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Comparative Analysis of The Effects Of Virtual Reality Active Video Game And Controller-Free Active Video Game Play On Physiological Response, Perceived Exertion, And Hedonic Experience

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COMPARATIVE ANALYSIS OF THE EFFECTS OF VIRTUAL REALITY ACTIVE VIDEO GAME AND CONTROLLER-FREE ACTIVE VIDEO GAME PLAY ON PHYSIOLOGICAL RESPONSE, PERCEIVED EXERTION, AND HEDONIC EXPERIENCE

by

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ABSTRACT

Over 60% of US adults are overweight or obese. Sedentary lifestyles are considered major contributors to the high rates and increasing prevalence of obesity. Physical activity is a critical component in shifting from sedentary lifestyles. Studies indicate that less than half of U.S. adults meet the CDC/ACSM physical activity recommendations. Interactive video games can increase PA, but no study has yet assessed physiologic effort, hedonics, and perceived exertion for playing immersive virtual reality (VR) and controller-free screen-based active video games (AVGs), compared to treadmill walking and resting. We ran 25 subjects (9 female, 16 male) in 10-minute sessions of five conditions. Head Mounted Display VR: Oculus (Fruit Ninja and Boxing), Screen-based AVG: Kinect (Fruit Ninja and Boxing), and Treadmill walking at 3 mph. One, six-condition (Rest, Treadmill 3.0, Kinect Boxing, Kinect Fruit Ninja, Oculus Boxing, Oculus Fruit Ninja) repeated-measures ANOVA was used to examine differences in HR_{mean}. Three, five-condition (Treadmill 3.0, Kinect Boxing, Kinect Fruit Ninja, Oculus Boxing, Oculus Fruit Ninja) repeated-measures ANOVA were used to examine differences in HR_{peak}, ratings of perceived exertion (RPE) and Hedonics (Liking). Post hoc analyses using pairwise comparisons were used to further assess significant main effects of the condition. A Pearson's product-moment correlation was run to assess the relationship between activity condition HR_{mean} and RPE

VR Boxing elicited the greatest physiological effort, producing vigorous-intensity PA. There was no significant difference in average heart rate for the Treadmill, Kinect Fruit

Ninja, Kinect Boxing, and VR Fruit Ninja. Thus, the Kinect and VR sport and casual games are comparable to treadmill walking PA levels and qualify as moderate-intensity activity. The VR Fruit Ninja, VR Boxing, Kinect Fruit Ninja were the most enjoyed activities. Despite having the highest Heart rate and the highest self-reported Rating of Perceived Exertion (RPE), VR Boxing was significantly more enjoyable than Treadmill Walking. There was no statistically significant correlation between Activity Condition HR_{mean} and RPE.

Both casual and sports VR and AVG activities are enjoyable activities for adults, stimulating moderate-to-vigorous activity through a traditionally sedentary medium. This research extends previous works in active video gaming effects on physiological cost, perceived exertion and hedonics and fills the gap relating virtual reality active video games. The significance of the research outcomes is that this analysis provides a scientifically validated approach to support the establishment of physical activity level goals and guidelines in the development of active video games as a response and/or remedy to address the sedentary lifestyles that are contributing to American and global obesity.

As I stare at this blank page, formulating the thoughts and words to describe this dedication, I am flooded with memories: Flashbacks of Encyclopedia Jeopardy, countless over-the-top science fair projects, extended lectures on “can’t” and “try,” and talks at-length about entrepreneurship and how to avoid starving artist syndrome. You were, are, and will always be my first and greatest inspiration and the wind beneath my wings. I soar without a worry because of your sacrifices. I can see the world through rose-colored glasses because you envisioned the best for me. I exist without limits because you ensured I wouldn’t fear a challenge and was prepared for any opportunity. Daddy, your legacy lives on and I will forever honor you. I dedicate this dissertation as my most humble demonstration of your sacrificial efforts. This journey was never for me, it was for us. WE made it! First-generation, Ph.D.! Dr. Wooden - just like you exclaimed me to be! I only wish I could hear you shout it, in person.

--With love, honor, and gratitude, this one’s for you, Daddy!

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LIST OF ACRONYMS (OR) ABBREVIATIONS

ACSM	American College of Sports Medicine
AVG	Active Video Games (AVGs)
BMI	Body Mass Index (BMI)
CDC	Center for Disease Control and Prevention
EE	Energy Expenditure (EE)
GI	Gesture Interface
HMD	Head Mounted Displays
HR	Heart Rate
MPA	Moderate-Intensity Physical Activity
MVPA	Moderate to Vigorous Activity
NHANES	National Health and Nutrition Examination Survey
NIH	National Institutes of Health
PA	Physical Activity
RPE	Rating of Perceived Exertion

VPA	Vigorous-Intensity Physical Activity
VR	Virtual Reality
WHO	World Health Organization

CHAPTER 1: INTRODUCTION

Background

The advent of active video gaming systems such as the Xbox 360 Kinect and the Oculus Rift has recently taken the world of gaming and computer interaction to a whole new level. Rather than controlling a video game solely with one's digits, the player's entire body can be used to maneuver his or her actions within the gaming interface. Oculus Rift/Oculus Touch and HTC Vive further developed active video games (AVGs) by incorporating motion-based controllers and head mounted displays (HMDs), for an immersive Virtual Reality (VR) experience. Compared to traditional sedentary and gamepad-controlled games, these new interfaces use a motion capturing controller that can be used to simulate most actions. For traditional gamers, AVGs and VR HMDs introduce a new level of activity to the sedentary lifestyle of traditional gaming. Additionally, the novel controllers and displays can further appeal to a market of, otherwise, non-traditional gamers.

Motion-controlled gaming systems and virtual reality head-mounted displays are presently mainstream and commercially available. As gaming evolves, this also considerably shapes the usage and experiences of the gamer. The new technology introduces prime opportunity to explore how these new gaming systems are influencing the overall user experience. It is certainly worthwhile to examine how these AVGs influence physical activity (PA) levels.

Problem Statement

In the United States, over 60% of the adult population is overweight or obese (Wyatt, Winters, & Dubbert, 2006). Lack of regular physical activity (PA) can be associated with an increased incidence of obesity. Sedentary pastimes such as television watching, Internet surfing, and video game playing are typical replacements for physical leisure activities (Maddison et al., 2007). Regular physical activity can decrease the risks of obesity-related diseases, such as cardiovascular disease and type 2 diabetes. Also, PA can help one's mental health and mood (WHO, 2016). Accordingly, the Center for Disease Control and Prevention recommends at least 150 minutes of moderate to vigorous physical activity (MVPA) for adults (CDC, 2007).

Recent research has revealed that interactive games can increase players' physical activity level and have the potential to combat overweight and obesity among adolescents and adults (Maddison et al., 2007; Peng, Lin, & Crouse, 2011; Straker & Abbott, 2007; Unnithan, Houser, & Fernhall, 2006). It is thus important to examine the immersive virtual reality active gaming experience and possible contribution to subsequent positive outcomes of enjoyment and increased physical activity. To date, there is no evidence of empirical research on Virtual Reality active video games relating the effects on one's physiological response, perceived exertion, and hedonics. This study aims to fill the gap in the literature by examining the effect of VR AVG play on heart rate (HR), ratings of perceived exertion (RPE), and enjoyment during virtual reality active video gaming and controller-free reality active video gaming.

Significance of Research

Obesity has reached epidemic proportions globally. It is a major contributor to the worldwide burden of chronic disease and disability. Sedentary lifestyles are considered major contributors to the high rates and increasing prevalence of obesity (WHO, 2008). Physical activity is a critical component in shifting from sedentary lifestyles. Studies indicate that less than half of U.S. adults meet the CDC/ACSM physical activity recommendations (CDC, 2007). Forman et. al address several technological interventions that explore the question, “Could technology help us tackle the obesity crisis (2016)?” Exergames are addressed as a method of physical activity designed to make exercising less tedious or unpleasant, and thereby more adherent. Although technology shows promise of aiding in the solution for the obesity epidemic, it is noted that AVGs have not been subjected to adequate empirical scrutiny. The significance of the research outcomes is that this analysis provides a scientifically validated approach to support the establishment of physical activity level goals and guidelines in the development of active video games as a response and/or remedy to address the sedentary lifestyles that are contributing to American and global obesity.

The objective of this study was to investigate if AVGs can elicit moderate to vigorous activity levels (MVPA) in adults. These findings may assist in identifying suitable alternatives for physical activity and in prescribing exercise options for adults to meet recommendations for weekly physical activity. This study expands the current body of knowledge that remains unexplored in virtual reality active video games. The research presents relevant physiological, psychophysiological and hedonics data that give researchers, game developers, and consumers insight on the implications of virtual reality and controller-free active gaming. The significance of this research may help in establishing guidelines for the development of active video games regarding physical activity level goals, as well as fun and safety.

Research Objective

The primary purpose of this research was to perform a physiological evaluation of human performance during active video gaming to determine if CDC-recommended moderate-to-vigorous physical activity (MVPA) levels can be observed while using active video game (AVG) systems. The gaming conditions include Oculus Rift virtual reality active video games (Fruit Ninja and Boxing) and Kinect active video games (Fruit Ninja and Boxing). Additional objectives were to examine the ratings of perceived exertion (RPE) and hedonic experience of AVGs. This research will extend previous works in active video gaming effects on physiological cost, perceived exertion and hedonics and aim fill the gap relating virtual reality active video games.

