MET criteria, the ACT game resulted in moderate exercise intensity. However, this game resulted in very light-to-light exercise intensity based on % $\dot{V}O_2R$ and %HRR criteria respectively. While this activity does not comply with ACSM PA guidelines based on % $\dot{V}O_2R$ and %HRR criteria, it has potential to bring health benefits by reducing sedentary pursuits (sitting) and increasing time spent in light intensity activities. Further research in the form of medium-long term longitudinal studies is needed to establish the usefulness of AVG technology to reduce physical inactivity and to assess the reduction of sedentary time by playing more AVGs.

CHAPTER IV

Study 2: Energy expenditure and enjoyment during conventional stationary cycling and interactive video game cycling in inactive adults

4.1. Introduction

Regular PA plays an important role in the prevention of more than 25 chronic diseases in modern life (Booth *et al.*, 2002). Evidence is also fast accumulating on the deleterious effects of sedentary behaviour (prolonged sitting) on health (Wilmot *et al.*, 2012). However, physical inactivity levels remain unacceptably high from a public health perspective (Tucker *et al.*, 2011; Hallal *et al.*, 2012). Furthermore, population PA levels decrease as the population grows older (Haskell *et al.*, 2007). It is widely recognised that increasing population PA levels and decreasing sedentary behaviour are necessary steps in the fight against chronic disease. Physical inactivity is defined as not meeting any of the following criteria: 30 min of moderate-intensity PA on at least 5 days every week; 20 min of vigorous-intensity PA on at least 3 days every week; or an equivalent combination achieving 600 metabolic equivalent (MET)-min$\cdot$wk^{-1} (WHO, 2010; IPAQ, 2011; WHO, 2011).

There is insufficient information exploring the link between enjoyment and PA adherence but there is some evidence supporting a positive impact of enjoyment on PA participation (Salmon *et al.*, 2003; Sorensen, 2005; Hagberg *et al.*, 2009). A review of qualitative studies of adult participation in PA revealed that enjoyment was one of the main motivating factors (Allender *et al.*, 2006). It has been reported that between 40 and 65% of individuals drop out of a PA program within 3-6 months (Dishman & Buckworth, 1996; Annesi, 2001). Since enjoyment is a powerful motivator for adults to participate in PA, a lack of enjoyment in attaining the PA recommendations could partly explain these figures.

In line with the behavioural choice theory, substituting conventional exercise with an activity that involves exercise but that is more enjoyable than conventional exercise in the form of AVGs resulted in higher adherence rates and affect states (Epstein *et al.*, 2004; Warburton *et al.*, 2007b; Rhodes *et al.*, 2009; Garn *et al.*, 2012). The available evidence suggests that light, moderate and vigorous PA intensity levels can be achieved while playing AVGs (Warburton *et al.*, 2009; Willems & Bond, 2009b; Guderian *et al.*, 2010; Mullins *et al.*, 2012). There is also preliminary evidence to suggest that a short bout of interactive cycling results in higher EE and similar RPE ratings when compared to a similar bout of conventional cycling (Warburton *et al.*, 2009). This study also tests the main tenet of the dual mode theory (Ekkekakis & Acevedo, 2006), a theory that attempt to explain the relationship between affect and exercise intensity. According to this theory, lower intensity exercise is associated with largely homogeneous, positive affective responses. However, affective responses are variable in response to exercise near the ventilatory threshold (VT) and become predominantly negative at intensities above the VT.

One of the challenges associated with AVG research is the use of comparable exercise modalities when comparing AVGs with conventional exercise. The GameBike is an interactive video game that requires the player to pedal in order to move a vehicle displayed on a video screen. The handlebars on the bicycle ergometer allow the vehicle to move left or right while travelling around a race track. Therefore, the aim of this study was to directly compare cardiometabolic responses between a bout of interactive GameBike cycling and a bout of conventional stationary cycling, while measuring enjoyment levels and exercise intensity in relation to individual ventilatory threshold (VT).

The purpose of this study was to compare conventional cycling on a bicycle ergometer to a similar bout on the GameBike. It was hypothesised that interactive game cycling would result in higher cardiovascular and metabolic responses than a bout of conventional stationary cycling at a matched workload. It was also anticipated that RPE with interactive video game cycling would be lower while enjoyment ratings would be higher than during conventional cycling.

4.2. Methods

4.2.1. Participants

A total of 34 healthy, young, men and women volunteered to take part in this study. All participants completed a PAR-Q, and a general health questionnaire that included questions on PA participation in the last 6 months. Participants who had two or more risk factors for atherosclerotic cardiovascular disease (ACSM, 2014) were referred for a medical screening before taking part in the study. The inclusion criteria for the study were as follows: 1) healthy male or female age 18-45 years, 2) non-smoker, 3) no more than one exercise session per week over the previous 6 months, 4) had a $\dot{V}O_2$peak within the 60th percentile for the age and gender group.

The body mass index (BMI) was calculated from height, measured to the nearest 0.1 cm, and body mass, to the nearest 0.1 kg (Seca Ltd, model 778, Germany). Given that the level of AVG playing experience varied considerably amongst participants, familiarisation sessions were provided. All testing sessions took place at the High Performance Laboratory at the School of Health and Human Performance at Dublin City University.

4.2.2. Experimental overview

Participants reported to the laboratory at Dublin City University on 4 different days separated by at least 48 h (Figure 4.1.). On day 1 of testing, participants carried out an incremental maximal test on a cycle ergometer to determine $\dot{V}O_2$peak and peak power output (PPO). On day 2 of the experimental protocol, participants attended the laboratory to familiarise themselves with the interactive video gaming by playing the game for 30 min. The remaining two visits were used to perform the exercise trial or gaming trial in random order. During both trials, participants exercised for 30 min at a matched workload of 55% of PPO. This intensity was selected based on findings from previous research studies that used interactive cycling video games (Warburton *et al.*, 2009). Participants refrained from drinking caffeine and alcohol for 24 h and from the ingestion of food or fluids (except water) for 3 hr prior to the test.

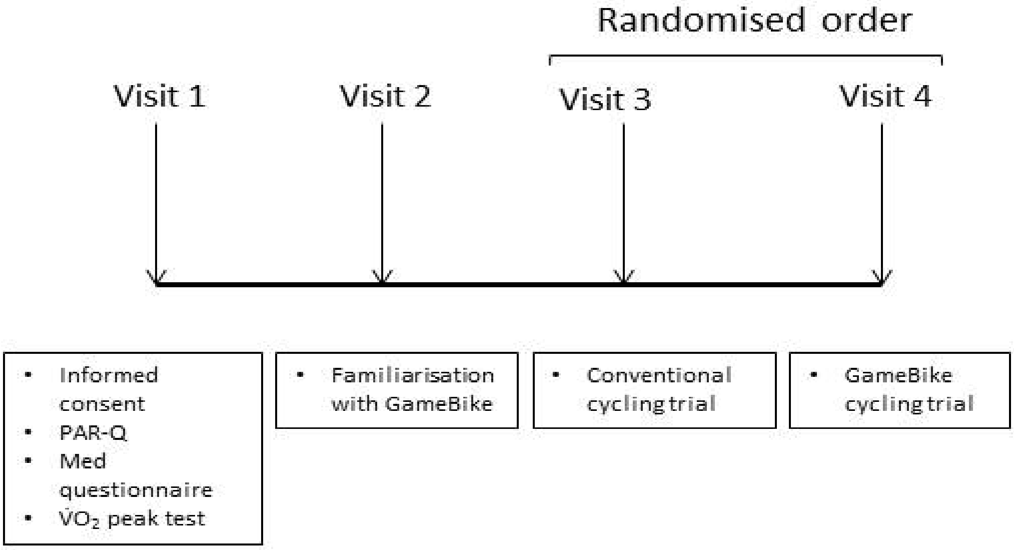


Figure 4.1. Schematic of study 2 protocol. All visits were interspersed by at least 48 hr.

4.2.3. Maximal Oxygen uptake test and peak power output determination

An incremental cycling test on an electronically braked cycle ergometer (Velotron; RacerMate, Seattle, WA) was used to determine $\dot{V}O_2$ peak using open-circuit spirometry (Innocor, Inn 00200, Innovision, Odense, Denmark). Prior to each test the Innocor system was volumetrically calibrated using a 3 L Hans Rudolph syringe, and the O_2 and CO_2 analysers were calibrated using ambient air (23.93% O_2, 0.03% CO_2). Baseline data collection was performed for 3 min followed by a standard incremental protocol. The protocol consisted of an initial power output of 50 W for females and 75W for males, 1 min duration, and 15 W increments until the participant reached volitional fatigue. Participants were instructed to cycle to exhaustion at a self-selected cadence. $\dot{V}O_2$ was considered to have peaked if two of the following criteria were met: (i) a levelling off of $\dot{V}O_2$ with increasing power output (an increase of less than 2 $mL \cdot kg^{-1} \cdot min^{-1}$); (ii) a HR within 10 beats of the age predicted HRmax (220 beats$\cdot$min^{-1} – age in years); (iii) a RER greater than 1.10.

The participants' PPO was defined as the highest power output in watts (w) that participants were able to reach. This was determined this by using the following equation (Kuipers *et al.*, 1985):

Peak power output (w) = POfinal + ((t/60) 15)

In this equation, 'POfinal' represents the last exercise intensity completed for 1 full min (in watts) and 't' signifies the number of seconds for which the final, uncompleted exercise intensity was sustained.

Expired gases (O_2 and CO_2) and ventilatory parameters were averaged every 20 s and the average of the three highest consecutive 20 s values was taken as the $\dot{V}O_2$peak. The rate of perceived exertion (RPE) was also measured using the 15point category Borg scale (Noble *et al.*, 1983).

4.2.4. Ventilatory threshold determination and % $\dot{V}O_2$ peak in relation to the ventilatory threshold

Following completion of the test, the VT was determined using the V-slope method (Beaver *et al.*, 1986) by two independent experts and by function available in the Innocor software. In the V-slope method, $\dot{V}CO_2$ is on the y-axis and $\dot{V}O_2$ is on the x-axis. Initially, the relationship of both variables is linear, but an upward bend denotes the excess CO_2 being exhaled. The VT is the point of intersection of the two regression lines for the upper and the lower part of the function. When the application of the V-slope method resulted in indeterminate results, the independent experts used the first rise of the ventilatory equivalent for O_2 (VE/ $\dot{V}O_2$) in a supportive manner.

The % $\dot{V}O_2$ peak above or below the VT was calculated by using the following formula:

$$\% \text{ VT} = ((\dot{V}O_2\text{trial} - \dot{V}O_2\text{@VT})\ 100) / \dot{V}O_2\text{@VT}$$

where % VT = % $\dot{V}O_2$peak above or below the $\dot{V}O_2$ @ VT, $\dot{V}O_2$trial = average $\dot{V}O_2$ during the trial in L/min, $\dot{V}O_2$@VT = oxygen uptake at ventilatory threshold in L/min.

4.2.5. Familiarisation session

Participants began by remaining in a supine position for 10 min while wearing a wireless HR monitor to obtain resting HR (Polar RS 400, Polar Electro, Kempele, Finland). Following this, they were allowed to play the interactive video game for 30 min. The participants cycled at a workload equal to 55% of their PPO. The video game requires the player to pedal in order to move a vehicle displayed on a video screen. The handlebars on the cycle ergometer allow the vehicle to move left or right while travelling around a race track. The video game provides visual and audio feedback, including music and mechanical sounds. All participants cycled on the same track and terrain, using the same bike and game setting (Single Event, Hampworth Station) while competing against 5 other computer operated bikes. When twenty laps were completed, the game was reset; however participants were instructed to keep cycling during this short break. During the familiarisation visit, participants were also shown the modified Physical Activity Enjoyment Scales (PACES) scale and they were given time to understand the statements contained in this scale.

4.2.6. Active video game cycling trial

The participants sat in an upright position on the cycle ergometer for 10 min before playing the interactive video game cycling. The last 3 min of these 10 min were averaged to calculate baseline values. Following this, the participants played the interactive cycling video game while cycling at a constant workload of 55% of their PPO. Participants were free to pedal at a self-selected cadence. The electronically braked cycle ergometer (Velotron; RacerMate, Seattle, WA) was modified as described elsewhere in the literature (Warburton *et al.*, 2009) to be able to adapt the handlebar and speed sensor from a GameBike GB 200 interactive video game system (CatEye, Osaka, Japan) and interface it with a Sony Playstation 2 (Sony, San Mateo, CA), see Figure 4.2. Participants received standarised verbal encouragement after 10-and 20-mins.

4.2.7. Conventional stationary cycling trial

This trial was identical to the interactive video game cycling trial except that participants were just cycling and not playing the game. The power output during the conventional stationary cycling trial was also 55% of subject's PPO and all other conditions were similar. The same physiological parameters were measured as during the interactive video game cycling trial.

Figure 4.2. Research participant playing GameBike in the adapted Velotron ergometer and wearing face mask for open-circuit spirometry analysis.

4.2.8. Psychological measurements

4.2.8.1. Physical Activity Enjoyment Scale (PACES) and RPE scale

Physical Activity Enjoyment Scale (PACES): a modified PACES scale that contained 6 of the original 18 items was used to assess enjoyment during the activities (see Appendix C1). These items were selected because they were the most relevant to the study aims. Individuals rated the extent to which they agreed with each item on a 7-point Likert scale, and responses were added to give a score ranging from 5 to 42 for each activity. Finally, a percentage enjoyment score was calculated. The PACES has been found to be reliable and valid in PA environments (Kendzierski & DeCarlo, 1991; Motl *et al.*, 2001; Carraro *et al.*, 2008; Dunton *et al.*, 2009). Reliability of the 6 items was high for each activity using pooled data from the 2 gender groups (Cronbach's alphas ≥ 0.942). The 15 point Borg scale was used to determine participants' level of perceived exertion(Borg, 1982) .

4.2.9. Physiological measurements

Oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (RER), minute ventilation ($\dot{V}_E$), METs, EE and HR while seated were measured during and for 20-mins after each trial. All physiological parameters measured during the trial were averaged every 10 min and for the duration of the trial (30 min).

The rate of EE was estimated using the Consolazio *et al*. (1963) formula:

$$\text{Rate of EE (Kcal/min)} = (3.78^{*}+ \dot{V}O_2) + (1.16^{*}\ \dot{V}CO_2),$$

where $\dot{V}O_2$ = oxygen uptake ($L^{\cdot}min^{-1}$) and $\dot{V}CO_2$ = carbon dioxide ($L^{\cdot}min^{-1}$). There is a methodological difference between this study and studies 1 and 3. Energy expenditure and rate of EE were estimated in studies 1 and 3 using the Weir equating, as opposed to the Consolazio et al formula. But there is no statistical significant difference between values obtained with both formulas.

The %HRR and $\dot{V}O_2R$ were calculated as previously described in Chapter III.

4.2.10. Statistical analysis

All figures and tabular values are reported as the mean ± SD. All data were tested for normal distribution with the Shapiro-Wilk test. Sphericity was assessed for each of the variables and the Greenhouse and Geisser's correction for the degrees of freedom was applied when sphericity was not met. To investigate differences within subjects by trial and by time within each trial, a mixed design ANOVA was performed. Gender was included as a between subjects variable. Multiple comparisons tests were corrected using the Bonferroni method. For a comparison of overall means of the two groups, paired t-tests were used. For those variables that did not meet parametric statistics assumptions (enjoyment and RPE), a Wilconxon signed rank test was used. Unpaired t-test were used to detect significant differences on subject characteristics. The relationship between enjoyment and RPE was determined by Pearson's product correlation coefficient. IBM SPSS v.19 (SPSS, Inc. USA) was used to analyse the data and the level of significance was set at $P < 0.05$.

4.3. Results

4.3.1. Participant characteristics

The physical characteristics of the participants are summarised in Table 4.1. As expected, there were some differences between the males and females that took part in this study. Males were significantly taller, heavier, and had a higher $\dot{V}O_2$ max and PPO than the females. The males were also significantly older than the females.

Table 4.1 Physical characteristics and cardiorespiratory responses during the maximal bike test.

	Male (n=18)	**Female (n=16)**	**All (=34)**
Age (yr)	28±7*	22±4	25±6
Height (m)	1.7±0.0*	1.6±0.1	1.7±0.1
Body mass (kg)	78.5±8.5*	66.1±9.7	72.6±10.9
BMI (kg$\cdot$m^{-2})	25.3±3.1	23.9±3.4	24.6±3.3
Resting HR (beats$\cdot$min^{-1})	62.7±10.0*	72.9±13.2	67.5±12.5
HRmax (beats$\cdot$min^{-1})	185.9±9.0*	189.8±14.0	187.7±11.6
$\dot{V}O_2$peak (mL$\cdot$kg^{-1}.min^{-1})	39.9±5.2*	29.9±5.2	35.2±7.2
%$\dot{V}O_2$peak @ VT	63±9.1	66.4±10.7	64.6±9.9
Peak PO (W)	263.3±36.0*	174.7±26.6	221.6±54.8
55% PPO (w)	143.9±20. 7*	96.1±14.6	121.5±130

Data presented as mean ± SD. * significantly different than female values (*P* <0.05). HRmax: maximal heart rate, $\dot{V}O_2$peak (mL$\cdot$kg$^{-1\cdot}$min^{-1}): rate of maximal oxygen uptake (millilitres per kilograms per min), PPO (W): peak power output in watts.

4.3.2. Physiological responses

There were no statistically significant differences in resting $\dot{V}O_2$ for the Conventional trial (M=3.99, SD=0.75) and for the GameBike trials (M=4.10, SD=0.96); t(32)=-0.643, *P*=0.525. We obtained similar results for resting HR, and EE between the conventional and GameBike trial.

4.3.2.1. Oxygen uptake

A significant effect of trial ($P < 0.05$, partial $\eta^2 = .166$) and time ($P < 0.01$), partial $\eta^2 = .678$) for oxygen consumption was idenfied. On average, participants had a significantly higher %$\dot{V}O_2$peak during the GameBike trial at 10 min average (*M* = 69.12, *SE* = 1.40) than during the Conventional trial (*M* = 65.28, *SE* = 1.25, *t*(33) = -3.60, *P* <0.05), *r* = 0.53). In addition to this, participants had significantly higher %$\dot{V}O_2$peak during the whole 30 min average in the GameBike trial (*M* = 71.06, *SE* = 1.34) than during the Conventional trial (*M* = 68.48, *SE* = 1.26, *t*(33) = -2.48, *P* <0.05), *r* =.39).

The %$\dot{V}O_2$peak was also higher after 20 min than 10 min for both conditions (*M*=3.66, *SE*= 0.451, *P* <0.01) but there were no differences between 20-30 min averages. Similar patterns were observed for $\dot{V}O_2$R.

Table 4.2. Physiological responses to stationary conventional cycling and GameBike cycling.

	Conventional	**GameBike**
HRmax (%)	81.5±6.7	82.5±7 .0
HRR (%)	71.5±10.1	72.7±10.1
% $\dot{V}$O2peak	68.5±7.4	71.1±7.8*
$\dot{V}O_2$R (%)	64.7±8.1	68.2±9.2*
Rate EE (kcal·min^{-1})	8.5±1.9	8.8±1.9*
TEE (kcal)	254.4±58.6	260.9±60.7
VT (%)	7.6±17.9	11.9±18.4*
Cadence(rpm)	84.9±17.7	85.4±23.5

Data are presented as, mean ± SD, (n=34). HR: heart rate, % HRmax percentage maximal heart rate, HRR(%) percentage heart rate reserve, $\dot{V}O_2$ oxygen uptake, $\dot{V}O_2$R oxygen uptake reserve, REE (kcal·min^{-1}) rate of energy expenditure, TEE (kcal) total energy expenditure, MET metabolic equivalent of the task, % VT: percentage above the ventilatory threshold. * Significantly different (*P* <0.05).

4.3.2.2. Heart rate

There were no statistically significant differences between the Conventional trial and the GameBike trial in %HRmax or HRR. Percentage HRmax increased significantly over time in both conditions ($P < 0.01$), partial $\eta^2 = 0.777$). There were no differences in cadence between the trials.

4.3.2.3. Energy expenditure

The GameBike trial resulted in a significantly higher rate of EE than the conventional trial, (*M*=0.316, *SE*= 0.135, $P < 0.05$). Paired-t-tests revealed that participants had a higher rate of EE during the GameBike trial (*M* = 8.54, *SE* = 0.30) than during the conventional cycling trial (*M* =8.11, *SE = 0.30, t(33)* = -3.23, $P < 0.05$, r = .49) at the 10 min average. The difference in the rate of EE between GameBike and Conventional trials approached statistically significant values for 20 min average ($P = 0.059$) and for total EE ($P = 0.07$). The rate of EE increased over time in both conditions ($P < 0.01$), partial $\eta^2 = .720$). The 10-min averaged rate of EE, along with the rate of EE for the 30-min trial is presented in Figure 4.3.

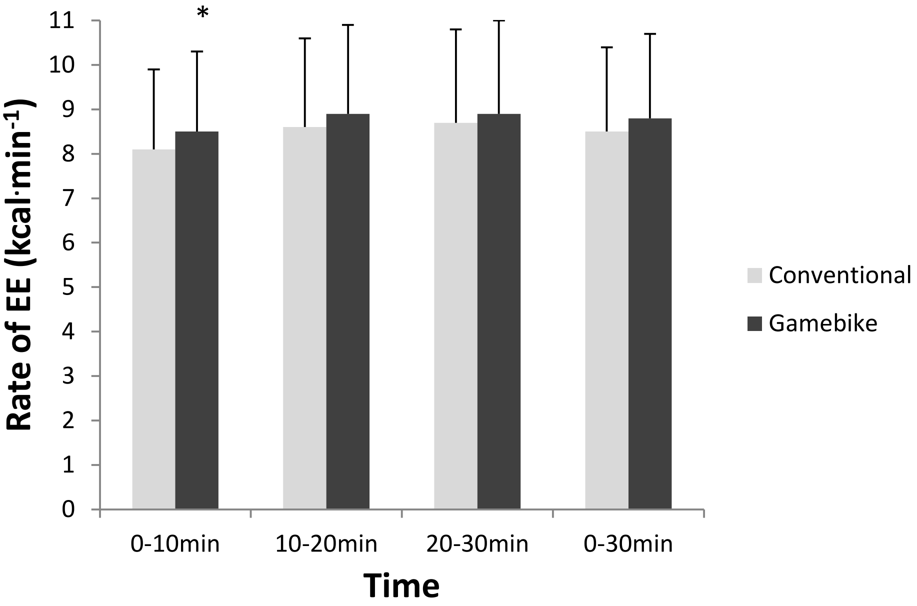


Figure 4.3. Rates of energy expenditure during GameBike and Conventional cycling trials. Comparison of 10 min and 30 min averages of rates of energy expenditure during GameBike and Conventional cycling trials(kcal·min^{-1}) . * Significant difference ($P < 0.05$).

4.3.2.4. %$\dot{V}O_2$peak at ventilatory threshold

On average, participants were working at a higher %$\dot{V}O_2$peak above the VT during the GameBike trial (*M* = 11.86, *SE* = 3.08) than during the Conventional cycling trial (*M* = 7.55, *SE* = 3.16*, t(33)* = -2.69, *P* < 0.05, r = .42)

4.3.3. Psychological responses

4.3.3.1. Enjoyment

Repeated measures ANOVA revealed a significant effect of trial (*P* < .001, partial η^2 = 0.680) and time (*P* < .001, partial η^2 = 0.499). During the GameBike trial participants reported greater levels of enjoyment than the conventional trial (*M* = 23.95, SE = 2.90, *P* < 0.001). Mean enjoyment decreased over time in both trials, with significant differences from 10 to 20 min (*M* = 5.51, SE = 1.10, *P* < 0.001), 10 to 30 min (*M* = 8.38, *SE* = 1.55, *P* < 0.001), and 20 to 30 min (*M* = 2.87, *SE* = 1.09, *P* = 0.038) but there was no effect of trial. When overall ratings were compared across the two conditions, enjoyment was higher in the GameBike than in the conventional condition (*t* = 6.21, *P* < 0.001).

There was also a significant effect of gender in the enjoyment responses (*P* = 0.046), with men reporting higher levels of enjoyment across trial and time periods.

4.3.3.2. Ratings of Perceived exertion

The rating of perceived exertion increased at each 10-min interval during the trials (*P* < .001, partial η^2 = 0.837) and there was no effect of trial (*P* = 0.507), see Table 4.3. For overall ratings, no difference was found for perceived exertion (*t* = -0.705, *P* = 0.486) and no gender differences were observed.

A negative correlation between RPE and enjoyment was identified in the conventional trial, -0.498, *P* < 0.01. However, this relation was not present in the GameBike trial. Further analysis revealed that RPE could account for only 24.8% of the variability in enjoyment during the conventional trial.

Table 4.3. Psychological responses during the Conventional and GameBike trials.

	Conventional			GameBike		
	Male	**Female**	**Total**	**Male**	**Female**	**Total**
RPE						
10 min	11.3±1.8	11.4±1.6	11.4±1.7	10.6±1.4	11.6±2.1	11.1±1.8
20 min	13.2±1.8	14±1.9	13.6±1.8	12.6±1.6	14.2±1.6	13.3±1.8
30 min	14.3±1.8	15.4±2.4	14.8±2.2	13.9±1.8	15.9±2.2	14.8±2.2
Average	12.9±1.6	13.6±1.8	13.2±1.7	12.4±1.4	13.9±1.8	13.1±1.8
Enjoyment (%)						
10 min	46.8±15.8	43±10.3	45±13.5	73±16*	65.2±11*	69.3±14*
20 min	43.8±14.5	35.7±12.5	40±14	66.7±17*	59.8±11.2*	64±14.5*
30 min	41.7±17.3	31.4±11.4	37±15.5	65.5±18*	56±18*	61±18.5*
Average	44.1±15.2	36.7±10.6	42±13.6	68.4±16*	60.3±11.8*	63.4±17*

Data are presented as mean ± SD, (n=34). * Significantly different (*P* <0.01).