Research Questions

The objective of this research was to compare the physical activity levels in two active video game (AVG) systems: Oculus Rift virtual reality AVG and Kinect controller-free AVG. A secondary aim was to examine ratings of perceived exertion (RPE) and enjoyment of playing the AVGs. The specific research questions are:

1. Is there a significant difference in the average heart rate for activity conditions?
2. Is there a significant difference in peak heart rate for activity conditions?

3. Is there a significant difference in RPE for activity conditions?
4. Are AVG activities more enjoyable than treadmill walking?
5. Is there an association between the subject's perceived exertion and actual physiological response?

Theoretical Framework

Concerning the growing popularity in research for active video games (AVGs), several studies have explored systems such as the Nintendo Wii and the Xbox Kinect on physiological and psychophysiological responses in active video game play. These studies serve as a baseline for this research, in terms of a theoretical framework and guideline for the methodology. This research adds to the body of knowledge the Virtual Reality AVG responses. Previous research methodology compares the various game systems and games to determine if there is a significant difference in energy expenditure, heart rate, ratings of perceived exertion (RPE), enjoyment, and user experience.

Table 1 provides a summary of the literature examining the Xbox Kinect AVGs. At the time of the Literature Review, there were no published studies on the VR AVGs. The HR_{mean}, RPE and Hedonics/Usability details provide insight regarding the activity levels and user experiences of various Kinect games that have been tested.

Table 1: Kinect AVG Previous Research

Researchers	*Year*	*n=*	*Games*	*HR$_{mean}$*	*RPE*	*Other Subjective Measure*
Bronner, S., et al.	2016	14	Dance Central-Ea DC Hard	103.2 ± 17.9 115.1 ± 17.1	-	Game Engagement Questionnaire
Eason, J. M., et al.	2016	30 F	Dance Class Kinect Just Dance	134 (17.60) 125 (8.79)	15 (1.97) 13 (1.12)	Post-session survey
Marks, D. W., et al.	2015	15	Wii Boxing Kinect Boxing Wii Just Dance 2 Kinect JD2	115.4 12.8 124.9* 13.0 110.1 14.5 111.5 12.3	-	-
McGuire, S. and M. E. Willems	2015	10 M	Football Boxing Track and field	82 ±30 120 ±28 125 ±21	-	-
Sanders, G. J., et al.	2015	27	Rest Treadmill 3.0 Wii Boxing Kinect Boxing	73.4 – 1.8 103.3 – 2.0 104.5 – 2.2 126.4 – 3.0	- 9.6 – 0.3 10.0 – 0.4 12.6 – 0.4	Liking- 4.1 – 0.4 6.2 – 0.3 8.2 – 0.2
Wu, P.-T., et al.	2015	17	Boxing Soccer Beach Volleyball Track and Field Ping-pong Bowling	140.83±19.0 126.52±18.03 113.56±14.99 117.41±16.76 105.27±19.28 89.33±11.71	-	-
SCHEER, K. S., et al.	2014	19	Wii Com-Boxing Wii Human Kinect Comp Kinect Human Move Computer Move Human	114.5 ± 4.6 117.6 ± 4.3 119.0 ± 4.3 119.6 ± 4.4 120.0 ± 4.6 120.3 ± 4.1	-	-
O'Donovan, C., et al.	2012	14	Wii Boxing SP Wii Boxing MP Reflex Ridge SP Reflex Ridge MP	107 (28) 119 (28) 114 (21) 118 (20)	-	-

Sanders et al. published a study, Heart Rate, and Liking During ‘‘Kinect Boxing’’ Versus ‘‘Wii Boxing’’: The Potential for Enjoyable Vigorous Physical Activity Videogames. Sanders et al.’s protocol involves the collection of heart rate, perceived exertion, and hedonics for Rest, Treadmill 3.0 walking, Wii Boxing, and Kinect Boxing. The experimental conditions of Sanders et al.'s research is depicted in Figure 1. Although the studies are not directly comparable, the methodology and data from the Sanders et al. study served as a reference for this research. This experiment builds upon the aforementioned study in that it incorporates the VR game system and includes an alternative game title for each active gaming system. In Figure 2, this study's experimental conditions are represented.

Figure 1: Sanders et al. Experiment Protocol Rest, Treadmill, Kinect Boxing, and Wii Boxing

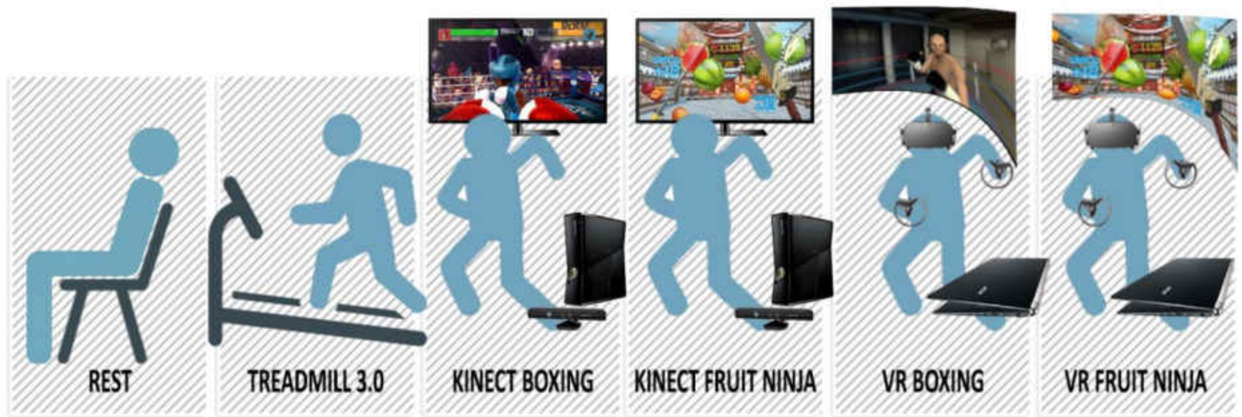


Figure 2: Experiment Conditions (Rest, Treadmill, Kinect Boxing, Kinect Fruit Ninja, VR Boxing, and VR Fruit Ninja)

CHAPTER 2: LITERATURE REVIEW

Introduction

Since 1980, obesity rates have increased by over 200%. Obesity is a major contributor to the global burden of chronic disease and disability, reaching epidemic proportions. Overweight and obesity increase the risk of health consequences ranging from cardiovascular disease to diabetes, to musculoskeletal disorders, to certain cancers. Sedentary lifestyles, such ones consisting of computer work, television watching, and video game playing, are considered major contributors to the high rates and increasing prevalence of obesity (World-Health-Organization, 2016).

In the United States, over 60% of the adult population is overweight or obese (Wyatt et al., 2006). Lack of regular physical activity (PA) can be associated with an increased incidence of obesity. Sedentary pastimes such as television watching, Internet surfing, and video game playing are common replacements for physical leisure activities (Maddison et al., 2007). Regular physical activity (PA) can decrease the risks of obesity-related diseases, such as cardiovascular disease and type 2 diabetes. Also, PA can help one's mental health and mood. Accordingly, the Center for Disease Control and Prevention recommends at least 150 minutes of moderate to vigorous physical activity (MVPA) for adults (CDC, 2007).

Recent research has revealed that interactive games can increase players' physical activity level and have the potential to combat overweight and obesity among adolescents and adults (Maddison et al., 2007; Peng et al., 2011; Straker & Abbott, 2007; Unnithan et al., 2006). It is thus important to examine the immersive virtual reality active gaming experience and possible contribution to subsequent positive outcomes of enjoyment and increased physical activity. To date, there is no evidence of empirical research on Virtual Reality active video games relating the effects on the player's physiological response, perceived exertion, and hedonics. This study aims to fill the gap in the literature by examining the effect of virtual reality and controller-free active video gaming on heart rate (HR), ratings of perceived exertion (RPE), and enjoyment.

With the continuing affordability and availability of physically interactive gaming technologies, consumers are beginning to replace or supplement sedentary video games with active video games. Furthermore, consumers who are not traditional gamers are buying into the novel technology. From the Nintendo Wii to PlayStation Move, to Microsoft Kinect, these active gaming systems have been found to allow the participants to reach aerobic intensity levels adequate for CDC recommendations for moderate-to-vigorous physical activity (MVPA) (Ainsworth et al., 2011). Virtual reality (VR) active video games (AVGs) such as the HTC Vive and Oculus Rift have the potential to increase physical activity of gamers in a fun and engaging manner. Thus, it is imperative to establish effective mechanisms to increase levels of physical activity empirically.

Obesity

The overall adoption of energy-dense diets and sedentary lifestyles are considered major contributors to the high rates and increasing prevalence of obesity. According to the World Health Organization (WHO), obesity has reached epidemic proportions globally. Obesity is a major contributor to the global burden of chronic disease and disability, with estimates of 1.9 billion adults overweight and at least 600 million adults clinically obese (2016). In the United States, a 2014 National Health Interview Survey reveals that 32.7% of adults are overweight, and 37.7% are obese, and 7.7% are extremely obese based on estimates of body mass index. The National Health and Nutrition Examination Survey (NHANES) is conducted by the National Center for Health Statistics of the U.S. Centers for Disease Control and Prevention. NHANES reports that the incidence of obesity has more than doubled from 15% in 1980 to 38% in 2014 (Nguyen & El-Serag, 2010; Ogden, Carroll, & Fryar, 2016). The prevalence and trends of overweight and obesity among U.S. men and women, ages 20–74 years from 1960–2014 is graphically depicted in Figure 3.

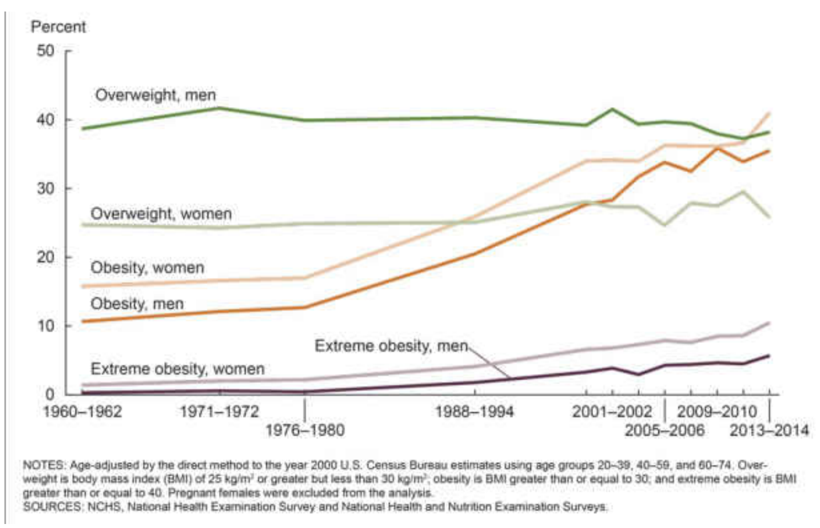


Figure 3: Prevalence and Trends of Overweight and Obesity among Men and Women Ages 20–74 Years in the U.S.: 1960–2014

The Centers for Disease Control and Prevention (CDC), defines overweight in adults as having a Body Mass Index (BMI) of 25 to 29.9 and obese adults as having a BMI of over 30. BMI is calculated differently for children and teens. In children, BMI at or above the 85th percentile is considered overweight and above the 95th percentile is determined to be obese (NIH, 1998).

Body Mass Index

Body Mass Index (BMI) is a number calculated from a person's weight and height. BMI does not measure body fat directly, but it is a reliable indicator of body fatness for most people. BMI can be considered an inexpensive and easy-to-perform alternative method compared to direct measures of body fat. BMI calculations are often used for population assessment of overweight and obesity (NIH, 1998).

For adults and children alike, BMI is calculated based on the following formulas:

Table 2: BMI Calculation Formulas (NIH, 1998).

Measurement Units	Formula and Calculation
Kilograms and meters	Formula: weight (kg) / [height (m)]2 With the metric system, the formula for BMI is weight in kilograms divided by height in meters squared. Since height is commonly measured in centimeters, divide height in centimeters by 100 to obtain height in meters. Example: Weight = 68 kg, Height = 165 cm (1.65 m) Calculation: $68 \div (1.65)^2 = 24.98$
Pounds and inches	Formula: weight (lb.) / [height (in)]2 x 703 Calculate BMI by dividing weight in pounds (lbs.) by height in inches (in) squared and multiplying by a conversion factor of 703. Example: Weight = 150 lbs., Height = 5'5" (65") Calculation: $[150 \div (65)^2] \times 703 = 24.96$

For adults 20 years old and older, BMI is interpreted using standard weight status categories that are the same for all ages and both men and women. The standard weight status categories associated with BMI ranges for adults are shown in Table 3.

Table 3: Classification of Overweight and Obesity by BMI

BMI	Weight Status
Below 18.5	Underweight
18.5 – 24.9	Normal
25.0 – 29.9	Overweight
30.0 and Above	Obese

Health Consequences of Overweight and Obesity

The WHO identifies that overweight and obesity are the fifth leading risk for global deaths, causing at least 2.8 million deaths. Worldwide, obesity can be attributed to 44% of the diabetes burden, 23% of the heart disease burden and between 7% and 41% of certain cancer burdens (WHO, 2008).

In the United States alone, 25.8 million children and adults have diabetes. This figure is composed of 25.6 million (11.3%) of Americans age 20 years or older and 215,000, or 0.26% of all people under 19 and younger. Some of the complications associated with diabetes include heart disease and stroke, high blood pressure, blindness, kidney disease, nervous system disease and amputation (CDC, 2011a). The CDC reports that the cost of diagnosed diabetes in the U.S., in 2007, has cost $174 billion. Additionally, if one were to consider the added impact of cases of undiagnosed diabetes, prediabetes, and gestational diabetes, it would bring the total to $218 billion. Furthermore, it is estimated that the medical expenditures of those diagnosed with diabetes are 2.3 times higher than their non-diabetic counterparts (CDC, 2011a).

Overweight and obesity, as well as their related noncommunicable diseases, are greatly preventable. The World Health Organization suggests that supportive environments and communities are fundamental in shaping an individual's choices. The gaming industry, educational institutions, workplaces, gyms, and other relevant communities can assist in fixing this epidemic by making regular physical activity an easy choice and encouraging adults to engage in regular physical activity for 150 minutes each week.

According to the CDC, less than half of the adults in the U.S. participate in physical activities with adequate intensity and regularity to meet minimum ACSM recommendations for the improvement or maintenance of cardiorespiratory fitness (2007).

Physical Inactivity

Recent reports of health statistics show that 33% of adults are considered inactive regarding physical activity in leisure time. About one-third of the adult population reported having some physical activity, and the other third engaged in physical activity on a regular basis. In terms of activity, 55% of adults had never engaged in vigorous leisure-time physical activity lasting 10 or more minutes in a week's time. Twenty-eight percent of the adult population reported participating in vigorous activity three or more times per week (Pleis, Ward, & Lucas, 2010). Overall, these figures indicate that less than half (45%) of U.S. adults met the CDC/ACSM physical activity recommendations

According to the World Health Organization (WHO), a sedentary lifestyle is considered a major contributor to the high rates and increasing prevalence of obesity (2016). Sedentary screen-based activities such as television and video games may lead to reduced physical activity, contributing to the incidences of overweight and obesity (Segal & Dietz, 1991). The lack of regular physical activity can be associated with increased incidence of obesity, type II diabetes mellitus, cardiovascular disease, stroke, hypertension, specific cancers, osteoporosis, and several mental disorders (Kesaniemi et al., 2001).

CDC Physical Activity Recommendations

One method the CDC suggests for determining a person's physical activity level is by measuring one's heart rate (CDC, 2011b).

Age-Predicted Maximal Heart Rate

This maximum rate is based on the person's age. An estimate of a person's maximum age-related heart rate can be obtained by subtracting the person's age from 220.

Moderate-Intensity Physical Activity (MPA)

An individual's target heart rate should be 50 to70% of his or her maximum heart rate to qualify as a moderate-intensity physical activity.

Vigorous-Intensity Physical Activity (VPA)

For vigorous-intensity physical activity, the target heart rate should be 70 to 85% of his or her maximum heart rate.

For example, for a 20-year-old individual, the age-predicted maximal heart rate would be calculated as 220 - 20 = 200 beats per minute (bpm).

The moderate-intensity 50% and 70% levels would be:

50% level: 200 x 0.50 = 100 bpm, and

70% level: 200 x 0.70 = 140 bpm

Moderate-intensity physical activity for a 20-year-old person requires that the HR remains between 100 and 140 bpm.

The vigorous-intensity 70% and 85% levels would be:

70% level: 200 x 0.70 = 140 bpm, and

85% level: 200 x 0.85 = 170 bpm

Thus, vigorous-intensity physical activity for a 20-year-old person will require that the heart rate remains between 140 and 170 bpm during physical activity.

Interactive Video Game Systems

The advancements of computer technology, including camera sensors and complex computer algorithms, now allow computer systems to track human movement accurately. These movements can be captured and even displayed on a monitor. Moreover, users can interact with objects within the computer system, through their movements. A system that utilizes human gesture recognition to interact with computer systems is defined as a Gesture Interface (GI)(Rodgers, 2011).

Gesture Interface in consumer entertainment gaming systems has been around for over two decades, but early GI systems were limited in the technology. The introduction of the Nintendo Power Glove in 1989 offered a glimpse of GI technology. However, with inconsistent real-time reaction with user hand gestures combined with unnatural movements relative to gameplay (not to mention limited games), the system itself did not review well with game critics(ABC, 2008). Until recently, video games have been considered sedentary activity. The new-age interactive video games are beginning to incorporate physical activity, as the player’s motion becomes a controller for the game. These interactive games are also coined “active games” and are also referred to as “exergames” (Maddison et al., 2007).

Interactive video gaming systems that use physical activity to control gameplay include Dance Dance Revolution (Konami, Tokyo, Japan), Wii (Nintendo, Redmond, WA), and the Kinect (Microsoft, Redmond, WA). Table 4 lists the advancement and description of notable gaming active gaming systems in chronological order.