4.4. Discussion

The main finding of this study was that a bout of AVG cycling resulted in significantly higher rates of EE, % above VT and $\dot{V}O_2$ when compared to a bout of conventional cycling at a matched workload. A secondary finding was that the interactive video game cycling condition resulted in significantly higher ratings of enjoyment that the conventional cycling condition despite the fact that there were no differences in RPE.

The mechanisms by which the interactive video game cycling produced higher rates of EE and higher relative oxygen are likely to be of a varied nature. Firstly, participants were using their upper bodies to steer the handlebars during the game and this is likely to increase $\dot{V}O_2$ and EE due to the larger muscles mass recruited during this activity. Both trials required upper body muscle recruitment for stability but steering was not possible in the conventional cycling condition. Secondly, the interactive video game trial could have provided distraction from the physical discomfort of playing the game as it provided both visual and audio interaction. This may have allowed for greater metabolic and cardiovascular responses to this trial. There is evidence that music has a beneficial effect on athletic performance and masks unpleasant feelings associated with intense exercise (Becker *et al.*, 1994; Bharani *et al.*, 2004). Thirdly, the game condition was likely to induce an increased state of arousal due to the visual and auditory stimulation experienced while playing the interactive game. However, both HR and cadence were similar between trials so it is unlikely that arousal caused the difference in the metabolic responses. This contrasts with the study by Warburton *et al*. (2009) in which the interactive video game condition resulted in 9% higher cadence than the traditional cycling condition. The authors cited this factor as one of the causes of higher metabolic requirements during the interactive video game condition than during traditional cycling.

A number of studies have looked at the acute effect of adding a video game to stationary cycling in diverse populations (O'Connor *et al.*, 2001; Haddock *et al.*, 2009; Warburton *et al.*, 2009; Kraft *et al.*, 2011). Haddock et al (2009) reported a significantly higher difference in the net increase in EE (Gross energy kcal$\cdot$min^{-1} minus resting kcal$\cdot$min^{-1}) during the interactive video game cycling condition than during conventional cycling. Similar to our findings, Haddock *et al*. (2009) did not find any significant differences in average HR and RPE between conventional and interactive video game cycling in 7-14 year old children. This means that participants perceived the AVG condition to be as tiring as the conventional exercise condition, but their EE was higher during the gaming condition than during the exercise condition. The use of interactive video game cycling received further support with a study by O’Connor *et al.* (2001). These authors compared fifteen individuals with different levels of spinal injury during standard wheelchair ergometry and wheelchair ergometry with a video game (similar to the GameBike in concept). They reported higher oxygen consumption and ventilation rates during the video game condition, despite similar HR responses during both trials.

Warburton *et al.* (2009) compared metabolic requirements of interactive video game cycling and traditional cycling at 25%, 50% and 75% of peak power output (PPO). Participants exercised on two separate days at three incremental stages using a constant workload for 5 min with 5 min rest intervals. Significantly higher HR, $\dot{V}O_2$ and rates of EE at 25% and 50% of PPO, but not at 75% of PPO were reported during the interactive video game when compared to conventional cycling. While this study has reported significant differences in $\dot{V}O_2$ and rates of EE, the differences in HR, $\dot{V}O_2$ and rates of EE at 25% and 55% reported by Warburton *et al.* (2009) are higher than those reported in the current study. This may be explained by the fact that participants in the current study cycled at their own chosen cadence for the duration of the trial while in Warburton *et al.* (2009) study, participants had to pedal at set frequencies throughout the game as part of the competition. In addition to this, participants in the current study performed continuous exercise for 30-min while Warburton *et al.* (2009) used discreet 5-min intervals. Despite the difference in magnitude of differences in the physiological variables measured compared to stationary cycling, participants in both studies were exercising at a vigorous exercise intensity during interactive video game cycling. Our study builds on the findings by Warburton *et al.* (2009) as it used a longer protocol and measured an important parameter of the affect contruct, enjoyment. An assessment of the intensity while cycling in both trials from a metabolic viewpoint (%VT) was also carried out and analysed these results in the context of enjoyment ratings.

One important finding in this study was that the interactive video game condition resulted in significantly higher ratings of enjoyment (63.4% ± 16.5) than the conventional cycling condition (42% ± 13.6). The reason behind this difference in enjoyment rating could be the challenge presented in the video game condition and the visual and auditory stimulation that the game involved.

This challenge and sensory stimulation might have contributed to an increased state of flow in the interactive video game condition. It has been documented that video games and sports are two domains in which the state of flow occurs (Csikszentmihalyi, 1990; Cowley *et al.*, 2008), and this state of flow is considered to be very important in the affective attitude (Csikszentmihalyi, 1990; Hanin, 1999). Unfortunately, the state of flow was not measured in this study but it was included as a variable in the final experiment. No differences were found in RPE, and these results are in agreement with those from other studies (Haddock *et al.*, 2009; Warburton *et al.*, 2009), but a negative relationship between RPE and enjoyment in the conventional trial was found, meaning that as RPE increased, enjoyment decreased. This relationship was not present in the GameBike trial. The interactive video game cycling used in the present study led to a more enjoyable experience than conventional cycling exercise. This may have important implications for a public health perspective since there is evidence supporting a positive impact of enjoyment on PA participation (Salmon *et al.*, 2003; Sorensen, 2005; Hagberg *et al.*, 2009).

Another finding of this study was that, interestingly, participants were exercising at a higher intensity relative to their individual ventilatory threshold during the interactive video game cycling condition (11.78% above VT) than during the conventional cycling condition (7.56% above VT). In spite of this, the AVG cycling resulted in enhanced affect states as the higher enjoyment rates shows (see table 4.3) and there were no differences in rates of perceived exertion between the two conditions. This finding seems to contradict one of the main tenets of the dual mode theory (Ekkekakis, 2009a). According to dual mode theory, affective responses to exercise are influenced by the continuous interplay of cortically mediated cognitive processes (e.g., self-efficacy, self-presentational concerns, goals, attributions) and ascending interoceptive cues (e.g., ventilation, acidosis, core temperature). Positive affective states decrease as the VT stage is reached and passed. Results from this study show that enjoyment levels were not negatively affected by a more stressful physiological state brought upon by high intensity exercise during gaming. It is possible that the audio-visual stimulation brought upon by playing the AVG worked as an effective distraction from the ascending interoceptive cues that increasing exercise intensity is associated with. As result of this, the enjoyment ratings during the conventional cycling conditions were significantly lower than during the AVG condition but participants were working at a significantly lower metabolic stress condition during the conventional cycling condition.

The present study has some limitations. Firstly, the sample size was too small to allow for powerful gender comparisons for the main outcome variables. Secondly, all testing took place in an artificial laboratory setting as opposed to a familiar home setting where AVG play usually takes place. Finally, VT calculation presents some methodological challenges and there can be some investigator bias that lead to differences in results. We did try to minimise this bias by getting two experts to calculate the VT and using the function to calculate the VT available in the Innocor software in a supportive manner.

4.5. Conclusion

In conclusion we have found that an acute bout interactive video game cycling resulted in higher metabolic and cardiovascular responses, but lead to higher enjoyment ratings than a similar bout of conventional cycling. This study shows that interactive video game cycling might be an effective strategy to encourage adults to increase PA levels and it could lead to higher adherence rates than conventional cycling exercise. This study allowed for a direct comparison of conventional exercise in the form of cycling with an AVG that involved the same mode of exercise using the same ergometer. But there is a considerable variety of AVGs in the market and generalisation should be avoided. Assessing other AVGs usefulness to increase PA levels is necessary. On top of this, there are AVGs that are sold as a fitness games as opposed to games that qualify as AVGs but do not have a fitness purpose. It is recommended to test the physiological, psychological and affect impact of these games in adults to determine if they can lead to health enhancing PA.

CHAPTER V

Study 3: Flow, enjoyment and energy expenditure during conventional exercise and active video game play

5.1 Introduction

From a public health perspective, increasing population PA levels and reducing sedentary time is a desirable outcome to pursue given that both are modifiable risk factors for chronic disease (Warburton *et al.*, 2006; Booth *et al.*, 2008). However, a high percentage of the population is physically inactive and is engaged in high volumes of sedentary behaviour. The determinants and correlates of PA participation and adherence are multifactorial and complex. One of these correlates is enjoyment and the affective response to PA.

The Hedonic or pleasure principle (Higgins, 1997) proposes that individuals decide to take part in activities from which they gain pleasure and avoid activities that bring about pain. Williams *et al.* (2008) showed that affective responses to a moderate intensity exercise was a good predictor of exercise behaviour 6 to 12 months later. In addition, an individual's perception of effort for a given activity is, to a certain extent, a determining factor of exercise adherence (Faulkner J, 2008). Affect states and perception of effort during an acute exercise session are likely to be determinants of intention and future exercise behaviour. According to Wankel (1993), enjoyment plays a central role in the promotion of exercise adherence and improving psychological well-being. Several studies have shown the importance of enjoyment in order to achieve a high degree of adherence to the activity (Salmon *et al.*, 2003; Sorensen, 2005; Hagberg *et al.*, 2009). Negative affect states can be a contributing factor to the 40-65% of dropout rates within the first 3-6 months of commencing an exercise programme (Dishman & Buckworth, 1996; Annesi, 2001). Vazou-Ekkekakis (2005) suggest that " the optimization of affective response should be taken into account when recommending or prescribing PA to the public" (Vazou-Ekkekakis, 2005). Another factor that can contribute to increased or decreased exercise adherence is the freedom individuals experience in deciding the PA they are engaging in. The self-determination theory (SDT) suggests that autonomy (power to make their own choices) is one of the three basic psychological needs (competence and relatedness are the other two) that are essential for individual well-being (Deci & Ryan, 1987; Deci & Ryan, 2000). According to SDT theory, when an individual feels autonomy they are intrinsically motivated and this might result in higher adherence rates to exercise programmes. The dual-mode model theory by Ekkekakis (2003; Ekkekakis *et al.*, 2011) suggests that affective responses to exercise are influenced by the continuous interplay of cortically mediated cognitive processes (e.g., self-efficacy, self-presentational concerns, goals, attributions) and ascending interoceptive cues (e.g., ventilation, acidosis, core temperature). Positive affect states decrease as the VT stage is reached and passed. The on-going debate in exercise science regarding the main determinants of adult PA participation is likely to be the focus of many research efforts, given its importance for public health. In any case, there is a need to reverse the trend of physical inactivity in the whole population and that of declining PA levels as the population ages.

The efforts to increase population PA levels and reduce sedentary time requires assessment of the efficacy of different activities or strategies to attain these two outcomes. There is potential for a relatively new type of video games to have a tangible impact on both increasing PA and reducing sedentary time. There is some evidence that these games result in moderate and vigorous exercise intensities (Warburton *et al.*, 2009; Graves *et al.*, 2010a; Miyachi *et al.*, 2010; Lyons *et al.*, 2011). There are still a lot of unanswered questions about the effect of this technology on health in the medium-long term, and also, it remains to be determined how these games compare with conventional exercise that has accepted health benefits. There has been an explosion in the number of AVGs on the market over the last few years. There are games that are marketed as fitness games and others that are active games but not fitness-themed. The fitness AVGs are sold with the primary purpose of increasing fitness levels, while the generic AVGs require the player to get off the couch and move to be able to play. The physiological stimulus that these different types of games exert on a healthy sedentary population is unclear. Self-selected intensity PA is a promising strategy to promote PA participation since it results in more positive affect states than more regimented PA programmes (Vazou-Ekkekakis, 2005; Ekkekakis, 2009b).

The purpose of this study was to compare the acute physiological and affect responses during AVGs (fitness-themed and entertainment-themed) and conventional exercise. The study was designed to investigate the relationship between affect states (enjoyment, psychological well-being and state of flow) and the exercise intensity. Our hypothesis is that the AVGs will result in similar rates EE and more positive affect states than conventional moderate exercise intensity.

5.2 Methods

5.2.1. Participants

Twenty three young, healthy participants volunteered to participate in this study. All participants completed a PAR-Q, and a general health questionnaire. The physical characteristics of the participants are summarised in Table 5.1. Body mass index was calculated from height, measured to the nearest 0.1 cm, and weight, to the nearest 0.1 kg (Seca Ltd, model 778, Germany). Body fat was analysed by bioelectrical impedance resistance, (Tanita Body Composition Analyser, TBF-300, Tanita Health Equip, Hong Kong, Japan) on the first day of participants reporting to the laboratory. Inclusion criteria for the study were as follows: 1) healthy male or female aged 18-45 years, 2) non-smoker, 3) consistently low level of participation in physical activities for the last 6 months (no more than once a week), 4) had a $\dot{V}O_2$peak below the top 40% of the population matched for age and gender (i.e. below the 60th percentile based on ACSM's norms).

Participants had a broad range of experience and ability playing AVGs so a familiarisation session was provided. All testing sessions took place at the High Performance Laboratory at the School of Health and Human Performance at

Dublin City University. An informed consent form was signed by all participants prior to their participation in the study. The study was approved by the Dublin City University Research Ethics Committee and complied with the declaration of Helsinki.

5.2.2. Experimental overview

Participants reported to the laboratory at Dublin City University on 6 different days separated by at least 48 h (see Figure 5.1.). On day 1 of testing, participants signed an informed consent, PAR-Q, and medical questionnaires and carried out an incremental maximal test on a treadmill to determine $\dot{V}O_2$max. On day 2, participants attended the laboratory for a familiarisation session. They first exercised on a treadmill to determine the speed for the moderate intensity exercise trial and then played the AVGs. After this, participants reported to the laboratory on four separate days to take part in two exercise trials and two gaming trials. The order of visits 3, 4, 5, and 6 was randomized. All experimental trials lasted 60-min, and included 10 min of seated rest, 30 min gaming or conventional exercise and 20 min seated rest. Participants were asked to refrain from consuming alcohol for at least the 24 h prior to each visit to the laboratory and from the ingestion of food, coffee and tea (except water) for 3 h before the test.

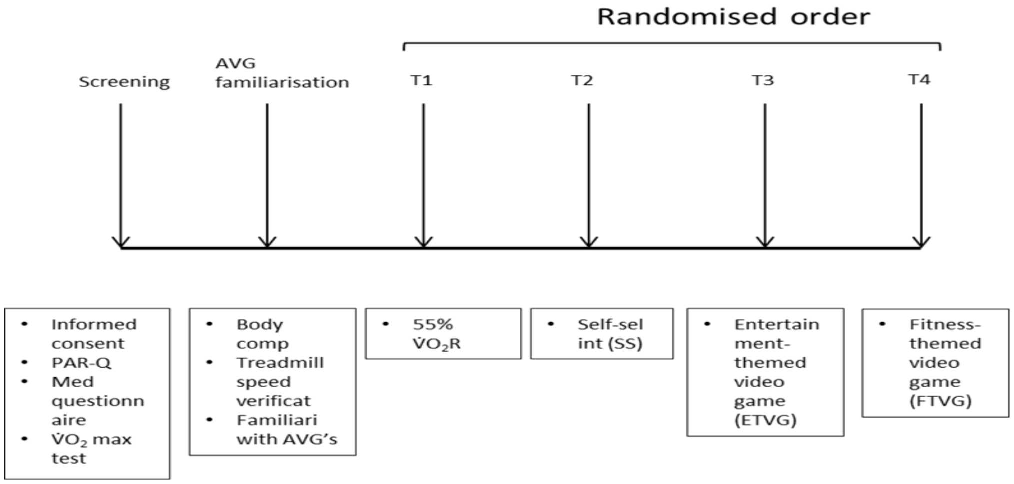


Figure 5.1: Schematic of study 3 protocol.. All visits were interspersed by at least 48 hr.

5.2.3. Maximal Oxygen uptake test

An incremental treadmill test (Woodway ELG55, Woodway USA Inc, Waukesha, USA) was used to determine $\dot{V}O_2$ max using open-circuit spirometry (K4B2, Cosmed, Rome, Italy). Prior to each test the K4B2 system was volumetrically calibrated using a 3 L Hans Rudolph syringe, and the O_2 and CO_2 analyzers were calibrated using ambient air (20.93% O_2, 0.03% CO_2), and gases of a known concentration (16% O_2, 5% CO_2). Participants were also fitted with a HR monitor (Polar RS400, Polar, Oulu, Finland) to monitor HR telemetrically. Baseline data collection was performed for 3 min followed by an incremental stage protocol. The protocol used consisted of 2 min incremental stages until the participant reached volitional fatigue. Initial speed and increments were individualised with the purpose of resulting in a test lasting between 8 and 12 min as in the first study. $\dot{V}O_2$ was considered to have peaked if two of the following criteria were met: (i) a levelling off of $\dot{V}O_2$ with increasing treadmill speed (an increase of less than 2 $mL \cdot kg^{-1}.min^{-1}$); (ii) a HR within 10 beats of the age predicted HRmax (220 $beats \cdot min^{-1}$ – age in years); (iii) a RER greater than 1.10. Expired gases (O_2 and CO_2) and ventilatory parameters were averaged every 20 s and the average of the three highest consecutive 20 s values was taken as the $\dot{V}O_2$max. Rate of perceived exertion were also measured using the 15 point category Borg scale. Individual VT was calculated by the function available in the Cosmed K4B2 software. This calculation is based on the V-slope method (Beaver *et al.*, 1986) as described in section 4.2.4 of chapter IV.

5.2.4. Familiarisation and verification of speed associated with 55% $\dot{V}O_2R$ session.

Participants reported to the laboratory on day 2 of the study after a 10-hr fast to determine percentage body fat by bioelectrical impedance resistance. Participants were fitted with the HR monitor and the portable metabolic unit before exercising on the treadmill for at least three different speeds for 10 min each to determine velocity associated with 55% $\dot{V}O_2R$. The treadmill speed required to elicit 55% $\dot{V}O_2R$ was interpolated based on the linear relationship between $\dot{V}O_2$ (*y*-axis) and treadmill speed (*x*-axis). For a given percentage of $\dot{V}O_2R$, the corresponding speed was estimated by solving for *x* using the linear function, $y=mx+c$, where *y* is $\dot{V}O_2$, *x* is treadmill speed, *m* is the slope of the relationship between $\dot{V}O_2$ and treadmill speed and *c* is the y-axis intercept. When the speed corresponding to 55% $\dot{V}O_2R$ was determined, participants were shown the two different AVGs used in this study. They had a chance to play all the different mini games used in this study as part of a FTVG and an ETVG.

5.2.5. Active video game conditions

Participants sat in an upright position for 10min before playing the entertainment-themed video game (ETVG) or the fitness-themed video game (FTVG) on XBOX 360 Kinect (Microsoft Corp, Redmond, USA). In the ETVG trial, subjects played three mini games of the Kinect Adventure games (Microsoft Corp, Redmond, USA). They played 'River Rush' three times at advanced level, 'Rally Ball' (once at intermediate and twice at advanced level) and 'Reflex Ridge' (once at intermediate level and twice at advanced level. On a separate day, participants played FTVG 'Your Shape Fitness Evolve 2012' (Ubisoft, Surrey, UK). They played 'Wall Breaker' at advanced level, 'Run The World' and 'Jump Rope Hard' at advanced and extreme level and 'Cardio' (Legs, Burn & Shape D) for the remaining time, up to a maximum of 30min. Immediately after this, participants sat down and filled in the psychological questionnaires detailed later in this section. Participants were actively playing for 23 ± 1.7 min and 19.45 ± 1.58 min of the ETVG and the FTVG respectively. This means that participants were active for 76.8% and 64.4% of the 30 min during the ETVG and the FTVG.

5.2.6. Exercise trials

Participants reported on two separate days to take part in a Self-Selected (SS) or a 55% $\dot{V}O_2R$ trial. In the SS trial, participants were told that they could select the speed of the treadmill for the first min of every 5 min block while the gradient was kept constant at 1%. Subjects were told to select an intensity that they would be happy to exercise at for 30min and were made aware that they could alter speed every 5 min. In the 55% $\dot{V}O_2R$ trial, participants exercised at a constant speed that was determined during a verification session.

5.2.7. Physiological measurements

Physiological variables measured included $\dot{V}O_2$, carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (RER), ventilation ($\dot{V}_E$), EE and HR for 10min while seated before playing or exercising and during the gaming/exercise part (30 min) of the trial.

The last 3 min of the 10 min baseline phase were averaged to calculate baseline values. We averaged all physiological variables for the first 15 min, the final 15 min and the whole 30 min session.

The rate of EE was estimated using the following formula as calculated by the Cosmed K4B2 metabolic system (Elia & Livesey, 1992):

EE ($kcal \cdot min^{-1}$) = ($3.781 * \dot{V}O_2$) + ($1.237 * \dot{V}CO_2$) if UN (ureic nitrogen) = 0.

where $\dot{V}O_2$ = oxygen uptake ($L \cdot min^{-1}$) and $\dot{V}CO_2$= carbon dioxide ($L \cdot min^{-1}$)

The % HRR and the $\dot{V}O_2R$ were calculated as described previously in section 3.2.5. of chapter III. The % $\dot{V}O_2$ max above or below the VT was calculated as described previously in chapter IV.

5.2.8. Psychological measurements

5.2.8.1 Enjoyment

The Interest/enjoyment subscale of the Intrinsic Motivation Inventory was used to measure enjoyment. This scale has been used in other interactive video game studies (Ijsselsteijn *et al.*, 2006; Lyons *et al.*, 2012), and exercise studies (Garcia-Mas *et al.*, 2010) and is reliable and valid (McAuley *et al.*, 1989).

Participants ranked their agreement with each statement on a Likert-type scale of one to seven at 15-min during the exercise or game and immediately after finishing the activity. Responses were averaged to create the enjoyment score (range = 1–7). At 15-min, subjects were asked to step off the treadmill or stop playing while they filled in the scale. Reliability of the 7 items was high for each activity using pooled data from the 2 gender groups (Cronbach's alphas between 0.89 and 0.93).

5.2.8.2 Perceived exertion

The participants' rate of perceived exertion was measured with the 15 point Borg Rate of perceived exertion scale (RPE scale)(Noble *et al.*, 1983) at minutes 15 and 29 during the exercise and the gaming trials.

5.2.8.3. Psychological Well-Being

This state was measured with the Subjective Exercise Experience Scale (SEES). This is a 12-item questionnaire that is scored on a 7-point Likert-type scale anchored with "Not at all" and "Very much so." The SEES provides three subscales: 1) psychological well-being (great, positive, strong, terrific); 2) psychological distress (awful, crummy, discouraged, miserable); and 3) fatigue (drained, exhausted, fatigued, tired). The SEES has demonstrated adequate reliability for psychological well-being, with Cronbach alphas ranging from 0.84 to 0.92 in the present study. We measured psychological distress and fatigue but we do not report the data since the internal validity for those measures was not acceptable. The SEES scale has been used in previous exercise studies (McAuley & Courneya, 1994; Bartholomew *et al.*, 2005) and video games studies (Douris *et al.*, 2012).

5.2.8.4. State of Flow

Participants filled in the Core Flow State Scale (C FSS) to measure the state of flow. The CFSS (Jackson *et al.*, 2008) contains 10 items that are descriptions of what it feels like to be ‘in flow’. This scale is designed to be used as a post-event flow assessment. Therefore, responses were given as soon as possible after activity completion. Models fit and reliability for this scale has been strong in initial validation studies (Martin & Jackson, 2008). The CFSS resulted in Cronbach alphas ≤0.924.

5.2.9. Statistical analysis

All figures and tabular values are reported as the mean ± SD. All data were tested for normal distribution with the Shapiro-Wilk test. Sphericity was assessed for each of the variables and the Greenhouse and Geisser’s correction for the degrees of freedom was applied when sphericity was not met. To investigate differences within subjects by trial and time within each trial, a mixed design ANOVA was used to analyse the data. Gender was included as a between subjects variable. Multiple comparisons tests were corrected using the Bonferroni method. One way repeated measures ANOVA was carried out to compare average values for the whole trials. Unpaired t-test was used to detect significant differences on subject characteristics. Correlation between enjoyment and VT was assessed by the Spearman’s correlation coefficient and R^2 analysis to determine variability between variables. IBM SPSS v.19 (SPSS, Inc. USA) was used to analyse the data and the level of significance was set at $P < 0.05$.

5.3 Results

5.3.1. Participant characteristics

There are some differences between the males and females as expected. Males were older, taller, heavier and also had a significantly higher $\dot{V}O_2$max compared to the females as shown in Table 5.1. No differences were found for BMI, HRrest and HRmax between the two groups.

Table 5.1. Physical characteristics and cardiorespiratory responses during maximal oxygen uptake test.

	Male (n=11)	**Female (n=12)**	**All (n=23)**
Age (yr)	26.8±5.1*	22.9±3.5	24.8±4.7
Height (m)	1.79±0.1*	1.65±0.1	1.71±0.1
Body mass (kg)	84.8±15.1*	69.1±8.9	76.6±14.4
BMI ($kg.m^{-2}$)	26.4±4.1	25.3±3.1	24.8±6.5
Body fat (%)	19.1±6.5*	32.2±4.8	25.9±8.7
HRrest (beats·min^{-1})	59.8±8.9	62±6.2	61.0±7.7
HRmax (beats·min^{-1})	198.0±6.9	193.8±7.4	195.8±7.3
$\dot{V}O_2$max ($mL^{-1}\cdot kg^{-1}\cdot min^{-1}$)	40.3±3.9*	35.8±3.6	37.9±4.4

Data presented as mean ± SD. * significantly different from female (*P* <0.05). HRrest: heart rate at rest, HRmax: maximal heart rate, $\dot{V}O_2$max: maximal oxygen uptake($mL^{-1}\cdot kg^{-1}\cdot min^{-1}$)

5.3.2. Physiological responses

5.3.2.1. Oxygen uptake

There were no statistically significant differences in resting $\dot{V}O_2$ amongst the four different conditions. All trials reached the criteria for moderate or vigorous intensity PA. Repeated measures ANOVA revealed significant effects of trial ($P < 0.001$, partial $\eta^2 = 0.823$) and time ($P < 0.001$, partial $\eta^2 =0.695$). Percentage $\dot{V}O_2$max was significantly higher during the SS condition than all of the other trials (55% $\dot{V}O_2R$ (*M*=15.99, SE=2.96, *P* < .001); ETVG conditions, (*M*=24.80, SE= 2.71, *P* < .001); FTVG. (*M*=13.29, SE= 2.79, *P* < .005)). The % $\dot{V}O_2$max was similar during 55% $\dot{V}O_2R$ and FTVG and both 55% $\dot{V}O_2R$ and FTVG resulted in significantly higher %$\dot{V}O_2$max than ETVG as shown in table 5.2.

Percentage $\dot{V}O_2$max increased over time across all conditions (*M*=5.54, SE= 0.801, *P* < .001) and an interaction between time and gender *F*(1,21) = 11.33, *P* < .005 was found meaning that % $\dot{V}O_2$max increased to a higher extent in males than females (*P* < .005, partial η^2 = 0.351). We also found an interaction between condition and time *F*(2.59, 54,49) = 7.09 *P* < .005, which means that % $\dot{V}O_2$max increased more across time in the ETVG than in the other 3 conditions. Similar trends were found when we compared % $\dot{V}O_2$max average values and $\dot{V}O_2$R among the different conditions (see Table 5.2. and Figure 5.2).

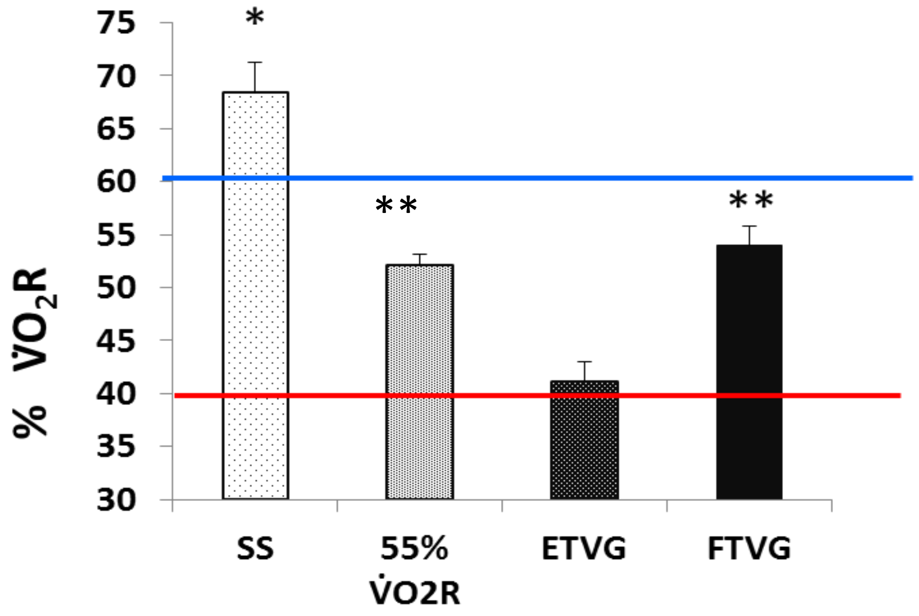


Figure 5.2: Percentage $\dot{V}O_2$R during the 4 different conditions. * Significantly different than 55 % $\dot{V}O_2$R, ETVG, and FTVG $p \leq 0.001$, **Significantly different than ETVG $p \leq 0.001$. Red and blue lines denote cut-off point for moderate and vigorous intensity exercise respectively.

5.3.2.2. Heart rate

There were no statistically significant differences in HRrest amongst the four different conditions. We found a significant effect of trial (*P* < .001, partial η^2 = 0.897) and time (*P* < 0.001, partial η^2 =.872). No differences were found for % HRmax between the SS condition and the FTVG and both were significantly greater than the 55% $\dot{V}O_2R$ and ETVG trials (*P* < 0.001) as shown in Table 5.2. Percentage HRmax increased over time across all conditions except during 55% $\dot{V}O_2R$ as expected (*M*=7.899, SE= 0.662, *P* < 0.001). We did not find any gender effect in the HR response to the different conditions, but a condition and time interaction was found. This means that HR values increased more in SS and ETVG conditions than in the other two conditions. % HRmax average values and % HRR values followed a similar pattern than that reported for % HRmax (Figure 5.3).

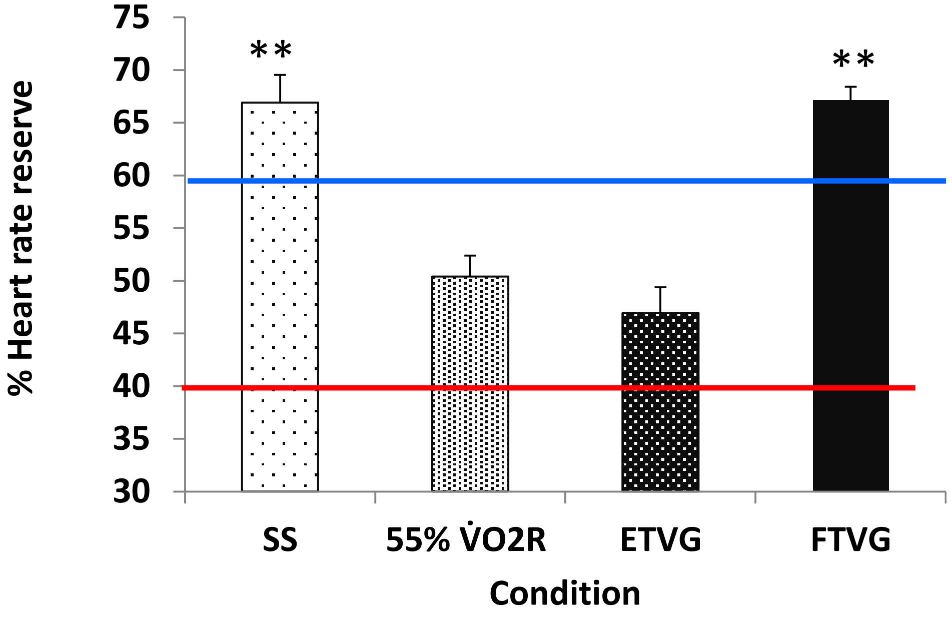


Figure 5.3: Percentage HRmax during the 4 different conditions. **Significantly different than 55% $\dot{V}O_2R$ and ETVG $p \leq 0.001$. Red and blue lines denote cut-off point for moderate and vigorous intensity exercise respectively.

5.3.2.3. Energy expenditure

There were no significant differences in the resting rate of EE amongst the four different conditions. Repeated measures ANOVA (square root data) revealed significant effects of trial (*P* < .001, partial η^2 = 0.801) and time (*P* < 0.001, partial η^2 = 0.721) during the active part of the trial. The self-selected condition resulted in a significant higher rate of EE than 55% $\dot{V}O_2R$ (*M* = 0.354, SE

= 0.062, $P < .001$), ETVG ($M = 0.614$, SE=.071, $P < 0.001$) and FTVG ($M = 0.287$, SE = 0.066, $P < 0.005$). No significant differences were found between 55% $\dot{V}O_2R$ and FTVG (M=.067, SE = 0.053, P =1.00). Both 55 $\dot{V}O_2R$ and FTVG resulted in significantly higher rates of EE than ETVG ($P < .001$). A condition and time interaction effect ($P < .001$) was also found. The rates of EE increased significantly over time in SS and ETVG conditions but not during 55% $\dot{V}O_2R$ and FTVG conditions. A between subjects effect of gender ($P < 0.001$) was also detected, indicating than males had a significantly higher rate EE than females. Total EE during the 30 min game or exercise trials showed a similar pattern in all trials, as shown in Table 5.2. and Figure 5.4.

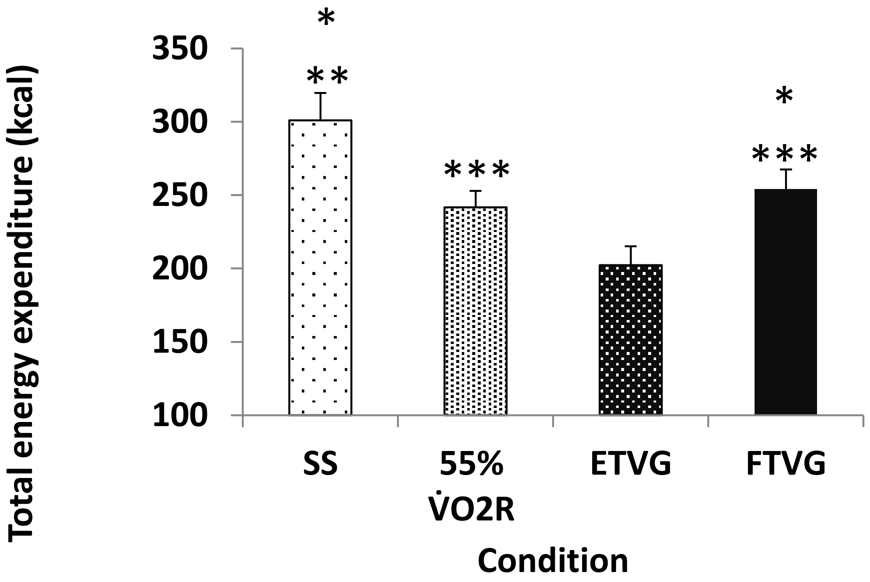


Figure 5.4. Total energy expenditure for the 4 conditions. * Significantly different than 55 % $\dot{V}O_2R$ & ETVG $p \leq 0.001$, ** Significantly different than FTVG $p \leq 0.05$, *** Significantly different than ETVG $p \leq 0.001$.

Table 5.2. Cardiometabolic response to exercise and active video game conditions.

	Self-selected			55% $\dot{V}O_2R$			**ETVG**			**FTVG**		
	Males n=11	**Females n=12**	**Total n=23**	**Males n=11**	**Females n=12**	**Total n=23**	**Males n=11**	**Females n=12**	**Total n=23**	**Males n=11**	**Females n=12**	**Total n=23**
Average HR (beats·min^{-1}) 0-30min	149.7±14.9	152.4±18.2	151.2±16.4a	126.1±14.1	131.7±16.1	129.0±15.1	130.4±20	119.3±13.8	119.4±30.4	152.5±8.1	150.8±12.3	151.6±10.3a
%HRmax 0-30min	75.8±8.6	78.7±8.9	77.3±8.7a	63.6±6.4	67.9±7	65.9±6.9	65.8±9.9	61.4±5.8	60.9±15.1	77±3.3	77.8±5	77.4±4.2a
HRR (%) 0-30min	65.3±11.9	68.5±13.4	66.9±12.5a	47.9±8.4	52.7±10.2	50.4±9.5	51.2±13.3	42.3±9.2	46.5±12	67.1±4.4	67.2±7.4	67.1±6a
Average $\dot{V}O_2$ (mL^{-1}·kg^{-1}·min^{-1}), 0-30min	29.5±5.6	25.5±6.5	27.4±6.3b	23.2±2.9	20.3±3	21.7±3.2c	20.1±4.3	15.9±3.4	17.9±4.4	24.1±3.5	20.4±2.8	22.2±3.6c
% $\dot{V}O_2$max (0-30min)	73±12.1	70.3±13.1	71.6±12.4b	57.5±4.9	56.42±3.9	56.9±4.3 c	49.7±7.8	44.5±7.8	46.9±8.1	60.1±9.2	57.1±6.7	58.6±7.9c
%$\dot{V}O_2$R (0-30 min)	70.7±13.3	66.6±14.8	68.3±13.9b	57.7±6.1	51.4±4.3	52.2±4.8 c	45.3±8.4	38.2±8.5	41.1±8.9	56.8±9.6	52.1±8.1	53.9±8.9c
Total EE 30m (kcal)	350±94.5	256±56.6	300±89.2b	284.9±46.2	202±±16.5	241.7±53.8 c	249.2±52.4	159.2±28.6	202.3±61.4	301.9±55.7	210.3±29.7	254.1±63.6c
Total EE 20 post (kcal)	49.7±12.4	39.5±6.9	44.4±11	45.6±7.9	36.9±4	41.1±7.5	50.4±7.5	34.3±11.3	42±12.5	52±7.4	37.1±4.1	44.3±9.6
EE above baseline in 30 min	303.4±87.8	218±57.7	258.8±84.1b	238.3±42.3	164±16.6	199.5±48.9 c	202.6±48.1	121.2±29.3	160.1±56.6	255.3±49.2	172.3±30.2	212±57.9c
% increase EE over baseline	641.8±115	581±172.2	610±147.6 b	517.7±98.5	434.8±60.3	474.5±89.6 c	437.5±88.6	322.7±89.8	377.6±105.1	548.3±70.1	457.8±97.5	501.1±95.5c
Rate EE, 0-30min (kcal·min^{-1})	12.3±3.1	8.5±1.9	10.3±3.1 b	9.4±1.5	6.7±0.5	8.1±1.8 c	8.3±1.7	5.3±1	6.7±2	10.1±1.9	7±1	8.5±2.1c
MET, 0-30min	8.4±1.5	7.3±1.9	7.8±1.7 b	6.7±0.6	5.8±0.8	6.2±0.9 c	5.8±1.2	4.5±1	5.1±1.2	7±1.1	5.8±0.8	6.4±1.1c
%VT 0-30min	3±10.1	-1.64±16.1	0.58±13.5 b	-17.9±11.2	-20.3±9.8	-19.2±10.3 c	-29.3±11.6	-33.4±12.7	-33.4±12.6	-14.4±14.8	-19.2±13.5	-17±14c

Data presented as mean ± SD. EE: energy expenditure, ETVG: entertainment-themed video game, FTVG: fitness-themed video game, HR: heart rate, HRR: heart rate reserve, , MET: metabolic equivalent of the task (3.5ml·kg^{-1}·min^{-1}), %VT: percentage above or below of ventilatory threshold. Significant sign differences are shown only for statistical comparison of total data. a: significantly different than 55% $\dot{V}O_2R$ and ETVG (*P* <0.05), b: significantly different than 55% $\dot{V}O_2R$, ETVG and FTVG (*P* <0.05), c: significantly different than ETVG (*P* <0.05).

5.3.3. Psychological responses

5.3.3.1. Enjoyment

The repeated measures ANOVA revealed significant effects of trial (*P* < .001, partial η^2 = 0.810) on the enjoyment ratings as shown in Table 5.3. The gaming conditions resulted in significantly greater enjoyment ratings than the exercise conditions (*P* < .001). No significant differences were found in enjoyment ratings between the exercise conditions (*M*=3.41, *SE*=1.86, *P* = 0.481) or between the gaming conditions (*M*=3.91, *SE*=1.70, *P* = 0.194). The between subjects effect of gender was non-significant (*P* = 0.280). Mean enjoyment did not change over time in any of the conditions (*P* < 0.642). A significant relationship between average enjoyment during the trial and %VT only in the SS trial was found (r=.565, *p*<0.005). We found that 31.9% of enjoyment could be accounted for by the variability in intensity in relation to the VT during the SS trial.

5.3.3.2. Ratings of Perceived exertion

Repeated measures ANOVA revealed a significant effect for the condition on RPE levels (*P* < 0.001, partial η^2 = 0.654). SS condition resulted in higher RPE ratings than 55% $\dot{V}O_2R$ (*M*=1.93, *SE*=0.363, *P*< .001) and ETVG (*M*=2.56, *SE*=0.376, *P*< 0.001), but there were no differences compared to the FTVG condition (*P*= 0.219). FTVG condition resulted in significantly higher RPE values than both 55% $\dot{V}O_2R$ and ETVG (*P* < 0.001).

We found a condition and time interaction effect meaning that the rating of perceived exertion increased significantly over time in SS condition (*P* < .005), and ETVG (*P* < .001) but not in 55% $\dot{V}O_2R$ (*P* < 0.428) and FTVG conditions. RPE average values for SS and 55% $\dot{V}O_2R$ did not show any significant difference.

5.3.3.3. State of flow

A significant effect of condition on the state of flow was found ($P < 0.05$, partial $\eta^2 = 0.520$)., with ETVG resulting in higher states of flow than the self-selected and the 55% $\dot{V}O_2R$ conditions as seen in Figure 5.5. There were no differences between males and females.

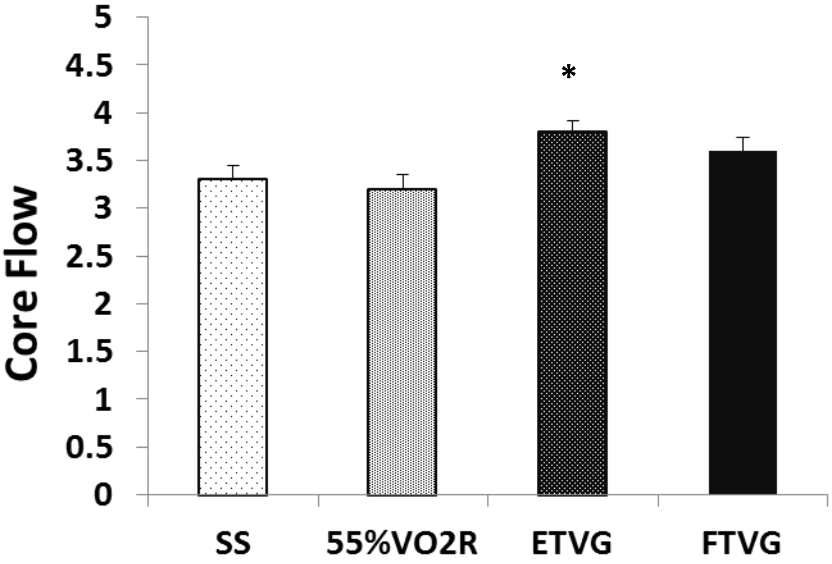


Figure 5.5. State of Flow immediately after the conditions. * Significantly higher ($P \leq 0.05$) than 55% $\dot{V}O_2R$ and SS.

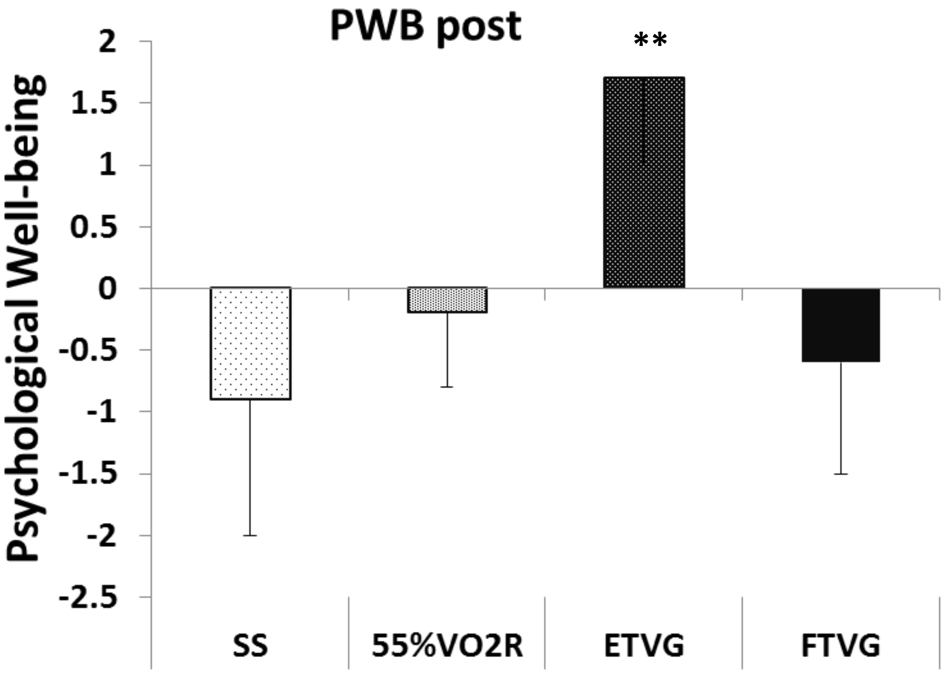
5.3.3.4. Psychological well-being

There were no differences in baseline scores of psychological well-being. A significant effect of condition ($P < 0.05$, partial $\eta^2 = 0.129$) was reported as shown in Figure 5.6. The ETVG also resulted in higher psychological well-being than the other 3 conditions after 20 min but these differences were not significant. There was a significant effect of gender ($P < 0.05$, partial $\eta^2 = 0.257$). Males reported higher psychological well-being scores at all points and the scores increased immediately after the condition except after the FTVG. Female well-being decreased immediately after exercise conditions, increased after ETVG and remained the same after FTVG.

Table 5.3. Psychological and affect responses to exercise and AVGs conditions.

	Self-selected			**$55\%\dot{V}O_2R$**			**ETVG**			**FTVG**		
	Males	**Females**	**Total**	**Males**	**Females**	**Total**	**Males**	**Females**	**Total**	**Males**	**Females**	**Total**
	n=11	**n=12**	**n=23**	**n=11**	**n=12**	**n=23**	**n=11**	**n=12**	**n=23**	**n=11**	**n=12**	**n=23**
RPE15min	11.9±1.2	11.2±1.4	11.5±1.3a	10.1±1.4	9.5±2.1	9.8±1.8c	9.2±1.8	8.1±1.7	8.6±1.8	13.8±1.5	12.4±1.8	13.1±1.8b
RPE 29 min	14.2±1.2	11.9±2.1	13±2a	11.2±1.7	10.7±2	10.9±1.8	11.9±2	9.8±2.6	10.8±2.5	14.1±1.6	11.8±3.1	12.9±2.7a
Average RPE	13±1	11.5±1.1	12.3±1.3a	10.6±1.3	10.1±2	10.3±1.7	10.5±1.7	8.9±2.1	9.7±2	14±0.6	12.1±2.2	13±1.8a
Enjoyment 15 min	3.5±1.1	1.7±1.5	3.6±1.3	3.3±1.2	2.9±1.1	3.1±1.2	5.9±0.9	5.2±1.2	5.5±1.1d	5±1.6	4.8±1	4.9±1.3d
Enjoyment post	3.7±1.3	3.5±1.6	3.6±1.4	3.5±1.4	2.7±1.2	3.1±1.4	6±0.9	5±1.1	5.5±1.1d	5±1.6	5±1	5±1.3d
Enjoyment average	3.6±1.2	3.6±1.5	3.6±1.3	3.4±1.3	2.8±1.1	3.1±1.2	5.9±0.9	5.1±1.1	5.5±1.1d	5±1.5	4.9±1	5±1.2d
Core Flow	3.5±0.7	3.1±0.7	3.3±0.7	3.3±0.8	3.2±0.6	3.2±0.7	3.9±0.7	3.7±0.5	3.8±0.6f	3.6±0.7	3.5±0.6	3.6±0.7
PWB before	21.5±3.6	17.6±5.3	19.5±4.9	21.8±3.6	19.6±4	20.6±3.9	22.2±3.6	17.9±4.5	20±4.6	22±3.1	17.9±4.1	19.9±4.1
PWB post	22.2±3	15.3±5.6	18.6±5.7	22.5±3.7	18.4±4.8	20.4±4.7	23.4±2.5	20.3±3.3	21.7±3.3e	21±4.8	17.8±4.2	19.3±4.7
PWB 20min post	22.2±2.3	18.3±6.5	20.2±5.3	22.8±3.3	18.5±5.7	20.6±5.1	21.4±3.7	20.3±4.5	20.8±4.1	21.9±2.9	18.1±.5.5	19.9±4.8

Data presented as mean ± SD. ETVG: entertainment-themed video game, FTVG: fitness-themed video game, RPE: rate of perceived exertion, PWB: psychological well-being. Significant sign differences are shown only for statistical comparison of total data. a: significantly different than 55% $\dot{V}O_2R$ and ETVG (P <0.05), b: significantly different than SS, 55% $\dot{V}O_2R$ and ETVG (P <0.05), c: significantly different than ETVG (P <0.05), d: significantly different than SS and 55% $\dot{V}O_2R$ (P <0.05), e: significantly different than SS, 55% $\dot{V}O_2R$ and FTVG (P <0.05) and f: significantly different than SS and FTVG (P <0.05).



Figures 5.6. Differences in psychological well-being immediately after the condition. ** Significantly higher (*P* ≤ 0.05) than SS, 55% $\dot{V}O_2R$ and FTVG.

5.4 Discussion

The principal finding of this study was that it is possible to attain the exercise intensity advocated in the PA recommendations by playing AVGs, and that these AVGs resulted in significantly more positive affect states than both self-selected intensity exercise and moderate intensity exercise imposed by the researchers.