Table 4: Active Video Game Systems

Image	Gaming GI System	Year Introduced	Description
	Nintendo Power Glove	1989	First accessory in gaming to recognize human hand movements via a glove controller
	Dance Dance Revolution	1998	Dance Dance Revolution uses sensors in a floor pad that detect the human stepping movement
	PlayStation EyeToy	2003	EyeToy uses color detection and motion to capture human movements for character movements
	Nintendo Wii	2006	Wii uses a remote to capture user movements in three-dimensional space

Image	Gaming GI System	Year Introduced	Description
	PlayStation Move	2009	Move uses a motion sensing wand to capture user movements in three-dimensional space
	Microsoft Kinect	2010	Kinect uses full body gesture recognition of a human to control avatar movements within the game without the use of a physical controller
	Oculus Touch	2016	Touch uses two handheld motion-sensing ergonomic controllers to capture user movements in three-dimensional space

A growing number of researchers have explored the physiological implications of these active video games (AVGs). Many AVGs are challenging the player by incorporating one's body movement into the gameplay and have been shown to increase players' energy expenditure compared to sedentary games (Jacob E. Barkley & Amanda Penko, 2009; Graf, Pratt, Hester, & Short, 2009; L. Graves, Stratton, Ridgers, & Cable, 2008; Lanningham-Foster et al., 2006; Lieberman et al., 2011; Penko & Barkley, 2010; Smallwood, Morris, Fallows, & Buckley, 2012). In fact, research has given light to the new-age AVGs, and some of these games have been added to the list of physical activities in the Compendium of Physical Activities as “Conditioning Exercise.” (Ainsworth et al., 2011). The lists credits Nintendo Wii Fit Yoga, Balance, and Sport: Boxing games as light intensity and Wii Fit Resistance exercise, Wii Fit Aerobic exercise, and Novice Dance Dance Revolution as moderate effort. Vigorous effort was noted only for higher-difficulty levels of Dance Dance Revolution games.

Dance Dance Revolution, Nintendo Wii, and the Xbox Kinect are among the most researched active video gaming systems. The potential benefits of increased activity levels have yet to be examined on recent Virtual Reality AVG systems such as the HTC Vive, and the Oculus Rift/Touch. Further research can help consumers and game developers understand more about the physical activity level achievement that users may accomplish through active gameplay.

Floor Sensor AVG: Dance Dance Revolution

Dance Dance Revolution was released by Konami in 1998. The game gained popularity as it was played in arcades and homes in Japan, the U.S. and Europe (Tan, Aziz, Chua, & Teh, 2002). The objective of this interactive dance game requires players to follow a sequence of arrows on the display by stepping on the floor sensors (Smith, 2005).

Wireless Controller AVG: Wii Tm

The Wii is a popular game system from Nintendo® released in November of 2006. The console uses a wireless controller about the size of a television remote to sense the player’s motions for a variety of games. The novelty of the Wii controller is that in addition to standard button controls, the wireless remote can be tracked in 3D using built-in accelerometers and a high-resolution infrared camera (Lee, 2008). The Wii remote can be used like a tennis racquet, golf club, or simulate the presence of a bowling ball. Other peripheral controllers include the Nunchuck and the pressure-sensitive balance board (Stach, Graham, Brehmer, & Hollatz, 2009).

Nintendo sales were 11% (Compared to Sony 69% and Microsoft 20%) in total game consoles in 2005. After the release of the Wii, Nintendo console sales climbed to approximately 40% of gaming console sales between 2007 to 2010. The Nintendo Wii offered a system that incorporated novel motion-controlled gaming, appealing to millions of people across all age groups, demographics, and countries (Hollensen, 2013). Microsoft's answer to the motion-controlled games, Xbox Kinect, was released in 2010 and regained unit sales, surpassing the Wii sales in 2011 and forward.

Controller-Free AVG: Kinect

The Xbox Kinect is a motion and voice-activated peripheral for the Xbox 360 that can be used as a hands-free controller for certain video games. This novel technology was launched by Microsoft in November of 2010. The system hardware uses cameras in collaboration with advanced sensing technology and a multi-array microphone. The Kinect offers facial recognition, full-body motion capture, and simultaneous tracking of up to four players (Sung, 2011). The Kinect's motion capturing allows users to control on-screen character avatars in real-time. The types of games for the Kinect include dance games where the user must mimic choreographed dance moves that are synchronized with real-time music. Other games include sports, fitness, adventure, and first-player fighter games (Microsoft, 2012).

The Kinect gesture recognition peripheral has broken the Guinness World Records title as the world's fastest-selling consumer electronics device. More than 29 million of the Kinect devices have been sold. The Xbox 360 peripheral sold an average 133,333 Kinect units a day in the first two months after its release in 2010. This figured totaled 8 million units sold in a 60-day period - faster than any other consumer electronic device released. The launch of the Kinect on November 4, 2010, helped boost Xbox 360 sales from 10.2 units in 2009 to 13.6 million units in 2010, allowing Microsoft to claim its console as the fastest growing games machine in 2010 (Hollensen, 2013; Thom, 2011).

Virtual Reality AVG: Oculus VR

Oculus Rift is a virtual reality (VR) headset that launched March of 2016. The head-mounted displays (HMDs) originally came with a simple remote and traditional gamepad (Simonite, 2016). Oculus released the hand-tracking Touch controllers December 6, 2016. These controllers pair with the Oculus Rift virtual reality head-mounted display to bring the gamer’s hands into VR by tracking gestures and finger movements. The addition of the touch controller allows users to experience a new level of immersion. The controllers let the users touch, punch, pick up, block, and manipulate objects in the virtual environment. In addition, the controllers can add haptic feedback through vibration (Brewster, 2016).

Technology Breakdown: Oculus Rift/Touch

Figure 4: Oculus Rift HMD, Touch controllers, and Trackers

The HMD is tethered via a 10-ft USB that carries data to the computer and powers the device. The video is transmitted through an HDMI or DVI adapter. The headset has a series of infrared LEDs embedded in it that translate positional tracking to Constellation Tracking System, which is the wireless sensor. The tracking system works in a similar fashion to the Nintendo's Wii Nunchuks. The magnetometer, a gyroscope and an accelerometer embedded in the HMD accurately track the Rift across 3-D space.

The headset features two pairs of lenses, which work to cover one’s field of view without blurring or motion sickness issues. The HMD has LED displays resolution delivered a 960 x 1080 display to each eye, for the 1920 x 1080 HD experience. 3D audio is also a special feature of the headset that allows for further immersion through realistic and 360-degree directional sound.

The most recent peripheral addition to the Oculus VR HMD experience is the Oculus Touch. These "Half Moon" ergonomic tracking controllers afford a more immersive VR experience for the player by adding the presence of the user's hands. Rather than using the originally supplied Xbox One gamepad controller, the user can view one's hands in the virtual space (Nield, 2016). Unlike the headset, the hand controllers are wireless. They feature the same infrared LEDs as the headset to allow for positional tracking. The Half Moon controllers have sensors mounted throughout, allowing recognition of hand gestures such as pointing, waving, and thumbs up. Another key feature of the hand controllers includes haptic feedback. The controllers still offer gamepad inputs such as an analog stick, buttons, and triggers so that traditional gaming experiences are consistent.

Figure 5: Oculus Rift and Touch gameplay demonstration

Technology Breakdown: Microsoft Kinect

Although many active video gaming systems have been introduced, most of them still need a physical controller to capture human movements. The introduction of the Microsoft Xbox Kinect, in 2010, presented gamers with a system that is totally air-based, and voice activated.

Figure 6: Xbox 360 Console and Kinect Sensor

The Xbox Kinect is sold as an accessory to the Xbox 360 entertainment system. The Kinect hardware uses camera technology in collaboration with advanced sensing technology and a multi-array microphone. The Kinect's motion capturing technology consists of two range cameras for depth sensing, infrared light sources, and a standard RGB camera. For depth sensing, the infrared light sources bounce light back to the sensing cameras which capture approximate distances. The depth sensing system then combines results from the RGB camera to lock into key joints of the human user. The sensing technology allows the system to track full body human movements in three-dimensional space. Supporting system functions include facial recognition, automatic player sign-in, and tracking of up to four players with 48 skeletal positions per player at 30 Hz(Solaro, 2011).   Finally, along with motion capturing technology, the Kinect's multi-array microphone allows for voice recognition in both gameplay and voice commands.

The Kinect's motion capturing, and voice recognition allows game users to control on-screen character avatars in real-time. In addition to its novel interface, the system's gameplay must offer users an engaging and challenging experience. The Kinect does this in a series of games designed specifically for the system. Types of games for the Kinect include dance games where the user must mimic choreographed dance moves that are synchronized with real-time music. Other games include sports, fitness, adventure, and first player fighter games.