All four conditions used in this study resulted in at least moderate exercise intensities according to ACSM exercise intensity classification but there were significant differences in physiological, psychological and affect responses during the trials. These differences make some of the conditions more or less promising in terms of promotion of health enhancing PA for sedentary populations.

The SS trial resulted in the highest exercise intensity, attaining the criteria for vigorous exercise intensity (ACSM, 2014), followed by the moderate intensity of the FTVG. The SS trial resulted also in non-significant higher enjoyment and state of flow scores than 55$\dot{V}O_2R$, but significantly lower enjoyment at 15 and 29 min than AVG conditions and lower psychological well-being right after the trial than the ETVG condition. During SS exercise, participants' average exercise intensity for the 30 min was 77.2 ± 7% HRmax and 71.6 ± 12.4% $\dot{V}O_2$max. Similarly, the rate of EE during SS condition were the highest of the four conditions, 10.3 ± 3.1 $kcal \cdot min^{-1}$. Interestingly, while SS values for $\dot{V}O_2$max and the rates of EE were the highest of the four conditions, % HRmax values during SS condition were similar during FTVG (77.4 ± 4.2%). Participants were also working at the highest intensities in relation to the VT in the SS condition, (0.58 ± 13.5%), but there were individual differences in the chosen intenstity. These findings are consistent with those of the literature (Lind *et al.*, 2005; Ekkekakis *et al.*, 2006; Rose & Parfitt, 2007). The subjects decided the intensity of exercise during the self-selected condition and this allowed them to have a greater sense of autonomy. Individuals with a higher sense of autonomy are more likely to be intrinsically motivated which might result in higher affect states (Deci & Ryan, 1987; Deci & Ryan, 2000). However, this is not what we found in our study since enjoyment and flow scores were nearly similar in both exercise conditions. The reason for this could be that participants were working on the high end of intensities that exercisers self-select and this might have a negative effect on enjoyment and flow.

The FTVG used in this study resulted in significantly higher % HRmax values than the 55%$\dot{V}O_2R$ and ETVG conditions, and higher enjoyment ratings than both these exercise conditions at 15 and 29 min. Based on the HRmax variable (77.4 ± 4.2% HRmax), participants exercised at vigorous intensity while they were playing the FTVG. The FTVG condition resulted in 58.6 ± 7.9% $\dot{V}O_2$max and 8.5 ± 2.1 kcal/min rate of EE. These are similar rates to those obtained during the 55%$\dot{V}O_2R$ condition (56.9 ± 4.2%$\dot{V}O_2$max and 8.1 ± 1.8 $kcal \cdot min^{-1}$). The

FTVG qualifies as moderate exercise intensity based on % $\dot{V}O_2$max. Some studies (Graves *et al.*, 2010a; Guderian *et al.*, 2010; Miyachi *et al.*, 2010; Lyons *et al.*, 2011; Worley *et al.*, 2011; Douris *et al.*, 2012; Garn *et al.*, 2012; Lyons *et al.*, 2012; Mullins *et al.*, 2012; O'Donovan & Hussey, 2012) have measured the cardio-metabolic response to other fitness-themed video games like Wii fit and Wii fit flus, the best-selling fitness games (see vgchartz.com). Wii Fit Plus offers different types of activities (aerobic, balance games, yoga, jogging). Miyachi *et al* .(2010) reported lower MET values in a metabolic chamber study than those reported in the present study, between 1.7 ± 0.3 and 5.6 ± 1.1 for resistance exercises, compared to 6.5 ± 1.2 MET in our participants while doing the resistance exercises (in the last 15 min of the FTVG). The same authors reported MET values of between 2.7 ± 0.5 and 5.1 ± 1 for the aerobic activities. Participants in our study were exercising at 6.3±1.1 MET during the aerobic part of the FTVG (min 0 to 15). Differences could be mainly explained by the different movement patterns recruited by the games. The FTVG trial included mini games such as ‘Wall breaker’ and ‘Jump rope hard’ that required greater upper and lower body extremities than Wii Fit Plus activities. Our participants were in the 60th percentile of the ACSM normative values for $\dot{V}O_2$max (ACSM, 2014), which means that they were quite inactive, possibly more than participants in Miyachi’s study (2010). Lyons *et al*. (2011) reported values of 3.10 ± 0.89 METs for a combination of aerobic and balance games of the Wii fit, values that are half of those obtained in the present study. Worley *et al*. (2011) reported values of 30.6% $\dot{V}O_2$max for Wii fit beginners step and 39.4% $\dot{V}O_2$max for Wii fit intermediate hula. It is not possible to make a direct comparison between Wii fit and the fitness game used in our study, but it is clear that the values obtained in the present study are higher than those reported in the literature.

The ETVG used in this study resulted in moderate intensity exercise and the most positive affect states of all the conditions tested. The ETVG condition yielded similar relative % HRmax values (60.9 ± 15.1%) to the 55%$\dot{V}O_2$R condition (65.9 ± 6.9%). However, % $\dot{V}O_2$max and the rate of EE during the ETVG were significantly lower than during the other three conditions. We could find only one study (O'Donovan *et al.*, 2012) that used Kinect Adventures. A direct comparison between O'Donovan study (2012) and ours is not possible since we used a combination of three mini games from Kinect Adventures for 30m, while O'Donovan *et al*. used only one Kinect Adventures game (Reflex Ridge) for 10 min. Our results are similar to those in the literature reporting that AVGs result in moderate exercise intensities. Participants' psychological well-being and state of flow were significantly higher after finishing the ETVG session compared to the other trials. Participants enjoyed the two AVG conditions significantly more than the two conventional exercise conditions. ETVG yielded the highest enjoyment ratings during and immediately after the game and this score was very consistent (5.5 ± 1.1 for both time points), but there was no significant difference with the FTVG (4.9 ± 1.3 and 5 ± 1.3).

The four different conditions tested in this study resulted in very different affect states and psychological well-being that might have important implications for exercise prescription. The highest enjoyment ratings occurred in the AVG conditions, where subjects did not have the autonomy to decide on games and intensity levels. In addition to this, ETVG resulted in the highest state of flow and greater psychological well-being at the end of the trial than SS and FTVG. This seems to contradict some of the evidence found in the literature (Vazou-Ekkekakis, 2005) reporting that exercise conditions in which participants did not have the freedom to select the exercise intensity resulted in the lowest enjoyment ratings. A possible explanation is that participants experienced more positive psychological and affect states during the AVG trials as the higher score for core flow and psychological well-being during the ETVG condition shows. This augmented state of flow and enhanced sense of well-being might have compensated for the lack of autonomy experienced during the AVG conditions. While video games and sport are two domains in which an enhanced state of flow is likely to occur (Csikszentmihalyi, 1990; Cowley *et al.*, 2008), there is a scarcity of research on AVGs and the state of flow. Thin *et al.* (2011) compared the flow state and enjoyment of 14 young adults while playing 6 different AVGs and cycling exercise. Thin *et al.* (2011) found that two of the flow dimensions (challenge-skill balance and merging of action and awareness) scored significantly higher than the exercise condition. We did not analyse the 9 different dimensions of flow separately, but got a significant difference in the overall state of flow.

The findings of this study support the principles of the dual-mode theory (Ekkekakis, 2003). The highest enjoyment ratings occurred in the ETVG condition, when the participants were working at the lowest intensity in relation to individuals' VT (see Table 5.2). However, the FTVG and the 55% $\dot{V}O_2R$ conditions resulted in similar percentages of VT, but enjoyment ratings were significantly higher during the FVTG than during the 55%$\dot{V}O_2R$. We found that 31.9% of enjoyment could be accounted for by the variability in intensity in relation to the VT during the SS trial. No relationship was found between enjoyment and %VT in the other trials. Other factors apart from exercise intensity were clearly playing a role in determining the affect response to the exercise and games.

Regarding RPE values, the FTVG yielded the highest values (13 ± 1.8), but these were not significantly higher than RPE values during the SS condition (12.3 ± 1.3). Participants' lowest RPE values occurred during the ETVG condition (9.7 ± 2), albeit lower to RPE during the 55%$\dot{V}O_2R$ condition (10.3 ± 1.7), they were not significantly different.

5.5. Conclusion

There are a variety of AVGs on the market and our results cannot be generalised. The AVGs used in this study resulted in moderate exercise intensities that comply with intensity recommendations of the ACSM PA guidelines. The FTVG yielded a similar EE and rate of EE to moderate intensity exercise (55%$\dot{V}O_2R$), but lower than SS exercise. The AVG trials resulted in the greatest affect states and psychological well-being of all conditions. Participants rated the ETVG as the most enjoyable and experienced a higher state of flow and psychological well-being during this condition than during the exercise trials.

The results of this study have implications in the fight against adult physical inactivity and sedentary behaviour. Video game usage is widely extended among the population, and this study shows that AVG technology can be a useful and efficient tool to help people to meet the PA recommendations and to reduce sedentary behaviour. The FTVG resulted in high exercise intensity but was not as enjoyable as the ETVG. Video game designers could take account of this and try to introduce elements in the games that make them more attractive, even if this means making them less demanding from a physiological point of view.

In conclusion, the main hypothesis of this research study, that AVGs result in similar rates of EE and more positive affect states, is partly accepted,. The FTVG resulted in similar rates of EE than 55%$\dot{V}O_2R$ and higher enjoyment than 55%$\dot{V}O_2R$ and SS conditions, but the ETVG resulted in lower rates of EE but the most positive psychological and affect states.

CHAPTER VI

Discussion, study implications, recommendations for future research and conclusion.

CHAPTER VI

6.1. Discussion

The aim of this research was to determine if the use of AVG results in health enhancing PA in an adult population (18-45 years of age). A secondary aim of the thesis was to examine affect and psychological responses associated with AVG play in an adult population, since these factors are likely to affect medium and long term exercise adherence rates. Three linked studies were designed as part of this PhD thesis to achieve these aims.

This PhD thesis provides evidence that Wii Sports, one of the best-selling AVGs in the market, can result in very light-to-light exercise intensity based on HRR and $\dot{V}O_2R$ criteria set by the American College of Sports Medicine (2014). In study 1, an assessment of a modification of Wii Sports in an attempt to make it more physiologically challenging was carried out. It was found that a lower body activation is essential for increasing exercise intensity, and that it is possible to achieve a significant increment in EE and to meet the current PA guidelines by introducing a modification to these games. Previous research concluded that the involvement of both arms during AVG play is also important to reach higher EE values (Warburton *et al.*, 2007b; Graves *et al.*, 2008b). The lower body has a greater muscle mass area than the upper body and its involvement will lead to higher physiological cost than engaging only upper body muscles. But, AVGs that require the involvement of all extremities would be even better for reaching higher intensity levels (Mellecker & McManus, 2013; Peng *et al.*, 2013).

There have been numerous laboratory and longitudinal studies on the effects of exercise on physiological systems and psychological responses to exercise (Brooks *et al.*; Plowman & Smith, 2013). These studies have provided undeniable evidence on the benefits of exercise. Since AVGs are a relatively new phenomenon, the level of scientific support is not sufficient to back the use of AVG technology. While there is vast evidence that AVG play results in a higher physiological stimulus than traditional stationary games in children, there is confounding results regarding the intensity that AVG play results in adults. In addition to this, the relationship between exercise intensity and affect responses during AVG play has been poorly documented. Therefore, a comparison of physiological, psychological and affect responses during conventional exercise and during AVGs was undertaken in studies 2 and 3. The second study allowed for a direct comparison since participants were cycling during both the conventional exercise and the AVG. The third study expanded on findings from the second study by measuring more affect variables, and by taking a closer look at different types of AVGs, fitness-themed AVGs and entertainment-themed video games (AVGs that do not pursue fitness goals). Results of both studies 2 and 3 showed that some AVGs are a valid alternative to conventional exercise in order to produce health-enhancing PA. Participants exercised at a higher percentage of $\dot{V}O_2R$, had a higher degree of metabolic stress, as shown by the percentage of VT, and had a higher rate of EE during the GameBike condition than during the conventional cycling. In study 3, participants exercised at moderate intensity exercise while playing both the ETVG (Xbox Kinect Adventures) and the FTVG (Xbox Kinect 2012 Fitness Evolve), based on $\dot{V}O_2R$ criteria. During the FTVG they were working at a similar intensity to light jogging exercise, a moderate intensity activity that results in positive effects on health as shown by many epidemiological studies. The physiological cost of AVG play reported in this thesis is somewhat lower than that reported in other research studies presented in the literature for Wii Sports and GameBike as discussed in chapters III and IV. One reason for this may be that the testing protocol used in these studies (46 min for Wii Sports and 30 min for GameBike) was longer than in most studies in the literature (5 to 10 min). It is likely that participants choose to pace themselves during a gaming session that last 30 and 46 min compared to a much shorter session. In addition to this, transition times between games were included in the analysis of data in study 1, and this is likely to result in lower average values for the physiological parameters. The transition times were included in the analysis in an effort to better mimic the way active video game play is done in real life and therefore increase ecological validity of our results.

This thesis also presents data to show that playing AVGs results in significantly more positive affect states than conventional exercise. In study 2, participants reported significantly higher ratings of enjoyment during GameBike play (63.4 ± 16.5%) than during conventional cycling (42 ± 13.6%). Enjoyment results in study 3 are consistent with those of study 2, and both the FTVG and the ETVG resulted in significantly higher enjoyment ratings than SS exercise and walking/jogging at 55% $\dot{V}O_2R$. These results are similar to those reported in the literature as discussed previously. This thesis took a step further and looked at the effect of AVG play and exercise on psychological well-being and the state of flow. Playing one of the AVGs (entertainment themed video game) resulted in an enhanced state of well-being immediately after the session and a significantly greater state of flow than SS intensity treadmill exercise and treadmill exercise at 55 $\dot{V}O_2R$. One important finding of this research thesis is that participants exercised at higher metabolic intensities as expressed by the %VT during AVG play (GameBike and FTVG) than during conventional exercise. Increases in exercise intensity beyond the VT are associated with more negative affect responses (Hall *et al.*, 2002; Parfitt *et al.*, 2006; Kilpatrick *et al.*, 2007) as explained by the dual-mode theory (Ekkekakis & Acevedo, 2006). Our results for conventional exercise provide support for this theory. However, the participants' affect responses (enjoyment and flow) during AVG play were significantly more positive than during exercise, in spite of the metabolic intensity being greater.

The hypothesis of this thesis was that the use of AVGs as part of an exercise program in an adult population aged 18-45 years of age is justified from a physiological and psychosocial viewpoint since they involve exercising at moderate and vigorous intensity exercise that meet the public PA recommendations for healthy adults. It was also hypothesised that AVGs are associated with more positive affective states than conventional exercise which are likely to result in higher adherence rates. Overall, the AVGs tested in this research resulted in very light-to-vigorous intensity exercise. Therefore, the first hypothesis is partially accepted as some of the AVGs tested (GameBike, Kinect Adventures, Kinect Fitness Evolve 2012) resulted in moderate-to-vigorous exercise intensities, but Wii Sports resulted in very light exercise intensity. The second hypothesis is accepted, as playing AVGs resulted in more positive affect and psychological states than conventional exercise.

6.2. Study Implications

There is compelling evidence on the enhanced health profile of inactive individuals becoming physically active. Furthermore, a number of studies (Paffenbarger *et al.*, 1986; Blair *et al.*, 1989) have concluded that the greatest mortality risk reduction occurs between the lowest and the next lowest fitness category, (see Figure 6.1). This conclusion has important implications for public health (Paffenbarger *et al.*, 1986; Warburton *et al.*, 2006b; Slentz *et al.*, 2007). One such implication is that physically inactive individuals could improve their health and reduce the mortality risk just by adding daily PA. While Wii Sports and AVGs of similar intensity do not comply with ACSM PA guidelines based on cardiovascular parameters (HRR and $\dot{V}O_2R$), they might have the potential to bring health benefits to very deconditioned individuals and the elderly by increasing time spent in light intensity activities. It is unknown if light intensity activities would be intense enough to reap fitness benefits for these groups, and therefore it is an area that needs investigation in the future. In addition to this, sedentary individuals that are not so deconditioned could make the transition to being physically active by using more intense AVGs. Paterson *et al.* (2007) provided evidence that a slight increase in habitual PA of 1 $hr^{\cdot}wk^{-1}$ of walking, was associated with some reduction in relative risk of age-related morbidities and mortality. The subjects who stopped being sedentary and became active had a 23% lower risk. Active video game play can result in similar exercise intensities to brisk walking, as results from study 3 shows, and therefore it could be effectively used to reduce age-related morbidities and mortality.

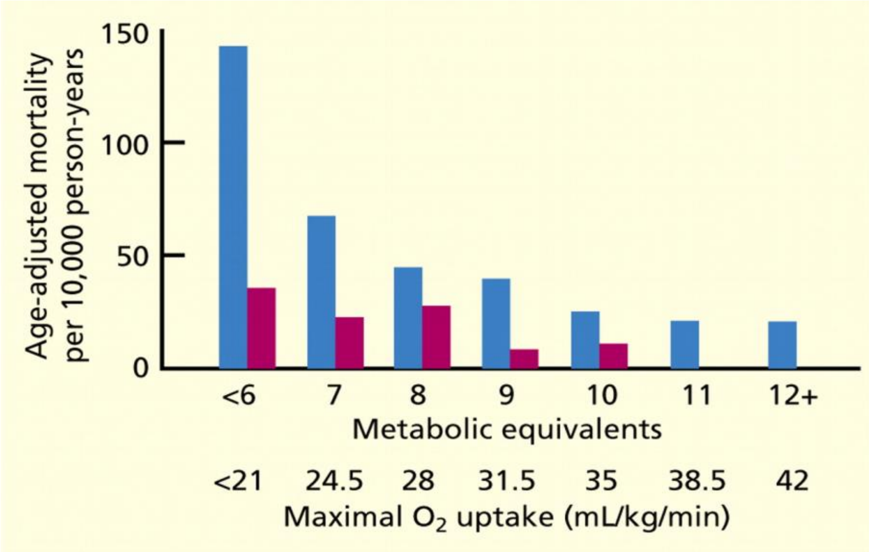


Figure 6.1. Age-adjusted, all-cause mortality rates. Age-adjusted, all-cause mortality rates per 10,000 person-years of follow-up by physical fitness categories in 3120 women (purple bars) and 10224 men (blue bars) in the Aerobics Centre Longitudinal Study. Physical fitness categories are expressed as METs achieved during the maximal treadmill exercise test. The estimated maximal oxygen uptake for each category is shown at the bottom of the figure (reproduced from Blair et al 1989).

This research thesis presents evidence to show that AVG play may lead to vigorous exercise intensity and significantly more positive affect states than doing conventional exercise. Previous research shows that the intensity of exercise is inversely and linearly associated with mortality (Lee & Skerrett, 2001). This finding is important since it means that adults could reduce their mortality risk by using this technology to increase vigorous intensity exercise and to stay motivated to remain in PA programmes. This point, the motivation to exercise through AVG play, is something that should be examined with intervention studies since this thesis did not assess whether the PA and more positive affect responses were sustained over time. A sustained positive affect state as result of

AVG play could have a tangible impact on increasing adherence rates to PA programmes since enjoyment is a significant determinant in adult participation in regular PA.

There is strong emerging evidence that reducing sedentary behaviour (mainly sitting time) brings about an enhanced metabolic profile (Wilmot *et al.*, 2012). One implication of this is that AVGs similar in intensity to Wii Sports (3.3 METs) or even of lighter intensity (but at least higher than 1.5 METs) could be attractive options to break sedentary time and reduce the negative metabolic effect of prolonged sitting. There is potential to use these games in common areas in office buildings, hospitals, schools, etc., and therefore minimise the deleterious effects of prolonged sedentary behaviour.

Playing AVGs is something that appeals to a lot of individuals, but it is something that will not attract the attention of many others. It is possible, and likely, that AVGs are not an attractive option to some people because they perceive it as something for "technologically minded people" and something that makes them confused and uneasy. AVGs must be easy to learn and use. Enjoyment is reduced if the user needs to spend a long time trying to work out how to play something. At the same time, AVG should be engaging and include various difficulty levels to cater for different abilities. This is a relatively new area and new games are constantly being developed with more engaging story lines that appeal to a wider audience. It is likely that AVGs will become more mainstream in the future. One challenge for video game designers is to collaborate with researchers to develop more enjoyable and immersive games that result in moderate-to-vigorous exercise intensities. This thesis provides evidence that AVG play can be more immersive than conventional exercise. This was the case for Kinect Adventures, the ETVG tested in study 3, but not so for Kinect Fitness Evolve 2012. One implication of this is that participants would be more likely to play Kinect Adventures than to play Kinect Fitness Evolve or to engage in conventional exercise, which is not a negative consequence since

Kinect adventures resulted in moderate intensity exercise. This is an important finding that has repercussions on the efforts to improve adult PA levels. It is preferable that physically inactive and sedentary adults increase their EE and PA levels through moderate and vigorous intensity exercise, but evidence shows that only a minority choose this option. Therefore, it would be a desirable outcome that those same adults stay or become physically active by playing immersive and enjoyable light-to-moderate intensity AVGs that do not have the overt objective of obtaining a fitness gain. Even further, for the big percentage of the population that are physically inactive and with high daily sedentary time, any minimal increase in daily EE is preferable than no increase at all.

The results obtained in these studies provide strong support for the use of AVG to increase PA in the population. We have provided evidence that AVG play is a powerful and engaging strategy to increase PA levels and decrease sedentary behaviour in adults. Since AVG play is a valid strategy to increase EE, it is advised that they are included in the PA guidelines as a viable option to meet recommendations alongside alternatives outside of the home and away from the screen.

6.3. Recommendations for future research

There is some evidence that medium-term AVG interventions lead to increased exercise adherence compared to conventional exercise programs (Warburton *et al.*, 2007b; Rhodes *et al.*, 2009). More studies are required to evaluate the efficacy of medium and long term AVG interventions and interventions that combine AVG play with traditional forms of exercise (jogging, running, exercise classes…) in order to reduce physical inactivity, increase compliance with PA guidelines, increase exercise adherence rates and reduce population sedentary time. The inclusion of AVG as a form of exercise could offer a variety element that traditional exercise programs lack, and could make it more appealing and interesting to participants. One topic of interest to researchers at present is the use of AVG technology as a stepping stone to get people to do more conventional exercise. There is little research in this area and it is an important topic of research.

AVGs are a valid approach to increasing PA levels and therefore improving primary prevention of a diversity of chronic diseases. But AVG technology could also play a role in improving secondary prevention of different disease states. There is evidence that exercise and many drug interventions are often potentially similar in terms of their mortality benefits in the secondary prevention of coronary heart disease, rehabilitation after stroke, treatment of heart failure, and prevention of diabetes (Naci & Ioannidis, 2013). The effectiveness of AVG interventions and those that combine regular PA and AVG as secondary prevention strategies should be assessed in order to make recommendations for AVG use and secondary prevention. The use of AVGs in community settings, the home environment, day care centres like diabetes and obesity centres, hospitals, schools, etc., and the medium and long-term applicability of AVG technology in these settings merits further investigation. In addition to this, the impact of AVG availability in those settings on sedentary behaviour is an interesting topic of research.

The scientific literature includes research studies looking at the effectiveness of AVG interventions on different health outcomes in children and adolescents, e.g. weight management (Maddison *et al.*, 2011; Christison & Khan, 2012; Maloney *et al.*, 2012; Simons *et al.*, 2014; Trost *et al.*, 2014) and vascular function (Murphy *et al.*, 2009; Mills *et al.*, 2013). However, there is a lack of similar data for the adult population and similar studies are needed. On top of this, the medium to long term effects of AVG programmes on metabolic profile, bone mass and mental health should be explored. The use of AVG play by older population to improve health outcomes is a fascinating area of research that should be addressed. Some of the currently available AVGs lead to light intensity exercise and they might be ideally suited to this population group (Graves *et al.*, 2010a). In addition to this, AVGs has been proven to be useful in the fight against degenerative cognitive conditions (Anderson-Hanley *et al.*, 2012). There has been a proliferation of games to stimulate the brain in an effort to delay and avoid degenerative cognitive conditions. More games that combine PA with cognitive stimulation are likely to appear on the market and determining their efficacy will help games developers to make better games.

There has been a growing interest in high intensity interval training (HIIT) in sports science over the last years. The use of high intensity AVG play should be explored since AVG play leads to more positive affect responses than conventional exercise as shown in studies 2 and 3. This potentially means that the unpleasant feelings associated with high intensity exercise are masked by playing the games and the subjects are more positive about the whole experience. AVGs that result in vigorous exercise intensity are available (DDR, GameBike, Kinect Fitness Evolve 2013), and games that lead to even higher exercise intensities could be developed. This might require designing games that involve upper and lower body since this results in greater energy expenditure and greater health benefits (Mellecker & McManus, 2013).

Current available technology allows for individuals in different locations to play virtually with and against each other. There is a social aspect to this type of gaming that should also be explored. It is unknown if AVG play might lead to undesirable psycho-social health and this point merits investigation. Also the psycho-social effects of AVGs that foster collaboration versus competition should be further investigated.

6.4. Conclusion

AVG play results in very light-to-vigorous exercise intensities, with most of the AVGs tested in this PhD thesis resulting in moderate-to-vigorous exercise intensity. It also results in more positive psychological and affect responses than conventional exercise. AVG play resulted in a blunting of the typical relationship between intensity of exercise and affect responses relationship. Evidence shows that as intensity of exercise increases, affect responses become more negative. However, we found that participants exercised at a higher intensity while playing AVGs than during conventional exercise, but the affect responses were more positive during AVG play than during conventional exercise. These results support the use of AVG play as an engaging and valid way of increasing adult PA levels and reducing sedentary time. AVG play might be part of the solution to the low level of PA and high volume of sedentary behavior that are so prevalent in society today.

Bibliography

ACSM. (1998). American College of Sports Medicine Position Stand. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. *Med Sci Sports Exerc* **30,** 975-991.

ACSM. (2010). *ACSM's guidelines for exercise testing and prescription*. Lippincott Williams & Wilkins, Philadelphia.

ACSM. (2014). *ACSM's guidelines for exercise testing and prescription*

Lippincott Williams & Wilkins, Philadelphia.

Adamo KB, Rutherford JA & Goldfield GS. (2010). Effects of interactive video game cycling on overweight and obese adolescent health. *Appl Physiol Nutr Metab* **35,** 805-815.

Agmon M, Perry CK, Phelan E, Demiris G & Nguyen HQ. (2011). A pilot study of Wii Fit exergames to improve balance in older adults. *J Geriatr Phys Ther* **34,** 161-167.

Ainsworth B, Haskell W, Whitt M & al. e. (2000). Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc* **32,** S498-504.

Allender S, Cowburn G & Foster C. (2006). Understanding participation in sport and physical activity among children and adults: a review of qualitative studies. *Health Educ Res* **21,** 826-835.

Alwan A, Maclean DR, Riley LM, d'Espaignet ET, Mathers CD, Stevens GA & Bettcher D. (2010). Monitoring and surveillance of chronic non-communicable diseases: progress and capacity in high-burden countries. *Lancet* **376,** 1861-1868.

Anderson-Hanley C, Arciero PJ, Brickman AM, Nimon JP, Okuma N, Westen SC, Merz ME, Pence BD, Woods JA, Kramer AF & Zimmerman EA. (2012). Exergaming and older adult cognition: a cluster randomized clinical trial. *Am J Prev Med* **42,** 109-119.

Anderson CA & Bushman BJ. (2001). Effects of violent video games on aggressive behavior, aggressive cognition, aggressive affect, physiological arousal, and prosocial behavior: a meta-analytic review of the scientific literature. *Psychol Sci* **12,** 353-359.

Annesi J. (2001). Effects of Music, Television, and a Combination Entertainment System on Distraction, Exercise Adherence, and Physical Output in Adults. *Can J Behav Sci,* **33,** 193-202.

Annesi JJ & Mazas J. (1997). Effects of virtual reality-enhanced exercise equipment on adherence and exercise-induced feeling states. *Percept Mot Skills* **85,** 835-844.

Archer E, Shook RP, Thomas DM, Church TS, Katzmarzyk PT, Hebert JR, McIver KL, Hand GA, Lavie CJ & Blair SN. (2013). 45-Year trends in women's use of time and household management energy expenditure. *PLoS One* **8,** e56620.

Astorino TA, Rietschel JC, Tam PA, Taylor K, Johnson SM, Freedman TP & Sakarya CE. (2004). Reinvestigation of optimal duration of VO2max testing. *J Exerc Physiol* **7,** 1-8.

Åstrand P-O, Rodahl K. (1986). *Textbook of work physiology: physiological bases of exercise*. McGraw-Hill, New York.

Australia. (2014). Australia's physical activity and sedentary behaviour guidelines, ed. Health AGDo.

Baik JH, Picetti R, Saiardi A, Thiriet G, Dierich A, Depaulis A, Le Meur M & Borrelli E. (1995). Parkinsonian-like locomotor impairment in mice lacking dopamine D2 receptors. *Nature* **377,** 424-428.

Bailey BW & McInnis K. (2011). Energy Cost of Exergaming: A Comparison of the Energy Cost of 6 Forms of Exergaming. *Arch Pediatr Adolesc Med*.

Baranowski T, Abdelsamad D, Baranowski J, O'Connor TM, Thompson D, Barnett A, Cerin E & Chen TA. (2012). Impact of an active video game on healthy children's physical activity. *Pediatrics* **129,** e636-642.

Baranowski T, Anderson C & Carmack C. (1998). Mediating variable framework in physical activity interventions: How are we doing? how might we do better? *Am J Prev Med* **15,** 266-297.

Barkley JE & Penko A. (2009). Physiological responses, perceived exertion, and Hedonics of playing a physical interactive video game relative to a sedentary alternative and treadmill walking in adults. *J Ex Phys online* **12,** 1389-1398.

Barnett A, Cerin E & Baranowski T. (2011). Active video games for youth: a systematic review. *J Phys Act Health* **8,** 724-737.

Bartholomew JB, Morrison D & Ciccolo JT. (2005). Effects of acute exercise on mood and well-being in patients with major depressive disorder. *Med Sci Sports Exerc* **37,** 2032-2037.

Bassett DR, Jr., Pucher J, Buehler R, Thompson DL & Crouter SE. (2008). Walking, cycling, and obesity rates in Europe, North America, and Australia. *J Phys Act Health* **5,** 795-814.

Bauman A, Reis R, Sallis J, Wells J, Loos J & B. M. (2012). Correlates of physical activity: why are some people physically active and others not? *Lancet* **380,** 258-271.

Bausch L, Beran J, Cahanes S & Krug L. (2008). Physiological responses while playihng Nintendo Wii Sports. *J Undergrad Kinesiol Res* **3,** 19-25.

Beaver WL, Wasserman K & Whipp BJ. (1986). A new method for detecting anaerobic threshold by gas exchange. *J Appl Physiol (1985)* **60,** 2020-2027.

Becker N, Brett S, Chambliss C, Crowers K, Haring P, Marsh C & Montemayor R. (1994). Mellow and frenetic antecedent music during athletic performance of children, adults, and seniors. *Percept Mot Skills* **79,** 1043-1046.

Berg A, Halle M, Franz I & Keul J. (1997). Physical activity and lipoprotein metabolism: epidemiological evidence and clinical trials. *Eur J Med Res* **2,** 259-264.

Berger B, Pargman D & Weinberg R. (2002). Foundations of Exercise Psychology. In *Foundations of Exercise Psychology*, ed. Berger BG, pp. 53-62. Morgantown, WV: Fitness Information Technology.

Bey L & Hamilton M. (2003). Suppression of skeletal muscle lipoprotein lipase activity during physical inactivity: a molecular reason to maintain daily low-intensity activity. *J Physiol* **551,** 673 - 682.

Bharani A, Sahu A & Mathew V. (2004). Effect of passive distraction on treadmill exercise test performance in healthy males using music. *Int J Cardiol* **97,** 305-306.

Biddle S & Mutrie N. (2001). *Psychology of physical activity. Determinants, well-being and interventions*. Routledge, Taylor and Francis group, New York.

Bingham SA, Goldberg GR, Coward WA, Prentice AM & Cummings JH. (1989). The effect of exercise and improved physical fitness on basal metabolic rate. *Br J Nutr* **61,** 155-173.

Blair SN, Cheng Y & Holder JS. (2001). Is physical activity or physical fitness more important in defining health benefits? *Med Sci Sports Exerc* **33,** S379-399; discussion S419-320.

Blair SN, Goodyear NN, Gibbons LW & Cooper KH. (1984). Physical fitness and incidence of hypertension in healthy normotensive men and women. *JAMA* **252,** 487-490.

Blair SN, Kohl HW, 3rd, Paffenbarger RS, Jr., Clark DG, Cooper KH & Gibbons LW. (1989). Physical fitness and all-cause mortality. A prospective study of healthy men and women. *JAMA* **262,** 2395-2401.

Bonetti AJ, Drury DG, Danoff JV & Miller TA. (2010). Comparison of acute exercise responses between conventional video gaming and isometric resistance exergaming. *J Strength Cond Res* **24,** 1799-1803.

Booth F, Laye M, Lees S, Rector R & Thyfault J. (2008). Reduced physical activity and risk of chronic disease: the biology behind the consequences. *Eur J Appl Physiol* **102,** 381-390.

Booth FW, Chakravarthy MV, Gordon SE & Spangenburg EE. (2002). Waging war on physical inactivity: using modern molecular ammunition against an ancient enemy. *J Appl Physiol* **93,** 3-30.

Booth ML, Owen N, Bauman A, Clavisi O & Leslie E. (2000). Social-cognitive and perceived environment influences associated with physical activity in older Australians. *Prev Med* **31,** 15-22.

Booth SL, Sallis JF, Ritenbaugh C, Hill JO, Birch LL, Frank LD, Glanz K, Himmelgreen DA, Mudd M, Popkin BM, Rickard KA, St Jeor S & Hays NP. (2001). Environmental and societal factors affect food choice and physical activity: rationale, influences, and leverage points. *Nutr Rev* **59,** S21-39; discussion S57-65.

Borg GA. (1982). Psychophysical bases of perceived exertion. *Med Sci Sports Exerc* **14,** 377-381.

Borghouts LB & Keizer HA. (2000). Exercise and insulin sensitivity: a review. *Int J Sports Med* **21,** 1-12.

Bosch PR, Poloni J, Thornton A & Lynskey JV. (2012). The heart rate response to nintendo wii boxing in young adults. *Cardiopulm Phys Ther J* **23,** 13-29.

Bouchard C, Blair, SN, Haskell, WL. (2007). *Physical activity and health*. Human Kinetics, Champaign, IL.

Bouchard C, Tremblay A, Despres JP, Nadeau A, Lupien PJ, Theriault G, Dussault J, Moorjani S, Pinault S & Fournier G. (1990). The response to long-term overfeeding in identical twins. *N Engl J Med* **322,** 1477-1482.

Boutcher S, McAuley E & Courneya K. (1997). Positive and negative affective response of trained and untrained subjects during and after aerobic exercise. *Austral J Psychol* **49,** 28-32.

Brehmer M, Graham T & Stach T. (2010). Activate your GAIM: a toolkit for input in active games. In *International Academic Conference on the Future of Game Design and Technology*. Vancouver, British Columbia, Canada.

Brenes G, Dearwater S, Shapera R, LaPorte RE & Collins E. (1986). High density lipoprotein cholesterol concentrations in physically active and sedentary spinal cord injured patients. *Arch Phys Med Rehabil* **67,** 445-450.

Brooks GA, Fahey TD & Baldwin KM. *Exercise physiology: human bioenergetics and its applications*.

Brownson RC, Boehmer TK & Luke DA. (2005). Declining rates of physical activity in the United States: what are the contributors? *Annu Rev Public Health* **26,** 421-443.

Brownson RC, Eyler AA, King AC, Brown DR, Shyu YL & Sallis JF. (2000). Patterns and correlates of physical activity among US women 40 years and older. *Am J Public Health* **90,** 264-270.

Brox E, Fernandez Luque L, Judith Evertsen G & Gonzalez Hernandez JE. (2011). Exergames for elderly. Social exergames to persuade seniours to increase physical activity. In *2011 5th International Conference on*

Pervasive Computing Technologies for

Healthcare and Workshops. Dublin, Ireland.

Bryan S & Katzmarzyk P. (2011). The association between meeting physical activity guidelines and chronic diseases among Canadian adults. *J Phys Act Health* **8,** 10-17.

Buchfuhrer MJ, Hansen JE, Robinson TE, Sue DY, Wasserman K & Whipp BJ. (1983). Optimizing the exercise protocol for cardiopulmonary assessment. *J Appl Physiol Respir Environ Exerc Physiol* **55,** 1558-1564.

Bucksch J & Schlicht W. (2006). Health-enhancing physical activity and the prevention of chronic diseases--an epidemiological review. *Soz Praventivmed* **51,** 281-301.

Burton LC, Shapiro S & German PS. (1999). Determinants of physical activity initiation and maintenance among community-dwelling older persons. *Prev Med* **29,** 422-430.

Butler AA, Marks DL, Fan W, Kuhn CM, Bartolome M & Cone RD. (2001). Melanocortin-4 receptor is required for acute homeostatic responses to increased dietary fat. *Nat Neurosci* **4,** 605-611.

Caillois R. (1958). *Man, play and games*. University of Illinois Press, Champaign, IL.

Canada. (2014). Canadian Physical Activity Guidelines and Canadian Sedentary Behaviour Guidelines, ed. Physiology CSfE.

Carraro A, Young M & Robazza C. (2008). A contribution to the validation of the physical activity enjoyment scale in an italian sample. *Social behavior and personality* **36,** 911-918.

Caspersen CJ, Powell KE & Christenson GM. (1985). Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Rep* **100,** 126-131.

Cawley J. (2004). An economic framework for understanding physical activity and eating behaviors. *Am J Prev Med* **27,** 117-125.

CDC. (1999). Neighborhood safety and the prevalence of physical inactivity—selected states, 1996., pp. 143–146,.

Charkoudian N & Joyner MJ. (2004). Physiologic considerations for exercise performance in women. *Clin Chest Med* **25,** 247-255.

Chastin SF, Schwarz U & Skelton DA. (2013). Development of a Consensus Taxonomy of Sedentary Behaviors (SIT): Report of Delphi Round 1. *PLoS One* **8,** e82313.

Christison A & Khan HA. (2012). Exergaming for health: a community-based pediatric weight management program using active video gaming. *Clin Pediatr (Phila)* **51,** 382-388.

Church TS, Thomas DM, Tudor-Locke C, Katzmarzyk PT, Earnest CP, Rodarte RQ, Martin CK, Blair SN & Bouchard C. (2011). Trends over 5 decades in U.S. occupation-related physical activity and their associations with obesity. *PLoS One* **6,** e19657.

Clark BK, Sugiyama T, Healy GN, Salmon J, Dunstan DW & Owen N. (2009). Validity and reliability of measures of television viewing time and other non-occupational sedentary behaviour of adults: a review. *Obes Rev* **10,** 7-16.

Consolazio C JR, Pecora L. (1963). *Physiological Measurements of Metabolic Functions in Man*. McGraw Hill, New York NY.

Cordain L, Gotshall RW & Eaton SB. (1997). Evolutionary aspects of exercise. *World Rev Nutr Diet* **81,** 49-60.

Cordain L, Gotshall RW, Eaton SB & Eaton SB, 3rd. (1998). Physical activity, energy expenditure and fitness: an evolutionary perspective. *Int J Sports Med* **19,** 328-335.

Cowley B, Charles D., Black M. & Hickey R. (2008). Toward an Understanding of Flow in Video Games. *ACM Comput Entertain* **6**.

Crouse SF, O'Brien BC, Grandjean PW, Lowe RC, Rohack JJ & Green JS. (1997). Effects of training and a single session of exercise on lipids and apolipoproteins in hypercholesterolemic men. *J Appl Physiol (1985)* **83,** 2019-2028.

Crouse SF, O'Brien BC, Rohack JJ, Lowe RC, Green JS, Tolson H & Reed JL. (1995). Changes in serum lipids and apolipoproteins after exercise in men with high cholesterol: influence of intensity. *J Appl Physiol (1985)* **79,** 279-286.

Csikszentmihalyi M. (1990). *Flow, the psychology of experience.* Harper & Row., New York.

Daley AJ. (2009). Can exergaming contribute to improving physical activity levels and health outcomes in children? *Pediatrics* **124,** 763-771.

de Geus E & de Moor M. (2011). Genes, exercise, and psychological factors. In *Genetic and molecular aspects of sports performance*, ed. Bouchard C HmE, pp. 294–305. Blackwell Publishing, Oxford.

Deci EL & Ryan RM. (1987). The support of autonomy and the control of behavior. *J Pers Soc Psychol* **53,** 1024-1037.

Deci EL & Ryan RM. (2000). The "What" and "Why" of Goal Pursuits: Human Needs and the Self-Determination of Behavior. *Psychol Inqu* **11,** 227-268.

Dishman RK. (1982). Compliance/adherence in health-related exercise. *Health Psychol* **1,** 237-267.

Dishman RK & Buckworth J. (1996). Increasing physical activity: a quantitative synthesis. *Med Sci Sports Exerc* **28,** 706-719.

Donahoo WT, Levine JA & Melanson EL. (2004). Variability in energy expenditure and its components. *Curr Opin Clin Nutr Metab Care* **7,** 599-605.

Douris PC, McDonald B, Vespi F, Kelley NC & Herman L. (2012). Comparison between Nintendo Wii Fit aerobics and traditional aerobic exercise in sedentary young adults. *J Strength Cond Res* **26,** 1052-1057.

Dumith SC, Hallal PC, Reis RS & Kohl HW, 3rd. (2011). Worldwide prevalence of physical inactivity and its association with human development index in 76 countries. *Prev Med* **53,** 24-28.

Duncan MJ, Birch S, Woodfield L & Hankey J. (2011). Physical activity levels during a 6-week, school based, active video gaming intervention using the gamercise power stepper in british children. *Med Sport* **15,** 81-87.

Dunstan DW, Salmon J, Owen N, Armstrong T, Zimmet PZ, Welborn TA, Cameron AJ, Dwyer T, Jolley D & Shaw JE. (2005). Associations of TV viewing and physical activity with the metabolic syndrome in Australian adults. *Diabetologia* **48,** 2254-2261.

Dunton GF, Tscherne J & Rodriguez D. (2009). Factorial validity and gender invariance of the physical activity enjoyment scale (PACES) in older adolescents. *Res Q Exerc Sport* **80,** 117-121.

Duvivier BM, Schaper NC, Bremers MA, van Crombrugge G, Menheere PP, Kars M & Savelberg HH. (2013). Minimal intensity physical activity (standing and walking) of longer duration improves insulin action and plasma lipids more than shorter periods of moderate to vigorous exercise (cycling) in sedentary subjects when energy expenditure is comparable. *PLoS One* **8,** e55542.

Eaton SB. (2003). An evolutionary perspective on human physical activity: implications for health. *Comp Biochem Physiol A Mol Integr Physiol* **136,** 153-159.

Eaton SB, Konner M & Shostak M. (1988). Stone agers in the fast lane: chronic degenerative diseases in evolutionary perspective. *Am J Med* **84,** 739-749.

Ekkekakis P. (2003). Pleasure and displeasure from the body: Perspectives from exercise. *Cogn & Emot* **17,** 213-239.

Ekkekakis P. (2009a). The Dual-Mode Theory of affective responses to exercise in metatheoretical context: II. Bodiless heads, ethereal cognitive schemata, and other improbable dualistic creatures, exercising. *Int Rev Sport Exerc Psychol* **2,** 139-160.

Ekkekakis P. (2009b). Let them roam free? Physiological and psychological evidence for the potential of self-selected exercise intensity in public health. *Sports Med* **39,** 857-888.

Ekkekakis P & Acevedo E. (2006). Affective responses to acute exercise: toward a psychobiological dose-response model. In *Psychobiology of Physical Activity*, ed. Acevedo E, Ekkekakis, P, pp. 91-110. Champaign, IL: Human Kinetics,, Champaign, IL.

Ekkekakis P, Hall EE & Petruzzello SJ. (2008). The relationship between exercise intensity and affective responses demystified: to crack the 40-year-old nut, replace the 40-year-old nutcracker! *Ann Behav Med* **35,** 136-149.

Ekkekakis P, Lind E & Joens-Matre RR. (2006). Can self-reported preference for exercise intensity predict physiologically defined self-selected exercise intensity? *Res Q Exerc Sport* **77,** 81-90.

Ekkekakis P, Parfitt G & Petruzzello S. (2011). The Pleasure and Displeasure People Feel When they Exercise at Different Intensities. *Sports Med* **41,** 641-671.

Ekkekakis P & Petruzzello SJ. (1999). Acute aerobic exercise and affect: current status, problems and prospects regarding dose-response. *Sports Med* **28,** 337-374.

Ekkekakis P & Petruzzello SJ. (2000). Analysis of the affect measurement conundrum in exercise psychology I. Fundamental issues. *Psychol of Sport & Exerc* **1,** 71-88.

Elia M. (1991). Energy expenditure in the whole body. In *Energy Metabolism*, ed. Kinney JM, Tucker, H.N., pp. 19-59. Raven Press, New York.

Elia M & Livesey G. (1992). Energy expenditure and fuel selection in biological systems: the theory and practice of calculations based on indirect calorimetry and tracer methods. *World Rev Nutr Diet* **70,** 68-131.

Epstein LH, Beecher MD, Graf JL & Roemmich JN. (2007). Choice of interactive dance and bicycle games in overweight and nonoverweight youth. *Ann Behav Med* **33,** 124-131.

Epstein LH, Roemmich JN, Saad FG & Handley EA. (2004). The value of sedentary alternatives influences child physical activity choice. *Int J Behav Med* **11,** 236-242.

ESA. (2012). Entertainment Software Association. Washington, DC 20004.

ESA & Canada. (2013). 2013 Essential facts about the Canadian video game industry.

ESA & USA. (2013). ESA 2013 Essential Facts.

EU, Working, Group, "Sport, & & Health". (2008). EU Physical Activity Guidelines Recommended Policy Actions in Support of Health-Enhancing Physical Activity, ed. Health" EWGS. Brussels.

Farrell PA, Gustafson AB, Morgan WP & Pert CB. (1987). Enkephalins, catecholamines, and psychological mood alterations: effects of prolonged exercise. *Med Sci Sports Exerc* **19,** 347-353.

Faulkner J ER. (2008). Perceived exertion research in the 21st century: developments, reflections and questions for the future. *J Exerc Sci Fit* **6,** 1-14.

Fawkner SG, Niven A, Thin AG, Macdonald MJ & Oakes JR. (2010). Adolescent girls' energy expenditure during dance simulation active computer gaming. *J Sports Sci* **28,** 61-65.

Fenner JN. (2005). Cross-cultural estimation of the human generation interval for use in genetics-based population divergence studies. *Am J Phys Anthropol* **128,** 415-423.

Ferguson MA, Alderson NL, Trost SG, Essig DA, Burke JR & Durstine JL. (1998). Effects of four different single exercise sessions on lipids, lipoproteins, and lipoprotein lipase. *J Appl Physiol (1985)* **85,** 1169-1174.

Fink E. (1979). The ontology of play. In *Sport and the body: A philosophical symposium*, 2nd edn, ed. Morgan EWGWJ, pp. 73-83. Philadelphia.

Fisher A, van Jaarsveld CH, Llewellyn CH & Wardle J. (2010). Environmental influences on children's physical activity: quantitative estimates using a twin design. *PLoS One* **5,** e10110.

Fitzgerald D, Trakarnratanakul N, Smyth B & Caulfield B. (2010). Effects of a wobble board-based therapeutic exergaming system for balance training on dynamic postural stability and intrinsic motivation levels. *J Orthop Sports Phys Ther* **40,** 11-19.

Fogel VA, Miltenberger RG, Graves R & Koehler S. (2010). The effects of exergaming on physical activity among inactive children in a physical education classroom. *J Appl Behav Anal* **43,** 591-600.

Franks PW, Ravussin E, Hanson RL, Harper IT, Allison DB, Knowler WC, Tataranni PA & Salbe AD. (2005). Habitual physical activity in children: the role of genes and the environment. *Am J Clin Nutr* **82,** 901-908.

Fruin ML & Rankin JW. (2004). Validity of a multi-sensor armband in estimating rest and exercise energy expenditure. *Med Sci Sports Exerc* **36,** 1063-1069.

Garber C, Blissmer B & Deschenes MR. (2011). American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc* **43,** 1334-1359.

Garcia-Mas A, Palou P, Gili M, Ponseti X, Borras PA, Vidal J, Cruz J, Torregrosa M, Villamarin F & Sousa C. (2010). Commitment, enjoyment and motivation in young soccer competitive players. *Span J Psychol* **13,** 609-616.

Garcia JA, Felix Navarro K, Schoene D, Smith ST & Pisan Y. (2012). Exergames for the elderly: Towards an embedded Kinect-based clinical test of falls risk. *Stud Health Technol Inform* **178,** 51-57.

Garn AC, Baker BL, Beasley EK & Solmon MA. (2012). What are the benefits of a commercial exergaming platform for college students? Examining physical activity, enjoyment, and future intentions. *J Phys Act Health* **9,** 311-318.

Gellish RL, Goslin BR, Olson RE, McDonald A, Russi GD & Moudgil VK. (2007). Longitudinal modeling of the relationship between age and maximal heart rate. *Med Sci Sports Exerc* **39,** 822-829.

Glass TA & McAtee MJ. (2006). Behavioral science at the crossroads in public health: extending horizons, envisioning the future. *Soc Sci Med* **62,** 1650-1671.

Goran MI & Reynolds K. (2005). Interactive multimedia for promoting physical activity (IMPACT) in children. *Obes Res* **13,** 762-771.

Graf DL, Pratt LV, Hester CN & Short KR. (2009). Playing active video games increases energy expenditure in children. *Pediatrics* **124,** 534-540.

Graves L, Ridgers N, Williams K, Stratton G, Atkinson G & Cable N. (2010a). The physiological cost and enjoyment of Wii Fit in adolescents, young adults, and older adults. *J Phys Act Health* **7,** 393-401.

Graves L, Stratton G, Ridgers ND & Cable NT. (2008a). Energy expenditure in adolescents playing new generation computer games. *Br J Sports Med* **42,** 592-594.

Graves LE, Ridgers ND, Atkinson G & Stratton G. (2010b). The effect of active video gaming on children's physical activity, behavior preferences and body composition. *Pediatr Exerc Sci* **22,** 535-546.

Graves LE, Ridgers ND & Stratton G. (2008b). The contribution of upper limb and total body movement to adolescents' energy expenditure whilst playing Nintendo Wii. *Eur J Appl Physiol* **104,** 617-623.