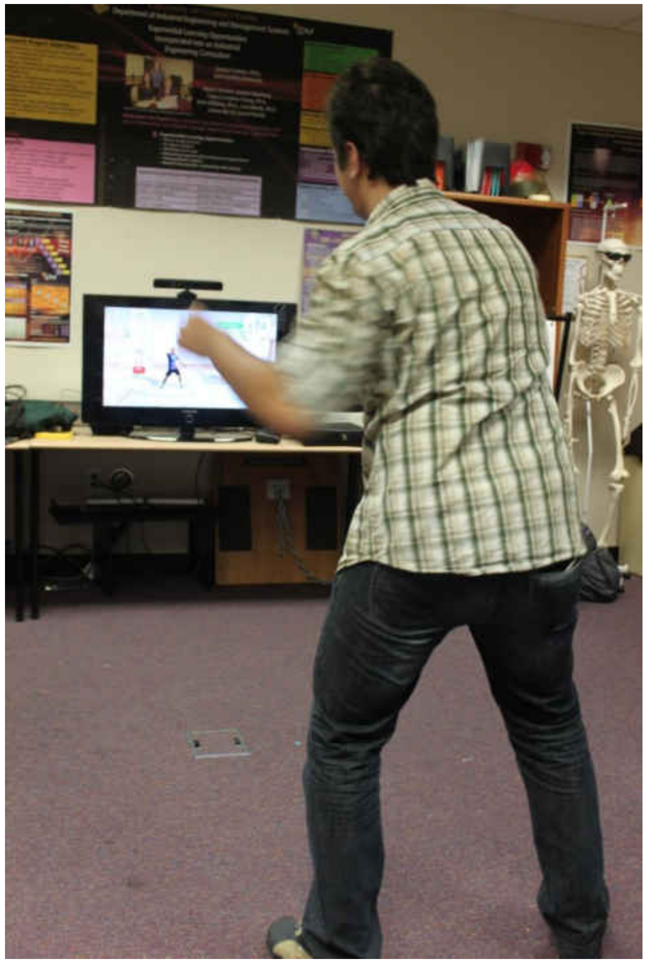


Figure 7: Xbox 360 and Kinect gameplay demonstration

Current Research on Physiological Response to Active Gaming

Video gaming technologies have evolved to incorporate the user’s actions into gameplay. Leading gaming manufacturers such as Nintendo Wii, Microsoft Xbox, and Sony PlayStation each have interactive controller technology and games available for their systems. The term ‘‘active video games’’ (AVGs) has been developed to describe these physically interactive video games. Numerous studies have investigated AVGs and the effect on increasing physiologic response, such as heart rate and energy expenditure (Jacob E. Barkley & Amanda Penko, 2009; Graf et al., 2009; L. Graves et al., 2008; Lanningham-Foster et al., 2006; Lieberman et al., 2011; Penko & Barkley, 2010; Smallwood et al., 2012).

Dance Dance Revolution (DDR) was one of the first games to incorporate physical activity into a video game. DDR was also the subject of various studies exploring heart rate (HR) and energy expenditure (EE) during gameplay. The objective of many of these studies was focused on identifying whether activity levels elicited by exergames is sufficient to meet the ACSM recommendation for physical activity (PA). Lanningham-Foster et al. (2006) published a study that involved measuring the EE in children during Television (TV) watching, sedentary video gaming, an EyeToy (Sony) active game, the DDR (Konami) interactive game, and treadmill walking (1.5 miles/hour). The participants consisted of 25 children, ages 8 to 12 years old. The researchers found that treadmill activity increased EE in subjects by 138±40%, while the EyeToy increased EE by 108±40 and DDR activity increased EE by 172± 68% above resting levels. The researchers concluded that the energy expenditure more than doubled when interactive gaming activity replaces sedentary screen-based activity. They further report that interventions such as active games may be considered for the prevention and treatment of obesity.

After the release of the Nintendo Wii in late 2006, researchers began examining this active gaming system and physical activity. L. E. F. Graves, Ridgers, and Stratton

(2008) conducted a study to address the contribution of the upper limb and total body movement to the energy expended during interactive gaming. The 13 subjects of this study were adolescents, ages 11 to 17 years of age. The experiment involved assessing EE and HR of the participants while playing three Wii games and one sedentary (Xbox 360) game. The study revealed that there was a significant increase in EE during Wii Boxing as opposed to Wii Tennis (200.5 ± 54.0 J·kg–1·min–1), Wii Bowling (182.1 ± 41.3 J·kg–1·min–1), as well as compared to sedentary gaming ((115.8 ± 18.3 51 J·kg–1·min–1). The resting heart rate was reported at 84 ± 14. J·kg–1·min–1. Non-dominant upper limb activity was greater for the Wii Boxing game compared to the Wii Bowling and Tennis. The activation of both limbs reportedly increased the physiological cost of active gameplay.

DDR and Wii Sports active video games were compared to treadmill walking by Graf et al. (2009). The researchers measured EE, HR, step rate and perceived exertion in 23 subjects, ages 10 to 13 years while watching television, playing DDR, playing Wii Bowling and Wii Boxing, and walking at 2.6, 4.2, and 5.7 kilometers per hour. Energy expenditure for active gaming and walking was 2 to 3 times greater than watching TV. Higher rates of EE were found for Wii Boxing, DDR level 2, and Walking 5.7 km/h activities compared to DDR beginner level, Wii bowling, and TV watching. The researchers concluded that EE during active video game play is similar to moderate-intensity walking. Further, active video gaming may promote energy expenditure for children who spend considerable time participating in screen-based sedentary activities.

J.E. Barkley and A. Penko (2009) were the first to explore the physiologic cost of playing the Nintendo Wii interactive gaming system for the adult population. The experiment involved twelve healthy adult participants: six males and six females. The age of the participants was 31.5 ±12.4 years. The researchers assessed the HR, EE and ratings of perceived exertion (RPE) of the subjects as they completed four, 10-minute tests: rest, treadmill walking (2.5 mph), sedentary gameplay, and Wii Sports Boxing gameplay. The results of this study revealed that the average HR, VO2, RPE, and liking were significantly greater for the Nintendo Wii than for the other conditions. Researchers concluded that the Wii Sports Boxing was well-liked and that the activity has the potential to offer greater physiological challenge than resting, sedentary gameplay, and treadmill walking in adults.

L. E. F. Graves, N. D. Ridgers, K. Williams, G. Stratton, and G. T. Atkinson (2010) conducted a study to find the physiological cost and enjoyment of Wii Fit in adolescents, young adults, and older adults. The experiment compared the EE, HR, and enjoyment measurements for a handheld sedentary game, Wii Yoga, Wii muscle conditioning, Wii Balance, Wii Aerobics, brisk treadmill walking, and treadmill jogging. The results revealed that for all groups, EE and HR of Wii Fit activities were significantly greater than handheld gaming. However, the EE of the exergames were lower than the treadmill exercise. The Wii aerobics elicited moderate-intensity activity (>3.0 METs) for all age groups. On the other hand, the HR during Wii Aerobics was below the recommended intensity for maintaining cardiorespiratory fitness. Regarding the enjoyment ratings, the Wii balance and aerobics activities were higher than the rating for treadmill exercising.

Kirkwood (2011) was one of the first researchers to conduct a study with the controller-free gesture interface gaming system for Microsoft's Xbox Kinect. This study assessed EE, metabolic responses, performance, and the ratings of perceived exertion (RPE) of 14 young adults ages 20.1 ± 1.64 years during Kinect Adventure and Wii Fit Plus gameplay. The research found that EE, HR, performance, and RPE were significant in both exergames. Additionally, it was reported that Xbox Kinect Adventures gameplay expended more calories and elicited higher-intensity activity than the Wii Fit Plus. The researcher concluded that individuals could meet moderate-intensity EE requirements of 150 to 400 kcals.

According to Scheer et al., the Nintendo Wii Boxing, Xbox Kinect Boxing, and PlayStation Move Gladiatorial Combat gameplay did not meet the minimal threshold for moderate PA (2014). Contrariwise, Wu et al. examined 6 Xbox Kinect exergames and found that boxing and soccer elicited vigorous-intensity PA (6.8±1.9 METs, 6.2±1.7 METs), while beach volleyball, track and field, and ping-pong provided moderate-intensity PA (5.7±1.8, 5.0±1.5, 4.0±1.6). Bowling provided the lowest level of PA at 2.6±0.8 METs, which would be categorized as light-intensity. These findings suggest that exergames may be a potential alternative method of exercise.

Sanders et al. examined four 10-minute conditions of seated rest, treadmill walking (3 mph), Wii Boxing and Kinect Boxing to find the mean heart rate and peak heart rate for

27 adults. Kinect boxing significantly increased HR_{mean} (64.1±1.6 percent of age-predicted maximum) and percentage HR_{peak} (76.5±1.9 percent) above all other conditions. In this study, Kinect Boxing elicited a peak heart rate great enough to be considered vigorous-intensity PA. In addition, Kinect boxing, albeit the highest PA intensity, was also the most preferred condition. This finding implies that AVGs for the Kinect may be a better, more enjoyable physical activity option than playing the Wii or traditional treadmill walking, as liking can be a predictor of an individual's behavior (2015). Other studies comparing the Wii and Kinect games also concluded the Kinect yielded higher activity levels than Wii games (Marks, Rispen, & Calara, 2015; O'Donovan et al., 2012)

McGuire et al. further examined Xbox Kinect sports games football, boxing and track and field with single player and multi-player conditions and discovered that multi-player mode could provide higher physiological demands. However, this was found to be game-dependent, as the multiplayer condition was significant in football and boxing, but not for the track and field gameplay (2015).