Guderian B, Borreson LA & Sletten LE ea. (2010). The cardiovascular and metabolic responses to Wii Fit video game playing in middle-aged and older adults. *J Sports Med Phys Fitness* **50,** 436-442.

Guszkowska M. (2004). [Effects of exercise on anxiety, depression and mood]. *Psychiatr Pol* **38,** 611-620.

Guttmann A. (1988). *A whole new ballgame: An interpretation of American sports.* The University of North Carolina Press, Chapel Hill: NC.

Haddock BL, Siegel SR & Wikin LD. (2009). The Addition of a Video Game to Stationary Cycling: The Impact on Energy Expenditure in Overweight Children. *Open Sports Sc J* **2,** 42-46.

Hagberg JM & Brown MD. (1995). Does exercise training play a role in the treatment of essential hypertension? *J Cardiovasc Risk* **2,** 296-302.

Hagberg LA, Lindahl B, Nyberg L & Hellenius ML. (2009). Importance of enjoyment when promoting physical exercise. *Scand J Med & Sci Sports* **19,** 740-747.

Hall EE, Ekkekakis P & Petruzzello SJ. (2002). The affective beneficence of vigorous exercise revisited. *Br J Health Psychol* **7,** 47-66.

Hallal P, Andersen L, Bull F, Guthold R, Haskell W & Ekelund U. (2012). Global physical activity levels: surveillance progress, pitfalls, and prospects. *Lancet* **380,** 247-257.

Hambrecht R, Wolf A, Gielen S, Linke A, Hofer J, Erbs S, Schoene N & Schuler G. (2000). Effect of exercise on coronary endothelial function in patients with coronary artery disease. *N Engl J Med* **342,** 454-460.

Hamilton M, Hamilton D & Zderic T. (2004). Exercise physiology versus inactivity physiology: an essential concept for understanding lipoprotein lipase regulation. *Exerc Sport Sci Rev* **32,** 161 - 166.

Hamilton M, Healy GN, Dunstan DW, Zderic TW, Owen N. (2008). Too little exertise and too much sitting: inactivity physiology and the need for new recommendations on sedentary behavior. *Curr Cardiovasc Risk Rep* **2,** 292-298.

Hamilton MT, Hamilton DG & Zderic TW. (2007). Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. *Diabetes* **56,** 2655-2667.

Hanin Y. (1999). *Emotions in Sport*. Human Kinetics, Champaign, IL.

Haskell W, Lee I, Pate R, Blair S, Franklin B, Macera C, Heath G, Thompson P & Bauman A. (2007). Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Med Sci Sports Exerc* **39,** 1423-1434.

Hawley JA, Brouns F & Jeukendrup A. (1998). Strategies to enhance fat utilisation during exercise. *Sports Med* **25,** 241-257.

Healy G, Matthews CE, Dunstan DW, Winkler EA & N. O. (2011). Sedentary time and cardio-metabolic biomarkers in US adults: NHANES 2003-06. *Eur Heart J* **32,** 590-597.

Healy GN, Dunstan DW, Salmon J, Cerin E, Shaw JE, Zimmet PZ & Owen N. (2008a). Breaks in sedentary time: beneficial associations with metabolic risk. *Diabetes care* **31,** 661-666.

Healy GN, Wijndaele K, Dunstan DW, Shaw JE, Salmon J, Zimmet PZ & Owen N. (2008b). Objectively measured sedentary time, physical activity, and metabolic risk: the Australian Diabetes, Obesity and Lifestyle Study (AusDiab). *Diabetes care* **31,** 369-371.

Heini AF, Minghelli G, Diaz E, Prentice AM & Schutz Y. (1996). Free-living energy expenditure assessed by two different methods in rural Gambian men. *Eur J Clin Nutr* **50,** 284-289.

Hickson RC. (1981). Skeletal muscle cytochrome c and myoglobin, endurance, and frequency of training. *J Appl Physiol Respir Environ Exerc Physiol* **51,** 746-749.

Higgins E. (1997). Beyond pleasure and pain. *Am Psychol* **52,** 1280-1300.

Hill A, Ward S, Deino A, Curtis G & Drake R. (1992). Earliest Homo. *Nature* **355,** 719-722.

Hillsdon M, Foster C, Naidoo B & Crombie H. (2004). The effectiveness of public health interventions for increasing physical activity among adults: a review of reviews, ed. Agency UHD.

Horton ES. (1986). Metabolic aspects of exercise and weight reduction. *Med Sci Sports Exerc* **18,** 10-18.

Hu F, Leitzmann M, Stampfer M, Colditz G, Willett W & Rimm E. (2001). Physical activity and television watching in relation to risk for type 2 diabetes mellitus in men. *Arch Intern Med* **161,** 1542-1548.

Hu F, Li T, Colditz G, Willett W & Manson J. (2003). Television watching and other sedentary behaviors in relation to risk of obesity and type 2 diabetes mellitus in women. *JAMA* **289,** 1785-1791.

Ijsselsteijn WA, Westerink J, de Jager M & Bonants R. (2006). Virtual Fitness: Stimulating Exercise Behavior through Media Technology. *Presence* **15,** 688-698.

IPAQ. (2011). International Physical Activity Questionnaire.

ISFE. (2012). http://www.isfe.eu/industry-facts, ed. Europe ISFo.

Jackson SA, Martin AJ & Eklund RC. (2008). Long and short measures of flow: the construct validity of the FSS-2, DFS-2, and new brief counterparts. *J Sport Exerc Psychol* **30,** 561-587.

Janssen S TH, Arends R. (2013). A Preliminary Study on the Effectiveness of Exergame Nintendo ‘‘Wii Fit Plus’’ on the Balance of Nursing Home Residents. *Games Health J* **2,** 89-95.

Jordan M, Donne B & D. F. (2010). Only lower limb controlled interactive computer gaming enables an effective increase in energy expenditure. *Eur J Appl Physiol* **111,** 1465-1472.

Joyner MJ & Nose H. (2009). Physiological regulation linked with physical activity and health. *J Physiol* **587,** 5525-5526.

Juneau CE & Potvin L. (2010). Trends in leisure-, transport-, and work-related physical activity in Canada 1994-2005. *Prev Med* **51,** 384-386.

Kanning M & Schlicht W. (2010). Be active and become happy: an ecological momentary assessment of physical activity and mood. *J Sport Exerc Psychol* **32,** 253-261.

Karvonen M, Kentala E & Mustala O. (1957). The effects of training on heart rate; a longitudinal study. *Ann Med Exp Biol Fenn* **35,** 307-315.

Kasapis C & Thompson PD. (2005). The effects of physical activity on serum C-reactive protein and inflammatory markers: a systematic review. *J Am Coll Cardiol* **45,** 1563-1569.

Keats MR, Jakobs A & Rhodes RE. (2011). The impact of active gaming on adherence to a cycling program: An exploratory study. *Health & Fitness J Can* **4,** 20.

Kelly MA, Rubinstein M, Phillips TJ, Lessov CN, Burkhart-Kasch S, Zhang G, Bunzow JR, Fang Y, Gerhardt GA, Grandy DK & Low MJ. (1998). Locomotor activity in D2 dopamine receptor-deficient mice is determined by gene dosage, genetic background, and developmental adaptations. *J Neurosci* **18,** 3470-3479.

Kendzierski D & DeCarlo KJ. (1991). Physical activity enjoyment scale: two validation studies. *J Sport Exerc Psychol* **13,** 50-64.

Kenney MJ & Seals DR. (1993). Postexercise hypotension. Key features, mechanisms, and clinical significance. *Hypertension* **22,** 653-664.

Keogh JW, Power N, Wooller L, Lucas P & Whatman C. (2013). Physical and Psychosocial Function in Residential Aged Care Elders: Effect of Nintendo Wii Sports Games. *J Aging Phys Act*.

Kilpatrick M, Kraemer R, Bartholomew J, Acevedo E & Jarreau D. (2007). Affective responses to exercise are dependent on intensity rather than total work. *Med Sci Sports Exerc* **39,** 1417-1422.

Kim Y, Wilkens LR, Park SY, Goodman MT, Monroe KR & Kolonel LN. (2013). Association between various sedentary behaviours and all-cause, cardiovascular disease and cancer mortality: the Multiethnic Cohort Study. *Int J Epidemiol* **42,** 1040-1056.

King AC, Castro C, Wilcox S, Eyler AA, Sallis JF & Brownson RC. (2000). Personal and environmental factors associated with physical inactivity among different racial-ethnic groups of U.S. middle-aged and older-aged women. *Health Psychol* **19,** 354-364.

King GA, Torres N, Potter C, Brooks TJ & Coleman KJ. (2004). Comparison of activity monitors to estimate energy cost of treadmill exercise. *Med Sci Sports Exerc* **36,** 1244-1251.

Kirk MA & Rhodes RE. (2011). Occupation correlates of adults' participation in leisure-time physical activity: a systematic review. *Am J Prev Med* **40,** 476-485.

Kitchen P, Williams A. & Chowhan J. (2011). Walking to work in Canada: health benefits, socio-economic characteristics and urban-regional variations. *BMC public health* **11,** 212.

Klingberg F & Klengel S. (1993). Lesions in four parts of the basal forebrain change basic behaviour in rats. *Neuroreport* **4,** 639-642.

Knuth A & Hallal P. (2009). Temporal trends in physical activity: a systematic review. *J Phys Act Health* **6,** 548-559.

Koeneman M, Verheijden M, Chinapaw M & Hopman-Rock M. (2011). Determinants of physical activity and exercise in healthy older adults: A systematic review. *Int J Behav Nutr Phys Act* **8,** 142.

Kosse NM, Caljouw SR, Vuijk P-J & Lamoth CJC. (2011). Exergaming: Interactive balance training in healthy community-dwelling older adults. *J CyberTher & Rehab* **4,** 399-407.

Koster A, Caserotti P, Patel KV, Matthews CE, Berrigan D, Van Domelen DR, Brychta RJ, Chen KY & Harris TB. (2012). Association of sedentary time with mortality independent of moderate to vigorous physical activity. *PLoS One* **7,** e37696.

Kraft JA, Russell WD, Bowman TA, Selsor CW, 3rd & Foster GD. (2011). Heart rate and perceived exertion during self-selected intensities for exergaming compared to traditional exercise in college-age participants. *J Strength Cond Res* **25,** 1736-1742.

Kruk J. (2007). Physical activity in the prevention of the most frequent chronic diseases: an analysis of the recent evidence. *Asian Pac J Cancer Prev* **8,** 325-338.

Kuipers H, Verstappen FT, Keizer HA, Geurten P & van Kranenburg G. (1985). Variability of aerobic performance in the laboratory and its physiologic correlates. *Int J Sports Med* **6,** 197-201.

Lakdawalla D & Philipson T. (2002). *The growth of obesity and technological change: a theoretical and empirical examination* vol. Working Paper 8946. Cambridge, MA.

Lamoth CJ, Alingh R & Caljouw SR. (2012). Exergaming for elderly: effects of different types of game feedback on performance of a balance task. *Stud Health Technol Inform* **181,** 103-107.

Lamoth CJ, Caljouw SR & Postema K. (2011). Active video gaming to improve balance in the elderly. *Stud Health Technol Inform* **167,** 159-164.

Lange BS, Requejo P, Flynn SM, Rizzo AA, Valero-Cuevas FJ, Baker L & Winstein C. (2010). The potential of virtual reality and gaming to assist successful aging with disability. *Phys Med Rehabil Clin N Am* **21,** 339-356.

Lanningham-Foster L, Foster RC, McCrady SK, Jensen TB, Mitre N & JA. L. (2009). Activity-promoting video games and increased energy expenditure. *J Pediatr* **154,** 819-823.

Lanningham-Foster L, Jensen TB, Foster RC, Redmond AB, Walker BA, Heinz D & Levine JA. (2006). Energy expenditure of sedentary screen time compared with active screen time for children. *Pediatrics* **118,** e1831-1835.

Lanningham-Foster L, Nysse LJ & Levine JA. (2003). Labor saved, calories lost: the energetic impact of domestic labor-saving devices. *Obes Res* **11,** 1178-1181.

Leatherdale S, Woodruff SJ & SR. M. (2010). Energy expenditure while playing active and inactive video games. *Am J Health Behav* **34,** 31-35.

Leblanc AG, Chaput JP, McFarlane A, Colley RC, Thivel D, Biddle SJ, Maddison R, Leatherdale ST & Tremblay MS. (2013). Active video games and health indicators in children and youth: a systematic review. *PLoS One* **8,** e65351.

Lee IM, Rexrode KM, Cook NR, Manson JE & Buring JE. (2001). Physical activity and coronary heart disease in women: is "no pain, no gain" passe? *JAMA* **285,** 1447-1454.

Lee IM & Skerrett PJ. (2001). Physical activity and all-cause mortality: what is the dose-response relation? *Med Sci Sports Exerc* **33,** S459-471; discussion S493-454.

Leitzmann MF, Park Y, Blair A, Ballard-Barbash R, Mouw T, Hollenbeck AR & Schatzkin A. (2007). Physical activity recommendations and decreased risk of mortality. *Arch Intern Med* **167,** 2453-2460.

Leonard W. (2008). Lifestyle, diet, and disease: comparative perspectives on the determinants of chronic health risks. In *Evolution in Health and Disease*, ed. Stearns SC K, JC. Oxford University press.

Levine JA. (2002). Non-exercise activity thermogenesis (NEAT). *Best Pract Res Clin Endocrinol Metab* **16,** 679-702.

Levine JA. (2003). Non-exercise activity thermogenesis. *Proc Nutr Soc* **62,** 667-679.

Levine JA. (2005). Measurement of energy expenditure. *Public Health Nutr* **8,** 1123-1132.

Levine JA. (2007). Nonexercise activity thermogenesis--liberating the life-force. *J Intern Med* **262,** 273-287.

Levine JA, Eberhardt NL & Jensen MD. (1999). Role of nonexercise activity thermogenesis in resistance to fat gain in humans. *Science* **283,** 212-214.

Levine JA & Kotz CM. (2005). NEAT--non-exercise activity thermogenesis--egocentric & geocentric environmental factors vs. biological regulation. *Acta Physiol Scand* **184,** 309-318.

Levine JA, Schleusner SJ & Jensen MD. (2000). Energy expenditure of nonexercise activity. *Am J Clin Nutr* **72,** 1451-1454.

Levine JA, Vander Weg MW, Hill JO & Klesges RC. (2006). Non-exercise activity thermogenesis: the crouching tiger hidden dragon of societal weight gain. *Arterioscler Thromb Vasc Biol* **26,** 729-736.

Lewis BA, Marcus BH, Pate RR & Dunn AL. (2002). Psychosocial mediators of physical activity behavior among adults and children. *Am J Prev Med* **23,** 26-35.

Lieberman DA. (2013). Modern times, modern bodies. In *The story of the human body Evolution, health & disease* pp. 209-247. Penguin books, London.

Lieberman DA, Chamberlin B, Medina E, Jr., Franklin BA, Sanner BM & Vafiadis DK. (2011). The power of play: Innovations in Getting Active Summit 2011: a science panel proceedings report from the American Heart Association. *Circulation* **123,** 2507-2516.

Lim SS, Vos T, Flaxman AD, Danaei G, Shibuya K, Adair-Rohani H, Amann M, Anderson HR, Andrews KG, Aryee M, Atkinson C, Bacchus LJ, Bahalim AN, Balakrishnan K, Balmes J, Barker-Collo S, Baxter A, Bell ML, Blore JD, Blyth F, Bonner C, Borges G, Bourne R, Boussinesq M, Brauer M, Brooks P, Bruce NG, Brunekreef B, Bryan-Hancock C, Bucello C, Buchbinder R, Bull F, Burnett RT, Byers TE, Calabria B, Carapetis J, Carnahan E, Chafe Z, Charlson F, Chen H, Chen JS, Cheng AT, Child

JC, Cohen A, Colson KE, Cowie BC, Darby S, Darling S, Davis A, Degenhardt L, Dentener F, Des Jarlais DC, Devries K, Dherani M, Ding EL, Dorsey ER, Driscoll T, Edmond K, Ali SE, Engell RE, Erwin PJ, Fahimi S, Falder G, Farzadfar F, Ferrari A, Finucane MM, Flaxman S, Fowkes FG, Freedman G, Freeman MK, Gakidou E, Ghosh S, Giovannucci E, Gmel G, Graham K, Grainger R, Grant B, Gunnell D, Gutierrez HR, Hall W, Hoek HW, Hogan A, Hosgood HD, 3rd, Hoy D, Hu H, Hubbell BJ, Hutchings SJ, Ibeanusi SE, Jacklyn GL, Jasrasaria R, Jonas JB, Kan H, Kanis JA, Kassebaum N, Kawakami N, Khang YH, Khatibzadeh S, Khoo JP, Kok C, Laden F, Lalloo R, Lan Q, Lathlean T, Leasher JL, Leigh J, Li Y, Lin JK, Lipshultz SE, London S, Lozano R, Lu Y, Mak J, Malekzadeh R, Mallinger L, Marcenes W, March L, Marks R, Martin R, McGale P, McGrath J, Mehta S, Mensah GA, Merriman TR, Micha R, Michaud C, Mishra V, Mohd Hanafiah K, Mokdad AA, Morawska L, Mozaffarian D, Murphy T, Naghavi M, Neal B, Nelson PK, Nolla JM, Norman R, Olives C, Omer SB, Orchard J, Osborne R, Ostro B, Page A, Pandey KD, Parry CD, Passmore E, Patra J, Pearce N, Pelizzari PM, Petzold M, Phillips MR, Pope D, Pope CA, 3rd, Powles J, Rao M, Razavi H, Rehfuess EA, Rehm JT, Ritz B, Rivara FP, Roberts T, Robinson C, Rodriguez-Portales JA, Romieu I, Room R, Rosenfeld LC, Roy A, Rushton L, Salomon JA, Sampson U, Sanchez-Riera L, Sanman E, Sapkota A, Seedat S, Shi P, Shield K, Shivakoti R, Singh GM, Sleet DA, Smith E, Smith KR, Stapelberg NJ, Steenland K, Stockl H, Stovner LJ, Straif K, Straney L, Thurston GD, Tran JH, Van Dingenen R, van Donkelaar A, Veerman JL, Vijayakumar L, Weintraub R, Weissman MM, White RA, Whiteford H, Wiersma ST, Wilkinson JD, Williams HC, Williams W, Wilson N, Woolf AD, Yip P, Zielinski JM, Lopez AD, Murray CJ, Ezzati M, AlMazroa MA & Memish ZA. (2012). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* **380,** 2224-2260.

Lind E, Joens-Matre RR & Ekkekakis P. (2005). What intensity of physical activity do previously sedentary middle-aged women select? Evidence of a coherent pattern from physiological, perceptual, and affective markers. *Prev Med* **40,** 407-419.

Lyons E, Tate DF, Ward DS, Bowling JM, Ribisl KM & S. K. (2011). Energy expenditure and enjoyment during video game play: differences by game type. *Med Sci Sports Exerc* **43,** 1987-1993.

Lyons EJ, Tate DF, Komoski SE, Carr PM & Ward DS. (2012). Novel approaches to obesity prevention: effects of game enjoyment and game type on energy expenditure in active video games. *J Diabetes Sci Technol* **6,** 839-848.

Lyons EJ, Tate DF, Ward DS, Ribisl KM, Bowling JM & Kalyanaraman S. (2013). Engagement, Enjoyment, and Energy Expenditure During Active Video Game Play. *Health Psychol*.

Macniven R, Bauman A & Abouzeid M. (2012). A review of population-based prevalence studies of physical activity in adults in the Asia-Pacific region. *BMC public health* **12,** 41.

Maddison R, Foley L, Ni Mhurchu C, Jiang Y, Jull A, Prapavessis H, Hohepa M & Rodgers A. (2011). Effects of active video games on body composition: a randomized controlled trial. *Am J Clin Nutr* **94,** 156-163.

Maddison R, Mhurchu CN, Jull A, Jiang Y, Prapavessis H & Rodgers A. (2007). Energy expended playing video console games: an opportunity to increase children's physical activity? *Pediatr Exerc Sci* **19,** 334-343.

Maddison R, Ni Mhurchu C, Jull A, Prapavessis H, Foley LS & Jiang Y. (2012). Active video games: the mediating effect of aerobic fitness on body composition. *Int J Behav Nutr Phys Act* **9,** 54.

Madsen KA, Yen S, Wlasiuk L, Newman TB & Lustig R. (2007). Feasibility of a dance videogame to promote weight loss among overweight children and adolescents. *Arch Pediatr Adolesc Med* **161,** 105-107.

Maillot P, Perrot A & Hartley A. (2011). Effects of interactive physical-activity video-game training on physical and cognitive function in older adults. *Psychology and aging*.

Maloney AE, Bethea TC, Kelsey KS, Marks JT, Paez S, Rosenberg AM, Catellier DJ, Hamer RM & Sikich L. (2008). A pilot of a video game (DDR) to promote physical activity and decrease sedentary screen time. *Obesity (Silver Spring)* **16,** 2074-2080.

Maloney AE, Threlkeld KA & Cook WL. (2012). Comparative Effectiveness of a 12-Week Physical Activity Intervention for Overweight and Obese Youth: Exergaming with “Dance Dance Revolution”. *Games Health J* **1,** 96-103.

Manson JE, Greenland P, LaCroix AZ, Stefanick ML, Mouton CP, Oberman A, Perri MG, Sheps DS, Pettinger MB & Siscovick DS. (2002). Walking compared with vigorous exercise for the prevention of cardiovascular events in women. *N Engl J Med* **347,** 716-725.

Maroulakis E & Zervas Y. (1993). Effects of aerobic exercise on mood of adult women. *Percept Mot Skills* **76,** 795-801.

Marti B. (1991). Health effects of recreational running in women. Some epidemiological and preventive aspects. *Sports Med* **11,** 20-51.

Martin A & Jackson S. (2008). Brief approaches to assessing task absorption and enhanced subjective experience: Examining 'short' and 'core' flow in diverse performance domains. *Motiv Emot* **32,** 141-157.

Martinez-Gonzalez MA, Martinez JA, Hu FB, Gibney MJ & Kearney J. (1999). Physical inactivity, sedentary lifestyle and obesity in the European Union. *Int J Obes Relat Metab Disord* **23,** 1192-1201.

Matsumoto H & Tekenaka K. (2004). Motivational profiles and stages of exercise behaviour change. *Int J Sport Health Sc* **2,** 89-96.

Matthews CE, George SM, Moore SC, Bowles HR, Blair A, Park Y, Troiano RP, Hollenbeck A & Schatzkin A. (2012). Amount of time spent in sedentary behaviors and cause-specific mortality in US adults. *Am J Clin Nutr* **95,** 437-445.

McAuley E & Courneya K. (1994). The Subjective Exercise Experiences Scale (SEES): Development and preliminary validation. *J Sport Exerc Psychol***,** 163-177.

McAuley E, Duncan T & Tammen VV. (1989). Psychometric properties of the Intrinsic Motivation Inventory in a competitive sport setting: a confirmatory factor analysis. *Res Q Exerc Sport* **60,** 48-58.

McConnell TR & Clark BA. (1988). Treadmill protocols for determination of maximum oxygen uptake in runners. *Br J Sports Med* **22,** 3-5.

McLaughlin JE, King GA, Howley ET, Bassett DR, Jr. & Ainsworth BE. (2001). Validation of the COSMED K4 b2 portable metabolic system. *Int J Sports Med* **22,** 280-284.

Mejia-Downs A, Fruth SJ, Clifford A, Hine S, Huckstep J, Merkel H, Wilkinson H & Yoder J. (2011). A Preliminary Exploration of the Effects of a 6-week Interactive Video Dance Exercise Program in an Adult Population. *Cardiopulm Phys Ther J* **22,** 5-11.

Melby C, Scholl C, Edwards G & Bullough R. (1993). Effect of acute resistance exercise on postexercise energy expenditure and resting metabolic rate. *J Appl Physiol (1985)* **75,** 1847-1853.

Mellecker RR, Lanningham-Foster L, Levine JA & McManus AM. (2010). Energy intake during activity enhanced video game play. *Appetite* **55,** 343-347.

Mellecker RR & McManus AM. (2008). Energy expenditure and cardiovascular responses to seated and active gaming in children. *Arch Pediatr Adolesc Med* **162,** 886-891.

Mellecker RR & McManus AM. (2013). Active video games and physical activity recommendations: A comparison of the Gamercize Stepper, XBOX Kinect and XaviX J-Mat. *J Sci Med Sport*.

Mills A, Rosenberg M, Stratton G, Carter HH, Spence AL, Pugh CJ, Green DJ & Naylor LH. (2013). The effect of exergaming on vascular function in children. *J Pediatr* **163,** 806-810.

Mitre N, Foster RC, Lanningham-Foster L & Levine JA. (2011). The energy expenditure of an activity-promoting video game compared to sedentary video games and TV watching. *J Pediatr Endocrinol Metab* **24,** 689-695.

Miyachi M, Yamamoto K, Ohkawara K & S. T. (2010). METs in adults while playing active video games: a metabolic chamber study. *Med Sci Sports Exerc* **42,** 1149-1153.

Monedero J, McDonnell AC, Keoghan M & O'Gorman DJ. (2014). Modified Active Videogame Play Results in Moderate-Intensity Exercise. *Games Health J* **3**.