Eason et al. compared the energy expenditure, heart rate and RPE between a dance fitness class and an Xbox Kinect dance video game among 30 female subjects. The study did find that the dance class average heart rate, calories expended, and RPE were significantly greater than the Xbox Kinect dance games. Although the Kinect was not as effective as the dance fitness class, it was noted that 97% of subjects demonstrated an increase in peak HR to over 50% of age-predicted heart rate maximum while playing the Xbox Kinect. The Kinect could serve as a potential option for moderate-intensity exercise for those who might otherwise be sedentary (2016). A summary of existing research relating to the topic of AVGs in adult populations is provided in Table 5.

Table 5: Existing AVG Research

Researchers	Year	n=	age	Activity Type					Measures			
				Nintendo Wii AVG	Xbox Kinect AVG	Virtual Reality AVG	Traditional Exercise	SVG/ Alt. Input	Energy Expenditure	Heart Rate	RPE	Hedonics/ Usability
Wooden Dissertation	2017	25	20.7 ±2.3		X	X	X			X	X	X
Barry, G., et al.	2016	50	33.8 ±12.7	-	X	-	X	-	-	X	X	X
Bronner, S., et al.	2016	14	26.6 ± 9.5	-	X	-	-	-	X	X	-	X
Cardona, J., et al.	2016	17	64.5 ± 6.5	-	X	-	-	X	-	X	-	X
Eason, J., et al.	2016	30 F	33.9 ±10.4	-	X	-	X	-	X	X	X	X
Mackintosh, K., et al.	2016	36	21.7 ± 3.8	X	-	-	-	-	X	X	-	X
Murray, E., et al.	2016	62 F	20.2 ±2.7	-	-	-	X	X	-	X	X	X
Pasco, D., et al.	2016	163	20.3 ±1.3	-	-	-	X	X	-	-	-	X
Santo, A., et al.	2016	24	18-41	X	-	-	-	X	X	X	X	X
Bronner, S., et al.	2015	7	29 ± 9	X	X	-	-	X	X	-	-	X
Marks, D., et al.	2015	15	21.3 ± 1.4	X	X	-	-	-	X	X	-	-
McGuire, S., Willems	2015	10 M	23 ± 5	-	X	-	-	-	X	X	-	-
Sanders, G. J., et al.	2015	27	22.7 ± 4.2	X	X	-	X	-	-	X	X	X
Wu, P., et al.	2015	17	22.0 ± 2.9	-	X	-	-	-	X	X	-	-
Scheer, K., et al.	2014	19	19.8 ± .3	X	X	-	X	X	X	X	-	-
Lyons, E., et al.	2012	120	24.1 ± 4.1	X	-	-	-	X	X	-	-	
O'Donovan, C., et al.	2012	14	21 ± 3	X	X	-	-	-	X	X	-	-
Lyons, E., et al.	2011	100	18-35	X			-	X	X	-	-	X
Noah, J., et al.	2011	12	18-53	-	-	-	-	X	X		-	X
Kirkwood, D.	2011	14	21 ± 1.6	X	X	-	-	-	X	X	X	-
Graves, L. E., et al.	2010	42	11-70	X	-	-	X	-	X	X	-	X
Barkley, J. E. and Penko	2009	12	31.5 ±12.4	X	-	-	X	X	X	X	X	X

Summary

Published research is available for the Wii and Kinect AVGs. However, Table 5 clearly displays a lack of literature exploring the physiological implications of virtual reality active video games. Energy Expenditure, Heart Rate, Ratings of Perceived Exertion (RPE), and Hedonics (Liking) are measures that are frequently collected in Active Video Gaming studies.

Overall, the existing literature provides insight into the application of AVGs to promote PA. Several researchers have established that AVG play can result in moderate-intensity physical activity and some activities have been found to elicit peak heart rate in the vigorous-intensity physical activity range. The addition of virtual reality AVG physiological data will further expand the body of knowledge in the field exergaming.

In addition to the physiological response, which is the primary concern for AVGs meeting physical requirements to CDC-recommended physical activity, it is also important to explore the user's experience in terms of their perceived exertion and hedonics. The likelihood of adherence to a physically-intensive regimen may be associated with how strenuous a task is perceived to be and how well-liked the activity is for the user. Previous research shows that physical activity can be as enjoyable and sometimes more enjoyable than sedentary video games and traditional modes of exercise.

CHAPTER 3: METHODOLOGY

Overview

To date, there is no evidence of empirical research on Virtual Reality active video games relating the effects on the physiological response, perceived exertion, and hedonics. This study aims to fill the gap in the literature by providing a comparative analysis of the controller-free AVG Xbox Kinect and the Virtual reality AVG Oculus Touch/Rift and examine the physiological, psychophysiological, and hedonic experiences.

The primary purpose of this research was to determine if moderate-to-vigorous physical activity (MVPA) levels can be observed while using active video game (AVG) systems. The secondary objective was to examine the ratings of perceived exertion (RPE) and enjoyment.

Subjects

Twenty-five undergraduate students (9 females, 16 males; mean age 20.68) volunteered to participate in the experiment at the Human Performance Laboratory at UCF. Subjects were recruited from March 10, 2018 to April 12, 2018 and participated in the experiment from April 10, 2018 to April 12, 2018. Flyers were posted, and digital invitations were sent via email and social media requesting volunteers to participate in a single laboratory visit completing 4 active video gaming conditions and a walking condition. The participants were informed of the potential risks of the research and provided a signed informed consent document, prior to participation. The Institutional

Review Board at the University of Central Florida approved the project on November 2, 2017.

Subjects in this study reported being free of any current medical conditions contradictory to physical activity. The subjects were also instructed to arrive at the site fasted and caffeine-free for a minimum of 4 hours. They were informed they were free to withdraw from the experiment for any reason at any time. Due to scheduling constraints, one subject withdrew from the experiment and the subject's data were excluded. Demographic data were summarized in Table 6.

Experimental Design

Each participant reported to the Human Performance Laboratory for a single appointment. Upon arrival, the subject's height (in) weight (lbs.) were recorded. After anthropometric data had been recorded, the participants rested in a seated position for 10 minutes while the heart rate was monitored to establish the baseline or resting heart rate.

Physical activity (PA) levels were compared using a within-subjects repeated measures design with randomization of treatment order for the 10-minute sessions of the five physical activity conditions.

There are five physical-activity conditions in this experiment in which subjects participated in random order. After the end of each activity, the subject was required to fill out a post-experiment PACES questionnaire. The sequence of the experimental procedure is illustrated in Figure 8.

Figure 8: Experiment Procedure

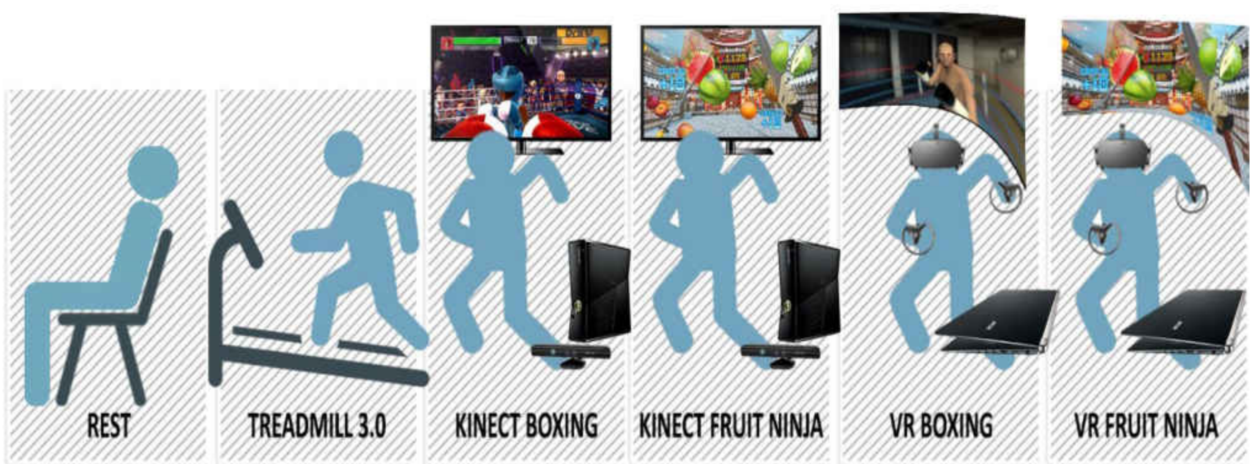
The physical-activity conditions for this project were Fruit Ninja on Oculus (VR AVG), Thrill of the Fight: Boxing on Oculus (VR AVG), Fruit Ninja on Kinect (Controller-free AVG), Kinect Sports: Boxing on Kinect (Controller-free AVG), and Treadmill walking at 3.0 mph. Treadmill walking at 3.0 mph was selected because the American College of Sports Medicine Guidelines for Exercise Testing and Prescription states that walking at 3.0 miles/hour is equivalent to a moderate-intense physical activity (2013). Furthermore, several other studies have used treadmill walking to compare levels of physical activity intensity (Jacob E. Barkley & Amanda Penko, 2009; Kirkwood, 2011; Penko & Barkley, 2010; Sanders et al., 2015; Scheer et al., 2014).