Montoye HJ. (1996). *Measuring Physical Activity and Energy Expenditure*. Human Kinetics, Champaign, IL

Moore LV, Harris CD, Carlson SA, Kruger J & Fulton JE. (2012). Trends in no leisure-time physical activity--United States, 1988-2010. *Res Q Exerc Sport* **83,** 587-591.

Morris JN, Heady JA, Raffle PA, Roberts CG & Parks JW. (1953). Coronary heart-disease and physical activity of work. *Lancet* **265,** 1053-1057; contd.

Moses J, Steptoe A, Mathews A & Edwards S. (1989). The effects of exercise training on mental well-being in the normal population: a controlled trial. *J Psychosom Res* **33,** 47-61.

Motl RW, Dishman RK, Saunders R, Dowda M, Felton G & Pate RR. (2001). Measuring enjoyment of physical activity in adolescent girls. *Am J Prev Med* **21,** 110-117.

Mullins NM, Tessmer KA, Mccarroll ML & Peppel BP. (2012). Physiological and Perceptual Responses to Nintendo® Wii Fit™ in Young and Older Adults. *Int J Exerc Sci* **5,** 79-92.

Murphy EC, Carson L, Neal W, Baylis C, Donley D & Yeater R. (2009). Effects of an exercise intervention using Dance Dance Revolution on endothelial function and other risk factors in overweight children. *Int J Pediatr Obes* **4,** 205-214.

Murphy MH, Donnelly P, Breslin G, Shibli S & Nevill AM. (2013). Does doing housework keep you healthy? The contribution of domestic physical activity to meeting current recommendations for health. *BMC public health* **13,** 966.

Myers J, Kaykha A, George S, Abella J, Zaheer N, Lear S, Yamazaki T & Froelicher V. (2004). Fitness versus physical activity patterns in predicting mortality in men. *Am J Med* **117,** 912-918.

Naci H & Ioannidis J. (2013). Comparative effectiveness of exercise and drug interventions on mortality outcomes: metaepidemiological study. *BMJ* **347**.

Naugle K & Wikstrom E. (2013). Cardiovascular and Affective Outcomes of Active Gaming: Using the Wii as a Cardiovascular Training Tool. *J Strength Cond Res*.

Ng S & Popkin B. (2012). Time use and physical activity: a shift away from movement across the globe. *Obes Rev* **13,** 659-680.

Ni Mhurchu C, Maddison R, Jiang Y, Jull A, Prapavessis H & Rodgers A. (2008). Couch potatoes to jumping beans: A pilot study of the effect of active video games on physical activity in children. *Int J Behav Nutr Phys Act* **5,** 8.

Nitz JC, Kuys S, Isles R & Fu S. (2010). Is the Wii Fit a new-generation tool for improving balance, health and well-being? A pilot study. *Climacteric : the journal of the International Menopause Society* **13,** 487-491.

Noble BJ, Borg GA, Jacobs I, Ceci R & Kaiser P. (1983). A category-ratio perceived exertion scale: relationship to blood and muscle lactates and heart rate. *Med Sci Sports Exerc* **15,** 523-528.

O'Connor TJ, Fitzgerald SG, Cooper RA, Thorman TA & Boninger ML. (2001). Does computer game play aid in motivation of exercise and increase metabolic activity during wheelchair ergometry? *Med Eng Phys* **23,** 267-273.

O'Donovan C, Hirsch E, Holohan E, McBride I, McManus R & Hussey J. (2012). Energy expended playing Xbox Kinect and Wii games: a preliminary study comparing single and multiplayer modes. *Physiotherapy* **98,** 224-229.

O'Donovan C & Hussey J. (2012). Active video games as a form of exercise and the effect of gaming experience: a preliminary study in healthy young adults. *Physiotherapy* **98,** 205-210.

O'Keefe JH, Vogel R, Lavie CJ & Cordain L. (2010). Organic fitness: physical activity consistent with our hunter-gatherer heritage. *Phys Sportsmed* **38,** 11-18.

Oh Y, Yang, S. (2010). Defining Exergames & Exergaming. In *Meaningful Play*. Michigan State University.

Oja P, Titze S, Bauman A & al. e. (2011). Health benefits of cycling: a systematic review. *Scand J Med Sci Sports* **21,** 496-509.

Owen N, Healy G, Matthews C & Dunstan D. (2010a). Too much sitting: the population health science of sedentary behavior. *Exerc Sport Sci Rev* **38,** 105 - 113.

Owen N, Leslie E, Salmon J & Fotheringham MJ. (2000). Environmental determinants of physical activity and sedentary behavior. *Exerc Sport Sci Rev* **28,** 153-158.

Owen N, Sparling PB, Healy GN, Dunstan DW & Matthews CE. (2010b). Sedentary behavior: emerging evidence for a new health risk. *Mayo Clin Proc* **85,** 1138-1141.

Owen N, Sugiyama T, Eakin EE, Gardiner PA, Tremblay MS & Sallis JF. (2011). Adults' sedentary behavior determinants and interventions. *Am J Prev Med* **41,** 189-196.

Owens SG, Garner JC, 3rd, Loftin JM, van Blerk N & Ermin K. (2011). Changes in physical activity and fitness after 3 months of home Wii Fit use. *J Strength Cond Res* **25,** 3191-3197.

Paffenbarger RS, Jr., Hyde RT, Wing AL & Hsieh CC. (1986). Physical activity, all-cause mortality, and longevity of college alumni. *N Engl J Med* **314,** 605-613.

Paffenbarger RS, Jr., Wing AL, Hyde RT & Jung DL. (1983). Physical activity and incidence of hypertension in college alumni. *Am J Epidemiol* **117,** 245-257.

Palacios-Cena D, Alonso-Blanco C, Jimenez-Garcia R, Hernandez-Barrera V, Carrasco-Garrido P, Pileno-Martinez E & Fernandez-de-Las-Penas C. (2011). Time trends in leisure time physical activity and physical fitness in elderly people: 20 year follow-up of the Spanish population national health survey (1987-2006). *BMC public health* **11,** 799.

Parfitt G, Rose EA & Burgess WM. (2006). The psychological and physiological responses of sedentary individuals to prescribed and preferred intensity exercise. *Br J Health Psychol* **11,** 39-53.

Peluso MA & Guerra de Andrade LH. (2005). Physical activity and mental health: the association between exercise and mood. *Clinics (Sao Paulo)* **60,** 61-70.

Peng W, Crouse JC & Lin J-H. (2013). Using Active Video Games for Physical Activity Promotion: A Systematic Review of the Current State of Research. *Health Educ Behav* **40,** 171-192.

Peng W, Lin JH & Crouse J. (2011). Is playing exergames really exercising? A meta-analysis of energy expenditure in active video games. *Cyberpsychol Behav Soc Netw* **14,** 681-688.

Penko AL & Barkley JE. (2010). Motivation and physiologic responses of playing a physically interactive video game relative to a sedentary alternative in children. *Ann Behav Med* **39,** 162-169.

Perron R, Graham, CA, Hall, EE. (2012). Comparison of Physiological and Psychological Responses to Exergaming and Treadmill Walking in Healthy Adults. *Games Health J* **1,** 411-415.

Pigford T & Andrews A. (2010). Feasibility and benefit of using the Nintendo Wii Fit for balance rehabilitation in an elderly patient experiencing recurrent falls. *J Student Phys Ther Res* **2,** 12 - 20.

Pimlott N. (2010). The miracle drug. *Can Fam Physician***,** 407-409.

Plonczynski DJ. (2003). Physical activity determinants of older women: what influences activity? *Medsurg Nurs* **12,** 213-221, 259; quiz 222.

Plowman S & Smith D. (2013). *Exercise Physiology for health, fitness, and performance*. Lippincott Williams & Wilkins.

Powers SK, Duarte J, Kavazis AN & Talbert EE. (2010). Reactive oxygen species are signalling molecules for skeletal muscle adaptation. *Exp Physiol* **95,** 1-9.

Pratt M, Macera CA, Sallis JF, O'Donnell M & Frank LD. (2004). Economic interventions to promote physical activity: application of the SLOTH model. *Am J Prev Med* **27,** 136-145.

Primack BA, Carroll MV, McNamara M, Klem ML, King B, Rich M, Chan CW & Nayak S. (2012). Role of Video Games in Improving Health-Related Outcomes: A Systematic Review. *Am J Prev Med* **42,** 630-638.

Prince SA, Adamo KB, Hamel ME, Hardt J, Connor Gorber S & Tremblay M. (2008). A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *Int J Behav Nutr Phys Act* **5,** 56.

Probert AW, Tremblay MS & Connor Gorber S. (2008). Desk potatoes: the importance of occupational physical activity on health. *Can J Public Health* **99,** 311-318.

Raglin JS & Morgan WP. (1987). Influence of exercise and quiet rest on state anxiety and blood pressure. *Med Sci Sports Exerc* **19,** 456-463.

Rhodes R & Pfaeffli L. (2010). Mediators of physical activity behaviour change among adult non-clinical populations: a review update. *Int J Behav Nutr Phys Act* **7,** 37.

Rhodes RE, Blanchard CM & Matheson DH. (2006). A multicomponent model of the theory of planned behaviour. *Br J Health Psychol* **11,** 119-137.

Rhodes RE, Martin AD, Taunton JE, Rhodes EC, Donnelly M & Elliot J. (1999). Factors associated with exercise adherence among older adults. An individual perspective. *Sports Med* **28,** 397-411.

Rhodes RE, Warburton DE & Bredin SS. (2009). Predicting the effect of interactive video bikes on exercise adherence: An efficacy trial. *Psychol Health Med* **14,** 631-640.

Ridgers ND, McKinney J, Stratton G & Graves LE. (2011). Comparing the physiological cost of Step-powered video gaming, sedentary video gaming, and self-paced ambulatory activity in university students. *Arch Exerc Health Dis* **2,** 81-88.

Ridley K & Olds T. (2001). Video center games: energy cost and children's behaviors. *Pediatr Exerc Sci* **13,** 413-421.

Rook A. (1954). An investigation into the longevity of Cambridge sportsmen. *Br Med J* **1,** 773-777.

Rose EA & Parfitt G. (2007). A quantitative analysis and qualitative explanation of the individual differences in affective responses to prescribed and self-selected exercise intensities. *J Sport Exerc Psychol* **29,** 281-309.

Rowell L. (1986). *Human circulation: regulation during physical stress*. Oxford University Press, New York.

Sahlin K, Tonkonogi M & Soderlund K. (1998). Energy supply and muscle fatigue in humans. *Acta Physiol Scand* **162,** 261-266.

Saklofske DH, Austin EJ, Rohr BA & Andrews JJW. (2007). Personality, Emotional Intelligence and Exercise. *J Health Psychol* **12,** 937-948.

Salmon J, Owen N, Bauman A, Schmitz MK & Booth M. (2000). Leisure-time, occupational, and household physical activity among professional, skilled, and less-skilled workers and homemakers. *Prev Med* **30,** 191-199.

Salmon J, Owen N, Crawford D, Bauman A & Sallis JF. (2003). Physical activity and sedentary behavior: a population-based study of barriers, enjoyment, and preference. *Health Psychol* **22,** 178-188.

Saltin B. (1969). Physiological effects of physical conditioning. *Med Sci Sports Exerc***,** 50-56.

Saltin B & Rowell LB. (1980). Functional adaptations to physical activity and inactivity. *Fed Proc* **39,** 1506-1513.

Sanders G, Santo A, Peacock CA, Williansom ML, Von Carlowitz KP & Barkley J. (2012). Physiologic responses, liking and motivation for playing the same video game on an active versus a traditional, non-active gaming system. *Int J Exerc Sci* **5,** 160-169.

Saris WH, Blair SN, van Baak MA, Eaton SB, Davies PS, Di Pietro L, Fogelholm M, Rissanen A, Schoeller D, Swinburn B, Tremblay A, Westerterp KR & Wyatt H. (2003). How much physical activity is enough to prevent unhealthy weight gain? Outcome of the IASO 1st Stock Conference and consensus statement. *Obes Rev* **4,** 101-114.

Sattelmair J, Pertman J, Ding EL, Kohl HW, 3rd, Haskell W & Lee IM. (2011). Dose response between physical activity and risk of coronary heart disease: a meta-analysis. *Circulation* **124,** 789-795.

Schoene D, Lord SR, Delbaere K, Severino C, Davies TA & Smith ST. (2013). A randomized controlled pilot study of home-based step training in older people using videogame technology. *PLoS One* **8,** e57734.

Schoene D, Lord SR, Verhoef P & Smith ST. (2011). A novel video game--based device for measuring stepping performance and fall risk in older people. *Arch Phys Med Rehabil* **92,** 947-953.

Schooling CM, Lam TH, Li ZB, Ho SY, Chan WM, Ho KS, Tham MK, Cowling BJ & Leung GM. (2006). Obesity, physical activity, and mortality in a prospective chinese elderly cohort. *Arch Intern Med* **166,** 1498-1504.

Sedentary Behaviour Research N. (2012). Letter to the editor: standardized use of the terms "sedentary" and "sedentary behaviours". *Appl Physiol Nutr Metab* **37,** 540-542.

Sell K, Lillie T & Taylor J. (2008). Energy expenditure during physically interactive video game playing in male college students with different playing experience. *J Am Coll Health* **56,** 505-511.

Sharma A, Madaan V & Petty FD. (2006). Exercise for mental health. *Prim Care Companion J Clin Psychiatry* **8,** 106.

Shubert TE. (2010). The use of commercial health video games to promote physical activity in older adults. *Annals of Long-term care* **18,** 27-32.

Siegel SR, L Haddock B, Dubois AM & Wilkin LD. (2009). Active Video/Arcade Games (Exergaming) and Energy Expenditure in College Students. *Int J Exerc Sci* **2,** 165-174.

Simons M, Chinapaw MJ, van de Bovenkamp M, de Boer MR, Seidell JC, Brug J & de Vet E. (2014). Active video games as a tool to prevent excessive weight gain in adolescents: rationale, design and methods of a randomized controlled trial. *BMC public health* **14,** 275.

Sjol A, Thomsen KK, Schroll M & Andersen LB. (2003). Secular trends in acute myocardial infarction in relation to physical activity in the general Danish population. *Scand J Med Sci Sports* **13,** 224-230.

Smallwood SR, Morris MM, Fallows SJ & Buckley JP. (2012). Physiologic Responses and Energy Expenditure of Kinect Active Video Game Play in Schoolchildren. *Arch Pediatr Adolesc Med***,** 1-5.

Soltani P, Salesi, M. (2013). Effects of Exergame and Music on Acute Exercise Responses to Graded Treadmill Running. *Games Health J* **2,** 75-80.

Sorensen L. (2005). Correlates of physical activity among middle-aged Finnish male police officers. In *Occup Med (Lond)*, 2005/03/11 edn, pp. 136-138.

Speakman JR & Selman C. (2003). Physical activity and resting metabolic rate. *Proc Nutr Soc* **62,** 621-634.

Stach T, Graham N, Brehmer M & Hollatz A. (2009). Classifying input for active games. In *International Conference of Advances in Computer Entertainment Technology*. Athens, Greece.

Stamatakis E & Chaudhury M. (2008). Temporal trends in adults' sports participation patterns in England between 1997 and 2006: the Health Survey for England. *Br J Sports Med* **42,** 901-908.

Ste Marie L, Miura GI, Marsh DJ, Yagaloff K & Palmiter RD. (2000). A metabolic defect promotes obesity in mice lacking melanocortin-4 receptors. *Proc Natl Acad Sci U S A* **97,** 12339-12344.

Stephens & T. (1988). Physical activity and mental health in the United States and Canada: evidence from four population surveys. *Prev Med* **17,** 35-47.

Steptoe A & Bolton J. (1988). The short-term influence of high and low intensity physical exercise on mood. *Psychol Health* **2,** 91-106.

Steptoe A & Cox S. (1988). Acute effects of aerobic exercise on mood. *Health Psychol* **7,** 329-340.

Stiegler P & Cunliffe A. (2006). The role of diet and exercise for the maintenance of fat-free mass and resting metabolic rate during weight loss. *Sports Med* **36,** 239-262.

Straker L & Abbott R. (2007). Effect of screen-based media on energy expenditure and heart rate in 9- to 12-year-old children. *Pediatr Exerc Sci* **19,** 459-471.

Stroud LC, Amonette WE & Dupler TL. (2010). Appl Physiol Nutr Metab. *Appl Physiol Nutr Metab* **35,** 643-649.

Studenski S, Perera S, Hile E, Keller V, Spadola-Bogard J & Garcia J. (2010). Interactive video dance games for healthy older adults. *J Nutr Health Aging* **14,** 850-852.

Swain D, Abernathy K, Smith C, Lee S & Bunn S. (1994). Target heart rates for the development of cardiorespiratory fitness. *Med Sci Sports Exerc* **26,** 112-116.

Swain DP & Leutholtz BC. (1997). Heart rate reserve is equivalent to %VO2 reserve, not to %VO2max. *Med Sci Sports Exerc* **29,** 410-414.

Swan J HP. (2012). A Review of the Beneficial Mental Health Effects of Exercise and Recommendations for Future Research. *Psychology & Society* **5,** 1-15.

Sween J, Wallington SF, Sheppard V, Taylor T, Llanos AA & Adams-Campbell LL. (2013). The Role of Exergaming in Improving Physical Activity: A Review. *J Phys Act Health*.

Swinburn B, Egger G & Raza F. (1999). Dissecting obesogenic environments: the development and application of a framework for identifying and prioritizing environmental interventions for obesity. *Prev Med* **29,** 563-570.

Szturm T, Betker AL, Moussavi Z, Desai A & Goodman V. (2011). Effects of an interactive computer game exercise regimen on balance impairment in frail community-dwelling older adults: a randomized controlled trial. *Phys Ther* **91,** 1449-1462.

Tan B, Aziz AR, Chua K & Teh K. (2002). Aerobic demands of the dance simulation game. *Int J Sports Med* **23,** 125-129.

Taylor LM, Maddison R, Pfaeffli LA, Rawstorn JC, Gant N & Kerse NM. (2012). Activity and Energy Expenditure in Older People Playing Active Video Games. *Arch Phys Med Rehabil*.

Terjung R. (1995). Muscle adaptations to aerobic training. *Sports Science Exchange* **8**.

Thayer RE, Peters Iii DP, Takahashi PJ & Birkhead-Flight AM. (1993). Mood and behavior (smoking and sugar snacking) following moderate exercise: A partial test of self-regulation theory. *Personality and Individual Differences* **14,** 97-104.

Thin AG, Hansen L & McEachen D. (2011). Flow Experience and Mood States While Playing Body Movement-Controlled Video Games. *Games and Culture* **6,** 414.

Thompson PD, Crouse SF, Goodpaster B, Kelley D, Moyna N & Pescatello L. (2001). The acute versus the chronic response to exercise. *Med Sci Sports Exerc* **33,** S438-445; discussion S452-433.

Thorp AA, Healy GN, Owen N, Salmon J, Ball K, Shaw JE, Zimmet PZ & Dunstan DW. (2010). Deleterious associations of sitting time and television viewing time with cardiometabolic risk biomarkers: Australian Diabetes, Obesity and Lifestyle (AusDiab) study 2004-2005. *Diabetes care* **33,** 327-334.

Thorp AA, Owen N, Neuhaus M & Dunstan DW. (2011). Sedentary Behaviors and Subsequent Health Outcomes in Adults: A Systematic Review of Longitudinal Studies, 1996–2011. *Am J Prev Med* **41,** 207-215.

Tokunaga K, Matsuzawa Y, Fujioka S, Kobatake T, Keno Y, Odaka H, Matsuo T & Tarui S. (1991). PVN-lesioned obese rats maintain ambulatory activity and its circadian rhythm. *Brain Res Bull* **26,** 393-396.

Tremblay MS, Colley RC, Saunders TJ, Healy GN & Owen N. (2010). Physiological and health implications of a sedentary lifestyle. *Appl Physiol Nutr Metab* **35,** 725-740.

Tremblay MS, Esliger DW, Tremblay A & Colley R. (2007). Incidental movement, lifestyle-embedded activity and sleep: new frontiers in physical activity assessment. *Can J Public Health* **98 Suppl 2,** S208-217.

Trost SG, Owen N, Bauman AE, Sallis JF & Brown W. (2002). Correlates of adults' participation in physical activity: review and update. *Med Sci Sports Exerc* **34,** 1996-2001.

Trost SG, Sundal D, Foster GD, Lent MR & Vojta D. (2014). Effects of a Pediatric Weight Management Program With and Without Active Video Games: A Randomized Trial. *JAMA Pediatr*.

Trout J & K. Z. (2008). Dance Dance Revolution: A physiological look at an interactive arcade game. *ICHPERD Jour Research* **3,** 67-72.

Tucker JM, Welk GJ & Beyler NK. (2011). Physical activity in U.S.: adults compliance with the Physical Activity Guidelines for Americans. *Am J Prev Med* **40,** 454-461.

Tudor-Locke CE & Myers AM. (2001). Challenges and opportunities for measuring physical activity in sedentary adults. *Sports Med* **31,** 91-100.

U.S. Department of Health and Human Services CfDCaP, National & Center for Chronic Disease Prevention and Health Promotion. (1996). Physical Activity and Health: A Report of the Surgeon General. 1996., ed. Services. USDoHaH. Atlanta, GA: U.S.

Unnithan VB, Houser W & Fernhall B. (2006). Evaluation of the energy cost of playing a dance simulation video game in overweight and non-overweight children and adolescents. *Int J Sports Med* **27,** 804-809.

van Stralen MM, De Vries H, Mudde AN, Bolman C & Lechner L. (2009). Determinants of initiation and maintenance of physical activity among older adults: a literature review. *Health Psychol Rev* **3,** 147-207.

Vazou-Ekkekakis V, Ekkekakis, P. (2005). Affective consequences of imposing the intensity of physical activity: does the loss of perceived autonomy matter? *Hell J Psychol* **6,** 125-144.

Wang JS, Jen CJ & Chen HI. (1995). Effects of exercise training and deconditioning on platelet function in men. *Arterioscler Thromb Vasc Biol* **15,** 1668-1674.

Wankel L. (1993). The importance of enjoyment to adherence and psychological benefits from physical activity. *Int J Sports Psychol* **24,** 151-169.

Warburton D, Katzmarzyk P, Rhodes R & RJ. S. (2007a). Evidence-informed physical activity guidelines for Canadian adults. *Can J Public Health* **98** S16-68.

Warburton D, Nicol C & SS. B. (2006). Health benefits of physical activity: the evidence. *CMAJ* **174,** 801-809.

Warburton D, Sarkany D, Johnson M & al. e. (2009). Metabolic requirements of interactive video game cycling. *Med Sci Sports Exerc* **41,** 920-926.

Warburton DE, Bredin SS, Horita LT, Zbogar D, Scott JM, Esch BT & Rhodes RE. (2007b). The health benefits of interactive video game exercise. *Appl Physiol Nutr Metab* **32,** 655-663.

Warburton DE, Gledhill N & Quinney A. (2001a). Musculoskeletal fitness and health. *Can J Appl Physiol* **26,** 217-237.

Warburton DE, Glendhill N & Quinney A. (2001b). The effects of changes in musculoskeletal fitness on health. *Can J Appl Physiol* **26,** 161-216.

Weir J. (1949). New methods for calculating metabolic rate with special reference to protein metabolism. *J Physiol* **109,** 1-9.

Wen CP, Wai JP, Tsai MK, Yang YC, Cheng TY, Lee MC, Chan HT, Tsao CK, Tsai SP & Wu X. (2011). Minimum amount of physical activity for reduced mortality and extended life expectancy: a prospective cohort study. *Lancet* **378,** 1244-1253.

Westerterp KR. (1998). Alterations in energy balance with exercise. *Am J Clin Nutr* **68,** 970S-974S.

White K, Schofield G & Kilding AE. (2011). Energy expended by boys playing active video games. *J Sci Med Sport* **14,** 130-134.

WHO. (2009). GLOBAL HEALTH RISKS. Mortality and burden of disease attributable to selected major risks, ed. Organisation WH.

WHO. (2010). Global recommendations on physical activity for health.

WHO. (2011). Global Physical Activity Surveillance.

WHO rofE. (2005). HEPA Europe. European network for the promotion of Health-Enhancing Physical Activity, ed. Europe RO.

Widman LM, McDonald CM & Abresch RT. (2006). Effectiveness of an upper extremity exercise device integrated with computer gaming for aerobic training in adolescents with spinal cord dysfunction. *J Spinal Cord Med* **29,** 363-370.

Willems M & Bond T. (2009a). Comparison of physiological and metabolic responses to playing Nintendo Wii sports and brisk treadmill walking. *J Human Kinetics* **22,** 43-50.

Willems M & Bond T. (2009b). Metabolic equivalents of brisk walking and playing new generation active computer games in young-adults. *Med Sportiva* **13,** 95-98.

Williams DM, Dunsiger S, Ciccolo JT, Lewis BA, Albrecht AE & Marcus BH. (2008). Acute Affective Response to a Moderate-intensity Exercise Stimulus Predicts Physical Activity Participation 6 and 12 Months Later. *Psychol Sport Exerc* **9,** 231-245.

Williams PT. (2001). Physical fitness and activity as separate heart disease risk factors: a meta-analysis. *Med Sci Sports Exerc* **33,** 754-761.

Wilmot EG, Edwardson CL, Achana FA, Davies MJ, Gorely T, Gray LJ, Khunti K, Yates T & Biddle SJ. (2012). Sedentary time in adults and the association with diabetes, cardiovascular disease and death: systematic review and meta-analysis. *Diabetologia*.

Wollersheim D, Merkes M, Shields N, Liamputtong P, Wallis L, Reynolds F & Koh L. (2010). Physical and Psychosocial effects of Wii video game use among older women. *Int J Emerging Tech Society* **8,** 85-98.

Woodcock J, Franco OH, Orsini N & Roberts I. (2011). Non-vigorous physical activity and all-cause mortality: systematic review and meta-analysis of cohort studies. *Int J Epidemiol* **40,** 121-138.

Worley JR, Rogers SN & Kraemer RR. (2011). Metabolic responses to Wii Fit video games at different game levels. *J Strength Cond Res* **25,** 689-693.

Yeung RR. (1996). The acute effects of exercise on mood state. *J Psychosom Res* **40,** 123-141.

Young W, Ferguson S, Brault S & Craig C. (2011). Assessing and training standing balance in older adults: a novel approach using the 'Nintendo Wii' Balance Board. *Gait and Posture* **33,** 303 - 305.

Zanetti S, Pumpa KL, Wheeler KW & Pyne DB. (2013). Validity of the SenseWear armband to assess energy expenditure during intermittent exercise and recovery in rugby union players. *J Strength Cond Res*.

Zervas Y, Ekkekakis P, Emmanuel C, Psychoudaki, M, & V. K. (1993). The acute effects of increasing levels of aerobic exercise intensity on mood states. In *8th World Congress of Sport Psychology*, ed. SERPA S AJ, FERREIRA V, PAULO-BRITO A. , Lisbon, Portugal.

Appendices

Appendix A1 Informed consent study 1

DUBLIN CITY UNIVERSITY

Study title: Cardiometabolic responses to Wii Sports and Modified Wii Sports in young adults

Principal investigators: Mr. Javier Monedero and Dr Donal O'Gorman.

This is what will happen during the research study

1. I will have the purpose of the study, each of the steps involved, and the risks of participating in the study explained to me. I will have the opportunity to ask any questions and if I am happy with the answers I will:
    a. Provide written informed consent for participation in the research project.
    b. I will then complete a medical history form, which will ask questions about my general health, personal and family health history, smoking, exercise, and dietary habits. If necessary, I will undergo a medical examination.
2. Pre-test evaluation
    a. I will have a number of measurements of my body size and shape. My height and weight will be measured.
    b. I understand that any of these procedures or tests may be waived at the discretion of the doctor for the following reasons: (i) I have completed the same or similar step in the past 6 months as part of another research protocol at the School of Health and Human Performance; (ii) It has been determined that I am not eligible to participate in this research project; and thus completion of the entire screening process will not be necessary.

3. Exercise capacity
    a. I will undergo an exercise test designed to measure my fitness. I understand that I will run on a treadmill, with the exercise intensity getting more difficult every 3 min until I can no longer keep going or the researchers tell me to stop. To assess my fitness I will have a facemask connected to a small analyser that I will carry in my chest secured with a light harness to measure the amount of air I breathe in and out. My heart rhythm and blood

pressure may be monitored by a doctor during exercise if the doctor thinks it is recommended.

4. Familiarisation
   I will be invited to come to the School of Health and Human Performance to learn how to play the video games. I will spend 20-30 min playing the different games and wearing a mask and portable metabolic system..

5. Gaming trials
   On three days over the following two weeks I will report to the laboratories. I will have to sit and rest for 10 min while wearing the face mask and play the active games for around 45 min. During these trials I will also wear the facemask to determine oxygen use. I will also wear a heart rate monitor. The trials will be performed in random order.

Completing participation on this research study involves attending the laboratories at the School of Health and Human Performance on 7 different days.

Sometimes there are side effects from performing exercise tests. These side effects are often called risks, and for this project, the risks are:

1. Exercise testing carries with it a very small risk of exercise induced asthma, abnormal heart rhythms, heart attack, or death in less than one in 30,000 patients. The risk of sudden death during exercise for healthy men is 1:15000-18000. Because I will be asked to give a maximum effort, I may experience some muscle soreness in my arms and legs or nausea following the maximal exercise test. It should be noted that if the experimental protocol is adhered to, the likelihood of these risks occurring is minimal.

There may be benefits from my participation in this study. These are:

- I will receive a copy of my personal results, and fitness measurements and energy use during exercise.
- I understand that no other benefits have been promised me.

Participant – please complete the following (Circle Yes or No for each question)

I have read the Plain Language Statement Yes/No

I understand the information provided Yes/No

I have had an opportunity to ask questions and discuss this study Yes/No

I have received satisfactory answers to all my questions Yes/No

<u>My confidentiality will be guarded:</u>

Dublin City University will protect all the information about me, and my part in this study, within the limitations of the law. My identity or personal information will not be revealed or published. All records associated with my participation in the study will be subject to the usual confidentiality standards applicable to medical records. In addition, the study findings may be presented at scientific meetings and published in a scientific journal and/or as part of a postgraduate thesis, but my identity will not be divulged and only presented as part of a group.

If I have questions about the research project, I am free to call Javier Monedero at 01 7008471 or Donal O'Gorman at 01-7008060.

<u>Taking part in this study is my decision.</u>

I understand that my participation in this study is voluntary and that I may withdraw my consent at any time by notifying any of the investigators. I may also request that my data and samples be removed from the database or storage and destroyed. My withdrawal from this study, or my refusal to participate, will in no way affect my relationship with Dublin City University or my entitlements as a student or staff member. I understand that my participation in this research may be terminated by the investigator without regard to my consent if I am unable or unwilling to comply with the guidelines and procedures explained to me.

Confirmation that involvement in the Research Study is voluntary

My consent is given voluntarily and I understand that I may withdraw from testing at any time without fear of sanction.

Confidentiality of Data

The information obtained from testing will be treated as private and confidential. It will not be released to any persons except those involved in this study. However, the information obtained may be used for statistical analysis or scientific purposes with your right to privacy retained. Confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

Responsibilities of the participant

You are responsible for fully disclosing your medical history, as well as symptoms that may occur during the test.

Inquiries

Please ask any questions about the procedures, results, data collection or any other questions you may have. Inquiries can be made to
Javier.monedero@dcu.ie
Tel. No.: 7008471.
Email: javier.monedero@dcu.ie

Signature:

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project

Participants Signature:__________________

Name in Block Capitals: __________________

Witness: __________________

Date: __________________

Appendix A2 Informed consent study 2.

DUBLIN CITY UNIVERSITY

Study title: Energy expenditure and enjoyment during conventional stationary cycling and interactive video game cycling in sedentary adults

Principal investigators: Mr. Javier Monedero and Dr Donal O'Gorman.

This is what will happen during the research study

1. I will have the purpose of the study, each of the steps involved, and the risks of participating in the study explained to me. I will have the opportunity to ask any questions and if I am happy with the answers I will:
    - Provide written informed consent for participation in the research project.
    - I will then complete a medical history form, which will ask questions about my general health, personal and family health history, smoking, exercise, and dietary habits. If necessary, I will undergo a medical examination.
2. Pre-test evaluation
    - I will have a number of measurements of my body size and shape. My height and weight will be measured.
    - I understand that any of these procedures or tests may be waived at the discretion of the doctor for the following reasons: (i) I have completed the same or similar step in the past 6 months as part of another research protocol at the School of Health and Human Performance; (ii) It has been determined that I am not eligible to participate in this research project; and thus completion of the entire screening process will not be necessary.

3. Exercise capacity
    - I will undergo an exercise test designed to measure my fitness. I understand that I will cycle on a stationary bike, with the exercise intensity getting more difficult every min until I can no longer keep going or the researchers tell me to stop. To assess my fitness I will have a facemask connected to an analyser to measure the amount of air I breathe in and out. My heart rhythm and blood pressure may be monitored by a doctor during exercise if the doctor thinks it is recommended.

4. Familiarisation
   I will be invited to come to the School of Health and Human Performance to learn how to play the video games. I will spend 20-30 min playing the different games and wearing a mask while connected to a metabolic system..

5. Gaming trials
   On two days over the following two weeks I will report to the laboratories. I will have to sit and rest for 10 min while wearing the face mask and play the active games or cycle the bike for around 30 min. I will remain seated for a further 20 min after finishing the cycle. During these trials I will also wear the facemask to determine oxygen use. I will also wear a heart rate monitor. The trials will be performed in random order.

   Completing participation on this research study involves attending the laboratories at the School of Health and Human Performance on 4 different days.

6. Level of enjoyment
   - I will be asked to fill in a short questionnaire during the trial to measure enjoyment. I will be asked to rate how difficult the exercise is (min 15).

   Completing participation on this research study involves attending the laboratories at the School of Health and Human Performance on 7 different days.

Sometimes there are side effects from performing exercise tests. These side effects are often called risks, and for this project, the risks are:

7. Exercise testing carries with it a very small risk of exercise induced asthma, abnormal heart rhythms, heart attack, or death in less than one in 30,000 patients. The risk of sudden death during exercise for healthy men is 1:15000-18000. Because I will be asked to give a maximum effort, I may experience some muscle soreness in my arms and legs or nausea following the maximal exercise test. It should be noted that if the experimental protocol is adhered to, the likelihood of these risks occurring is minimal.

There may be benefits from my participation in this study. These are:

- I will receive a copy of my personal results, body fat and fitness measurements and energy use during exercise.
- I understand that no other benefits have been promised me.

Participant – please complete the following (Circle Yes or No for each question)
I have read the Plain Language Statement Yes/No
I understand the information provided Yes/No
I have had an opportunity to ask questions and discuss this study Yes/No
I have received satisfactory answers to all my questions Yes/No

<u>My confidentiality will be guarded:</u>

Dublin City University will protect all the information about me, and my part in this study, within the limitations of the law. My identity or personal information will not be revealed or published. All records associated with my participation in the study will be subject to the usual confidentiality standards applicable to medical records. In addition, the study findings may be presented at scientific meetings and published in a scientific journal and/or as part of a postgraduate thesis, but my identity will not be divulged and only presented as part of a group.

If I have questions about the research project, I am free to call Javier Monedero at 01 7008471 or Donal O'Gorman at 01-7008060.

<u>Taking part in this study is my decision.</u>

I understand that my participation in this study is voluntary and that I may withdraw my consent at any time by notifying any of the investigators. I may also request that my data and samples be removed from the database or storage and destroyed. My withdrawal from this study, or my refusal to participate, will in no way affect my relationship with Dublin City University or my entitlements as a student or staff member. I understand that my participation in this research may be terminated by the investigator without regard to my consent if I am unable or unwilling to comply with the guidelines and procedures explained to me.

Confirmation of particular requirements as highlighted in the Plain Language Statement
There will be four testing sessions in this study. The first involves a health questionnaire and a maximal exercise test on a stationary bicycle. The 2nd session will involve playing an interactive game while cycling for 45 min. The final two

sessions will involve cycling while playing the same interactive game as in the second session on the same bicycle and the final session will involve cycling with the video game turned off for 30 min at a moderate intensity. You will be asked a short set of questions every 10 min during the gaming trials. You will also have a mouthpiece in your mouth and will be connected to a gas analyser to get expired gases analysed. The 3rd and 4th sessions may take place in reverse order. A short questionnaire will be completed at the end of each session. You may withdraw from testing at any time.

Confirmation that involvement in the Research Study is voluntary

My consent is given voluntarily and I understand that I may withdraw from testing at any time without fear of sanction.

Confidentiality of Data

The information obtained from testing will be treated as private and confidential. It will not be released to any persons except those involved in this study. However, the information obtained may be used for statistical analysis or scientific purposes with your right to privacy retained. Confidentiality of information provided can only be protected within the limitations of the law. It is possible for data to be subject to subpoena, freedom of information claim or mandated reporting by some professions.

Responsibilities of the participant

You are responsible for fully disclosing your medical history, as well as symptoms that may occur during the test.

Inquiries

Please ask any questions about the procedures, results, data collection or any other questions you may have. Inquiries can be made to
Javier.monedero@dcu.ie
Tel. No.: 7008471.
Email: javier.monedero@dcu.ie

Signature:

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project

Participants Signature:__________________

Name in Block Capitals: __________________

Witness: __________________

Date: ________________________----------------------------

Appendix A3 Informed consent study 3.

Study title: Flow, enjoyment and energy expenditure during conventional exercise and active video game play

Principal investigators:Dr. Donal O'Gorman, Mr. Javier Monedero. School of Health and Human Performance.
Other investigators: Dr. Catherine Woods, Dr Kieran Moran

Purpose
The purpose of this project is to compare physiological and psychological response to interactive video game and running.

This is what will happen during the research study

- I will have the purpose of the study, each of the steps involved, and the risks of participating in the study explained to me. I will have the opportunity to ask any questions and if I am happy with the answers I will:
- Provide written informed consent for participation in the research project.
- I will then complete a medical history form, which will ask questions about my general health, personal and family health history, smoking, exercise, and dietary habits. If necessary, I will undergo a medical examination.

Pre-test evaluation

- I will have a number of measurements of my body size and shape. My height and weight will be measured and body mass index determined. My percentage body fat will be estimated by measuring the thickness of fat at different sites around my body.
- I understand that any of these procedures or tests may be waived at the discretion of the doctor for the following reasons: (i) I have completed the same or similar step in the past 6 months as part of another research protocol at the School of Health and Human Performance; (ii) It has been determined that I am not eligible to participate in this research project; and thus completion of the entire screening process will not be necessary.

Exercise capacity

- I will undergo an exercise test designed to measure my fitness. I understand that I will run on a treadmill, with the exercise intensity getting more difficult every 3 min until I can no longer keep going or the researchers tell me to stop. To assess my fitness I will have a facemask connected to a small analyser that I will carry in my chest secured with a light harness to measure the amount of air I breathe in and out. My heart rhythm and blood pressure may be monitored by a doctor during exercise if the doctor thinks it is recommended.

Familiarisation

I will be invited to come to the School of Health and Human Performance on 2 occasions. On one of those days I will learn how to play the video games. On the second day, I will spend 20 min determining my preferred treadmill speed and another 20 min wearing the facemask running at 3 different speeds.

Gaming and exercise trials

On four days over the following two weeks I will report to the laboratories. I will have to sit and rest for 10 min while wearing the face mask and play the active games for 30 min or run for the same time. During these trials I will also wear the facemask to determine oxygen use. I will also wear two small sensors, one in my lower back and one on one knee. The trials will be performed in random order.

Level of enjoyment

- I will be asked to fill in a short questionnaire before the trial. I will be asked twice to rate how difficult the exercise is (min 15 and 30) and fill in one short questionnaire during the gaming and exercise trials.
- I will be asked to fill in three questionnaires after the gaming and exercise trials. This will take between 5-7 min. Finally, I will be asked to fill in another short questionnaire 20 min after finishing playing or walking/running on the treadmill.

Completing participation on this research study involves attending the laboratories at the School of Health and Human Performance on 7 different days.

Sometimes there are side effects from performing exercise tests. These side effects are often called risks, and for this project, the risks are:

Exercise testing carries with it a very small risk of exercise induced asthma, abnormal heart rhythms, heart attack, or death in less than one in 30,000 patients. The risk of sudden death during exercise for healthy men is

1:15000-18000. Because I will be asked to give a maximum effort, I may experience some muscle soreness in my arms and legs or nausea following the maximal exercise test. It should be noted that if the experimental protocol is adhered to, the likelihood of these risks occurring is minimal.

There may be benefits from my participation in this study. These are:

- I will receive a copy of my personal results, body fat and fitness measurements and energy use during exercise.
- I understand that no other benefits have been promised me.

Participant – please complete the following (Circle Yes or No for each question)

I have read the Plain Language Statement Yes/No
I understand the information provided Yes/No
I have had an opportunity to ask questions and discuss this study Yes/No
I have received satisfactory answers to all my questions Yes/No

My confidentiality will be guarded:

Dublin City University will protect all the information about me, and my part in this study, within the limitations of the law. My identity or personal information will not be revealed or published. All records associated with my participation in the study will be subject to the usual confidentiality standards applicable to medical records. In addition, the study findings may be presented at scientific meetings and published in a scientific journal and/or as part of a postgraduate thesis, but my identity will not be divulged and only presented as part of a group.

If I have questions about the research project, I am free to call Javier Monedero at 01 7008471 or Donal O'Gorman at 01-7008060.

Taking part in this study is my decision.

I understand that my participation in this study is voluntary and that I may withdraw my consent at any time by notifying any of the investigators. I may also request that my data and samples be removed from the database or storage and destroyed. My withdrawal from this study, or my refusal to participate, will in no way affect my relationship with Dublin City University or my entitlements as a student or staff member. I understand that my participation in this research may be terminated by the investigator without regard to my consent if I am unable or unwilling to comply with the guidelines and procedures explained to me.

Signature:

I have read and understood the information in this form. My questions and concerns have been answered by the researchers, and I have a copy of this consent form. Therefore, I consent to take part in this research project

Participants Signature: ________________

Name in Block Capitals: ________________

Witness: ________________

Date: ________________

Appendix B General health questionnaire

SCHOOL OF HEALTH AND HUMAN PERFORMANCE
DUBLIN CITY UNIVERSITY

General Health Questionnaire

Name:………………………………..Occupation:……………………………

Address:……………………………………………………………………

Telephone: (Home)…………………..(Work):………………………………..

Do you have, or have you ever suffered from: -Diabetes? Yes / No

-Asthma? Yes / No

-Epilepsy? Yes / No

Have you ever had pains in your chest or heart? Yes / No

Do you ever feel faint or have spells of dizziness? Yes / No

Do you have or have you ever had high blood pressure? Yes / No

Do you have a muscle, back or joint problem that could be aggravated by physical activity or made worse with exercise? Yes / No

Do you have any current injuries? Yes / No

In the past week, have you suffered from any illness which required you to be in bed or off work for one day or more? Yes / No

Do you smoke? If yes, how many per day? Yes / No

Do you drink? If yes, how many units per week? Yes / No

Is there a good physical reason not mentioned here why you should not carry out laboratory testing? Yes / No

Please provide any further information concerning any condition/complaints which you suffer from and any medication which you may be taking by prescription or otherwise:

…………………………………………………………………………………………………

…………………………………………………………………………………………………

Date: Signature:
Authorising Signature:

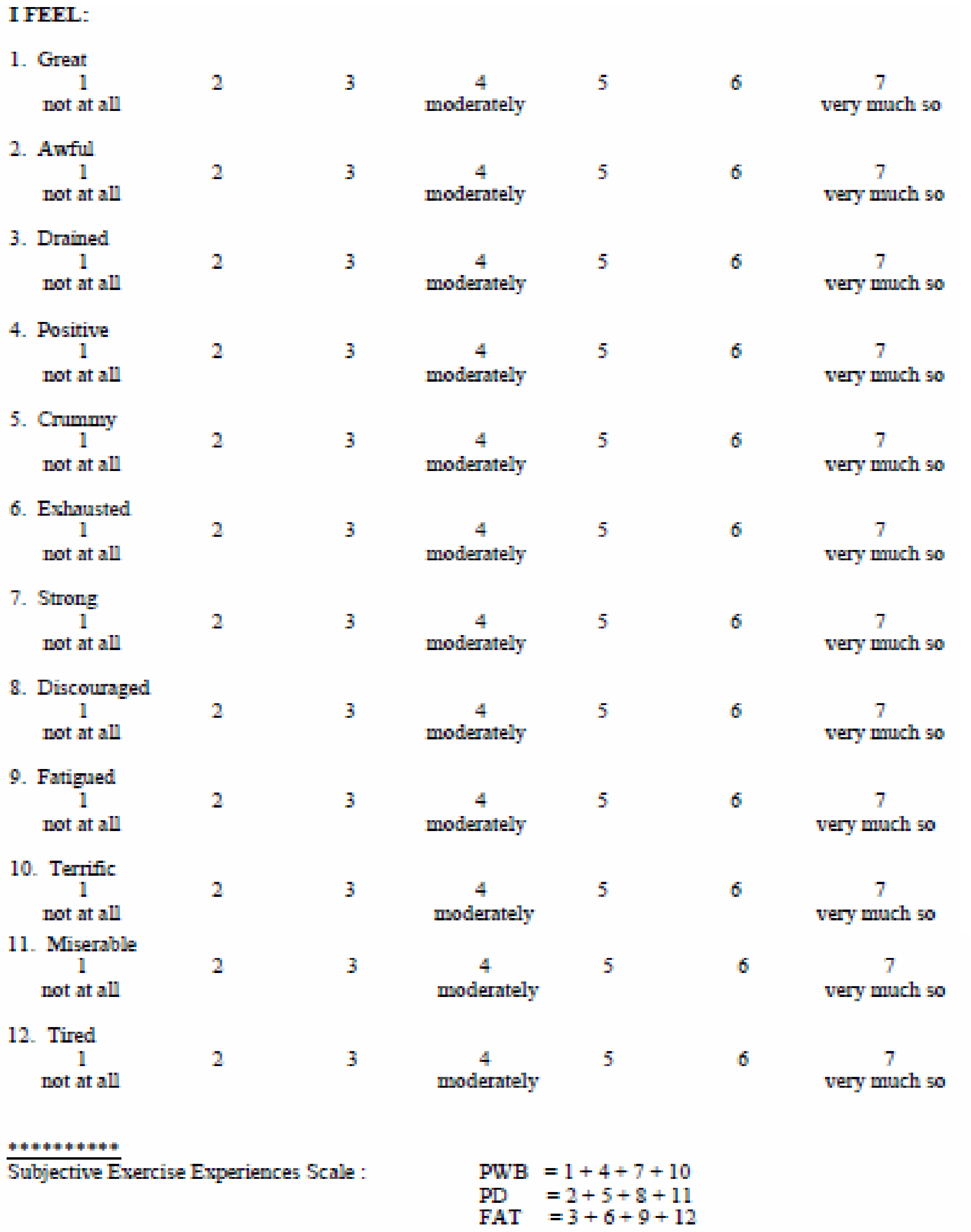
Appendix C1 Modified PACES scale

PACES SCALE	***10 min***	***20 min***	***30 min***
* 1 2 3 4 5 6 7 I enjoy it I hate it			
12 3 4 5 6 7 I feel bored I feel interested			
12 3 4 5 6 7 I dislike it I like it			
* 1 2 3 4 5 6 7 I am absorbed I am not absorbed in this activity in this activity			
1 2 3 4 5 6 7 It’s not fun at all It’s a lot of fun			
1 2 3 4 5 6 7 It’s not at all It’s very stimulating stimulating			

Appendix C2 Subjective Exercise Experience Scale (SEES)

(to complete before trial)

This inventory contains a number of items designed to reflect how you feel at this particular moment in time (i.e., Right Now). Please circle the number on each item that indicates **HOW YOU FEEL RIGHT NOW.**



I FEEL:

1. Great

1	2	3	4	5	6	7
not at all			moderately			very much so

2. Awful

1	2	3	4	5	6	7
not at all			moderately			very much so

3. Drained

1	2	3	4	5	6	7
not at all			moderately			very much so

4. Positive

1	2	3	4	5	6	7
not at all			moderately			very much so

5. Crummy

1	2	3	4	5	6	7
not at all			moderately			very much so

6. Exhausted

1	2	3	4	5	6	7
not at all			moderately			very much so

7. Strong

1	2	3	4	5	6	7
not at all			moderately			very much so

8. Discouraged

1	2	3	4	5	6	7
not at all			moderately			very much so

9. Fatigued

1	2	3	4	5	6	7
not at all			moderately			very much so

10. Terrific

1	2	3	4	5	6	7
not at all			moderately			very much so

11. Miserable

1	2	3	4	5	6	7
not at all			moderately			very much so

12. Tired

1	2	3	4	5	6	7
not at all			moderately			very much so

****

Subjective Exercise Experiences Scale :

PWB = 1 + 4 + 7 + 10
PD = 2 + 5 + 8 + 11
FAT = 3 + 6 + 9 + 12

Appendix C3 Interest/enjoyment scale

Interest/enjoyment (to complete in the middle of the trial)

For each of the following statements, please indicate how true it is for you, using the following scale:

	1	2	3	4	5	6	7
	Not at all true		Somewhat true			Very true	
I enjoyed doing this activity very much							
This activity was fun to do							
I thought this was a boring activity. (R)							
This activity did not hold my attention at all. (R)							
I would describe this activity as very interesting							
I thought this activity was quite enjoyable							
While I was doing this activity, I was thinking about how much I enjoyed it.							

Appendix C4 Core flow state scale (CFSS)

(to complete right after trial)

Please answer the following questions in relation to your experience in the event or activity you have just completed. These questions relate to the thoughts and feelings you may have experienced while taking part. There are no right or wrong answers. Think about how you felt during the event/activity, then answer the questions using the rating scale below. For each question, circle the number that best matches your experience.

During the event of (name event):____

		Strongly Disagree	**Disagree**	**Neither Agree nor Disagree**	**Agree**	**Strongly Agree**
1	I was ‘totally involved’	1	2	3	4	5
2	It felt like ‘everything clicked’’	1	2	3	4	5
3	I was ‘tuned in’ to what I was doing	1	2	3	4	5
4	I was ‘in the zone’	1	2	3	4	5
5	I felt ‘in control’	1	2	3	4	5
6	I was ‘switched on’	1	2	3	4	5
7	It felt like I was ‘in the flow’ of things	1	2	3	4	5
8	It felt like ‘nothing else mattered’’	1	2	3	4	5
9	I was ‘in the groove’	1	2	3	4	5
10	I was ‘totally focused’ on what I was doing	1	2	3	4	5