These games were selected because it had been observed that Wii and Kinect boxing had elicited MVPA in other studies (Marks et al., 2015; Sanders et al., 2015). The two different AVG systems (Xbox Kinect and Oculus Rift) were selected for the study because they are available and popular among consumers and each system had similar boxing and fruit ninja game options.

Prior to this study, there are no published studies of physiological response, perceived exertion, or hedonics of any commercially available virtual reality active video games. At the time of this study, there was no single title for boxing that was available for both the Kinect and the Oculus system. Since the gaming skill and movements required (punching a computer opponent) were very similar, a boxing-themed game was selected for each system, although they were not the same title or developer. The Fruit Ninja title was available for both systems and selected as a casual style game.

Indirect calorimetry was not used in this study to measure oxygen consumption. There are some physical restrictions that would be imposed by the stationary metabolic cart. These conditions may interfere with gameplay and pose an additional unnecessary risk to the participant.

Physical-Activity Conditions



HR_{mean}	N/A	N/A	N/A	HR_{mean}	HR_{peak}	RPE	Liking	HR_{mean}	HR_{peak}	RPE	Liking	HR_{mean}	HR_{peak}	RPE	Liking	HR_{mean}	HR_{peak}	RPE	Liking	HR_{mean}	HR_{peak}	RPE	Liking
$Subject_1$				$Subject_1$				$Subject_1$				$Subject_1$				$Subject_1$				$Subject_1$			
$Subject_2$				$Subject_2$				$Subject_2$				$Subject_2$				$Subject_2$				$Subject_2$			
…				…				…				…				…				…			
$Subject_{25}$				$Subject_{25}$				$Subject_{25}$				$Subject_{25}$				$Subject_{25}$				$Subject_{25}$			

Figure 9: AVG Repeated Measures Experiment Design

Research Variables

The independent variables in this study were the activity conditions: Oculus Head Mounted Display Virtual Reality: VR Fruit Ninja and VR Boxing, Screen-based controller-free AVG: Kinect Fruit Ninja and Kinect Boxing, Treadmill walking at 3.0 mph, and Rest. The dependent variables include mean heart rate (HR_{mean}), peak heart rate (HR_{peak}), ratings of perceived exertion (RPE), and enjoyment (hedonic experience).

Independent Variables

Activity Conditions: VR Fruit Ninja, VR Boxing, Kinect Fruit Ninja, Kinect Boxing, Treadmill Walking 3.0 mph, Rest.

Dependent Variables

Heart Rate mean (HR_{mean}), Heart Rate peak (HR_{peak}), Rating of Perceived Exertion (RPE), Enjoyment (Liking)

Research Hypotheses

Previous theoretical frameworks and studies in the literature review provided some indication to link Heart rate, liking and RPE with responses to Kinect active gaming. Therefore, and based on the previous evidence, the following is hypothesized:

Hypothesis 1

Considering the resting condition, it was hypothesized that the average Heart Rate of all the active gaming conditions would be significantly different from resting conditions and at least one active gaming activity would be significantly different from the Treadmill Walking condition.

Null hypothesis 1: HR_{mean} of the activity conditions are equal. There is no significant difference between the HR_{mean} for activity conditions

Alternative hypothesis 1: at least two of the HR_{mean} of the activity conditions are significantly different (i.e., they are not all equal).

Hypothesis 1:

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$$

$$H_a: \mu_i \neq \mu_j \; for \; some \; i, j$$

In the statement above, μ_1 = HR_{mean} Treadmill Walking at 3.0 mph, μ_2 = HR_{mean} Kinect Fruit Ninja, μ_3= HR_{mean} VR Fruit Ninja, μ_4= HR_{mean} Kinect Boxing, μ_5 = HR_{mean} VR Boxing, and μ_6 = HR_{mean} Rest.

Hypothesis 2

Considering the Peak Heart Rate of all the active gaming conditions, it was hypothesized that at least one active gaming activity would be significantly different.

Null hypothesis 2: HR_{peak} of the activity conditions are equal. There is no significant difference between the HR_{peak} for activity conditions

Alternative hypothesis 2: at least two of the HR_{peak} of the activity conditions are significantly different (i.e., they are not all equal).

Hypothesis 2:

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$$

$$H_a: \mu_i \neq \mu_j \; for \; some \; i, j$$

In the statement above, μ_1 = HR_{peak} Treadmill Walking at 3.0 mph, μ_2 = HR_{peak} Kinect Fruit Ninja, μ_3= HR_{peak} VR Fruit Ninja, μ_4= HR_{peak} Kinect Boxing, and μ_5 = HR_{peak} VR Boxing.

Hypothesis 3

For RPE of each activity condition, it was hypothesized that RPE would be statistically significantly different.

Null hypothesis 3: RPE for the activity conditions are equal.

Alternative hypothesis 3: RPE for the activity conditions are not all equal.

Hypothesis 3:

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$$

$$H_a: \mu_i \neq \mu_j \; for \; some \; i, j$$

In the statement above, μ_1 = RPE for Treadmill Walking at 3.0 mph, μ_2 = RPE for Kinect Fruit Ninja, μ_3= RPE for VR Fruit Ninja, μ_4= RPE for Kinect Boxing, and μ_5 = RPE for VR Boxing.

Hypothesis 4

For Liking each activity condition, it was hypothesized that Liking would be significantly different for at least one activity condition.

Null hypothesis 4: Liking for the activity conditions are equal.

Alternative hypothesis 4: Liking for the activity conditions are not all equal.

Hypothesis 4:

$$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$$

$$H_a: \mu_i \neq \mu_j \ for \ some \ i, j$$

In the statement above, μ_1 = Liking for Treadmill Walking at 3.0 mph, μ_2 = Liking for Kinect Fruit Ninja, μ_3= Liking for VR Fruit Ninja, μ_4= Liking for Kinect Boxing, and μ_5 = Liking for VR Boxing.

Hypothesis 5

It was predicted that there would be a positive relationship between the rating of perceived exertion and average heart rate.

Null hypothesis 5: There is no significant correlation between RPE and HR_{mean}.

Alternative hypothesis 5: There is a significant correlation between RPE and HR_{mean}.

Hypothesis 5:

$$H_0: \rho = 0$$

$$H_a: \rho_i \neq 0 \; for \; some \; i$$

In the statement above, ρ_1 = population correlation coefficient of RPE vs HR_{mean} for Treadmill Walking at 3.0 mph, ρ_2 = population correlation coefficient of RPE vs HR_{mean} for Kinect Fruit Ninja, ρ_3 = population correlation coefficient of RPE vs HR_{mean} for VR Fruit Ninja, ρ_4 = population correlation coefficient of RPE vs HR_{mean} for Kinect Boxing, and ρ_5 = population correlation coefficient of RPE vs HR_{mean} for VR Boxing.

Experimental Procedures

Each task was performed for 10 minutes. Each session allowed for a 5-minute introduction and practice phase. The tasks were randomized to avoid any order effects that might have been present. The heart rate was recorded every minute of each activity and between tasks. The subjects were allowed time to achieve resting heart rate before performing the next task.

Screening

Each subject's medical status was evaluated using the PAR-Q Questionnaire. Individuals classified as high risk, taking medications that could affect heart rate and those with any physical injury or disability affecting full participation were ineligible for participation in the study. Once a subject had been cleared to participate in the study, their height, weight, age, gender, BMI, resting heart rate, and maximum heart rate were recorded. Height was measured using a stadiometer, and body mass were measured using a digital scale. BMI was calculated with the formula, as described by NIH by dividing weight in pounds (lbs.) by height in inches (in) squared and multiplying by a conversion factor of 703 as displayed in Equation 1 (1998).

$$BMI = [weight\ (lb) \div (height\ (in))2]\ x\ 703 \qquad (1)$$

$$HR_{max} = 220 - Age \qquad (2)$$

The subject’s age-based maximum heart rate (HR_{max}) was calculated by Equation 2 (Åstrand, 2003).

Orientation Session

Prior to starting the trial, subjects participated in orientation. The purpose of the orientation was to explain and demonstrate the proper use of the interactive gaming systems. Before testing began, subjects performed a small practice session to warm up and acclimate themselves to the XBOX Kinect and Oculus Touch/Rift.

Assessments

Demographic Measurements

Height

Height was measured during the screening using a stadiometer. The participants were measured without shoes and with their backs and heels of their feet against the wall.

Body Weight

Body weight (lbs.) was measured by a scale (Tanita, Tokyo, Japan). Participants were weighed with their shoes removed.

Heart Rate

Subjects were asked to wear a heart rate monitor throughout the testing phases to evaluate task performance. The heart rate was collected and assessed during and in-between each session, using a heart rate monitor (Polar, Kempele, Finland). The heart rate data were collected at one-minute intervals. The CDC classifies physical activity intensity according to the subject's age-predicted maximum heart rate (220 – age in years) (HR_{max}). Moderate physical activity (MPA) is classified as 50–70 percent of an individual's HR_{max}, whereas vigorous physical activity (VPA) intensities are classified as 70–85 percent of HR_{max} (CDC, 2011b). The subject could stop the test at any time. For each 10-minute condition, the mean heart rate (HR_{mean}) and peak heart rate (HR_{peak}) was calculated and recorded.

Perceived Exertion

During testing, at every minute interval, subjects were questioned about their rate of perceived exertion using the Borg Ratings of Perceived Exertion Scale. The score is based on the subject's physical sensations and interpretations of physical exertion during activity ("Perceived Exertion (Borg Rating of Perceived Exertion Scale)," 2011).

Enjoyment

The modified PACES survey employed by L. E. Graves, N. D. Ridgers, K. Williams, G. Stratton, and G. T. Atkinson (2010) was used in this study to compare the enjoyment of the activities performed by subjects. Concluding each session, individuals rated the extent to which they agreed with each item on a 7-point Likert-type scale. For each activity, for each participant, the total responses were summed. From the overall score, ranging from 5 to 35, a percentage enjoyment score was calculated. The PACES survey has been found to have both reliability and validity in physical activity environments (Kendzierski & DeCarlo, 1991).

Data Analysis

One, six-condition (Rest, Treadmill 3.0, Kinect Boxing, Kinect Fruit Ninja, Oculus Boxing, Oculus Fruit Ninja) repeated-measures analyses of variance were used to examine differences in HR_{mean}. For HR_{mean}, a one-way repeated measure ANOVA was used to identify if the five experimental blocks (Treadmill 3.0, Kinect Fruit Ninja, Oculus Fruit Ninja, Kinect Boxing, and Oculus Boxing) were significantly different from the baseline block. The baseline in this experiment was the resting heart rate. The repeated measures ANOVA was corrected using Greenhouse-Geisser if non-sphericity was identified.

Three, five-condition (Treadmill 3.0, Kinect Boxing, Kinect Fruit Ninja, Oculus Boxing, Oculus Fruit Ninja) repeated-measures analyses of variance were used to examine differences in HR_{peak}, ratings of perceived exertion (RPE) and Hedonics (Liking).

Post hoc analyses using pairwise comparisons were used to further assess significant main effects of the condition.

The experiment was designed as a within-subjects design, where all subjects perform all levels of the independent variable (activity condition). This is also referred to as a repeated-measures design. Each subject act as their own control, reducing the amount of error occurring from the natural variance between individuals. The order that the subjects completed the activity conditions were counterbalanced by randomizing the order of activities for each participant. The objective was to prevent confounding such as practice effect or fatigue effect, due to the order of task performance. Further, there were no significant ($p<0.05$) main or interaction effects of gender for any of the dependent variables. Thus, the data are shown as pooled for males and females. The statistical analyses were conducted using IBM SPSS for Windows software (version 24.0; IBM Inc., Armonk, NY).

CHAPTER 4: RESULTS

Descriptive Statistics

Means and standard deviations were calculated for all physical characteristics such as age, height, weight, and body mass index (BMI).

Physical Characteristics

There were nine females and 16 male participants for the study. The subject-descriptive data is provided in Table 6.

The males were significantly taller ($p<0.05$) than the females. However, there was no significant difference in weight, age, BMI, HRmax, Moderate PA levels and Vigorous PA levels between males and females.

Table 6. Subject descriptive data and anthropometric characteristics

	Males (n=16)	**Females (n=9)**	**Total (n=25)**
Age (years)	20.31 ± 1.74	21.33 ± 3.04	20.68 ± 2.29
Height (in)	70.50 ± 2.37	65.33 ± 3.84	68.64 ± 3.85
Weight (lbs.)	160.63 ± 22.67	158.94 ± 42.06	160.02 ± 30.19
BMI	22.76 ± 3.41	25.96 ± 5.81	23.92 ± 4.59
HRmax (bpm)	199.69 ± 1.74	199.67 ± 3.04	199.32 ± 2.87
Moderate PA (bpm)	99.84 ± 0.87	99.33 ± 1.52	99.66 ± 1.14
Vigorous PA (bpm)	139.78 ± 1.22	139.07 ± 2.13	139.52 ± 1.60

Gender

In order to assess if there was a main effect of gender for each dependent variable response (HR_{mean}, HR_{peak}, RPE, Liking), a one-way repeated measures ANOVA was performed with Gender as the between-subjects factor.

Gender Effect on HR_{mean}

There were no outliers and the data were normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was violated, as assessed by Mauchly's test of sphericity, $\chi^2(14) = 30.114$, $p = .008$. Epsilon (ε) was .659, as calculated according to Greenhouse & Geisser (1959) and was used to correct the one-way repeated measures ANOVA. HR_{mean} was statistically significantly different for the activity conditions. However, there was no significant main effect or interaction effect of gender. F (3.295, 71.245) = .403, $p = .770$, partial $\eta^2 = 0.017$.

Gender Effect on HR_{peak}

There were no outliers and the data were normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was not violated. HR_{peak} was statistically significantly different for the activity conditions. However, there was no significant main effect or interaction effect of gender. F (4, 104.395) = .685, $p = .604$, partial $\eta^2 = 0.029$.

Gender Effect on RPE

There were no outliers and the data were normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was not violated. RPE was statistically significantly different for the activity conditions. However, there was no significant main effect or interaction effect of gender. F (4, 1.295) = .641, $p = .635$, partial $\eta^2 = 0.027$.

Gender Effect on Enjoyment

There were no outliers and the data were normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was not violated. Liking was statistically significantly different for the activity conditions. However, there was no significant main effect or interaction effect of gender. $F(4, .005) = .996$, $p = .414$, partial $\eta^2 = 0.041$.

Overall, there was no significant main effect or interaction effect of gender for the dependent variables. Past research has also indicated that there were no significant main or interaction effects of gender for any of the dependent variables (Jacob E. Barkley & Amanda Penko, 2009; Sanders et al., 2015). The lack of significant gender-effect should be interpreted with caution, as the participants in the study were all college students, with a mean age of 21 years. Further studies could be performed to determine if there is a main effect gender for a larger sample size that may include greater age range and more variability in terms of professional background.

Two, six-condition (Rest, Treadmill 3.0, Kinect Fruit Ninja, Oculus VR Fruit Ninja, Kinect Boxing, and Oculus VR Boxing) repeated-measures analyses of variance were used to examine differences in HR_{mean} and HR_{peak}. Two, five-condition (Treadmill 3.0, Kinect Fruit Ninja, Oculus VR Fruit Ninja, Kinect Boxing, and Oculus VR Boxing) repeated-measures analyses of variance were used to examine differences in ratings of perceived exertion (RPE) and Hedonics (Liking). The repeated measures ANOVA was corrected using Greenhouse-Geisser if non-sphericity was identified. Post hoc analyses using pairwise comparisons with Bonferroni adjustment were used to further assess significant main effects of the condition. Summary of the significant results is illustrated in Table 7.

Table 7. Subject HR_{mean}, HR_{peak}, Liking, RPE for Activity Condition (means ± SD)

	Rest	**Treadmill 3.0**	**Kinect Fruit Ninja**	**VR Fruit Ninja**	**Kinect Boxing**	**VR Boxing**
HR_{mean}	80.24 ± 7.80	115.32 ± 8.35	119.46 ± 12.08	119.60 ± 13.70	123.62 ± 19.25	148.51 ±18.61
HR_{peak}	*	121.40 ± 10.47	129.68 ± 16.7	126.32 ± 17.85	136.36 ± 22.09	162.88 ± 19.24
Liking	*	74% ± 11%	86% ± 10%	96% ± 5%	85% ± 9%	91% ± 8%
RPE	*	10.04 ± 1.71	10.72 ± 2.35	10.87 ± 2.45	11.52 ± 1.15	14.20 ± 2.02

($p < 0.001$) for all.

Hypothesis Testing

The hypotheses in this study were tested by obtaining the p-value. A hypothesis was supported if the statistical value is $p<0.05$. Table 17 provides a summary of the research questions and hypotheses tested.

HR_{mean}

In order to assess if there were statistically significant differences in HR_{mean} for the activity conditions, a one-way repeated measures ANOVA was performed. There were no outliers and the data were normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was violated, as assessed by Mauchly's test of sphericity, $\chi^2(14) = 30.037$, $p = .008$. Epsilon (ε) was .667, as calculated according to Greenhouse & Geisser (1959) and was used to correct the one-way repeated measures ANOVA. HR_{mean} was statistically significantly different for the activity conditions, $F(3.336, 80.071) = 105.550$, $p < .001$, partial $\eta^2 = 0.815$. Summary of the significant results for HRmean are provided in Table 8 and depicted in Figure 10.

Table 8. HR_{mean} Descriptive Statistics

Activity	Mean	Standard Deviation	Std. Error	95% CI Lower Bound	95% CI Upper Bound
Rest	80.240	7.80641	1.561	77.018	83.462
Treadmill 3.0	115.320	8.35000	1.670	111.873	118.767
Kin Fruit Ninja	119.456	12.07991	2.416	114.470	124.442
VR Fruit Ninja	119.600	13.69872	2.740	113.945	125.255
Kin Boxing	123.620	19.25158	3.850	115.673	131.567
VR Boxing	148.512	18.61035	3.722	140.830	156.194

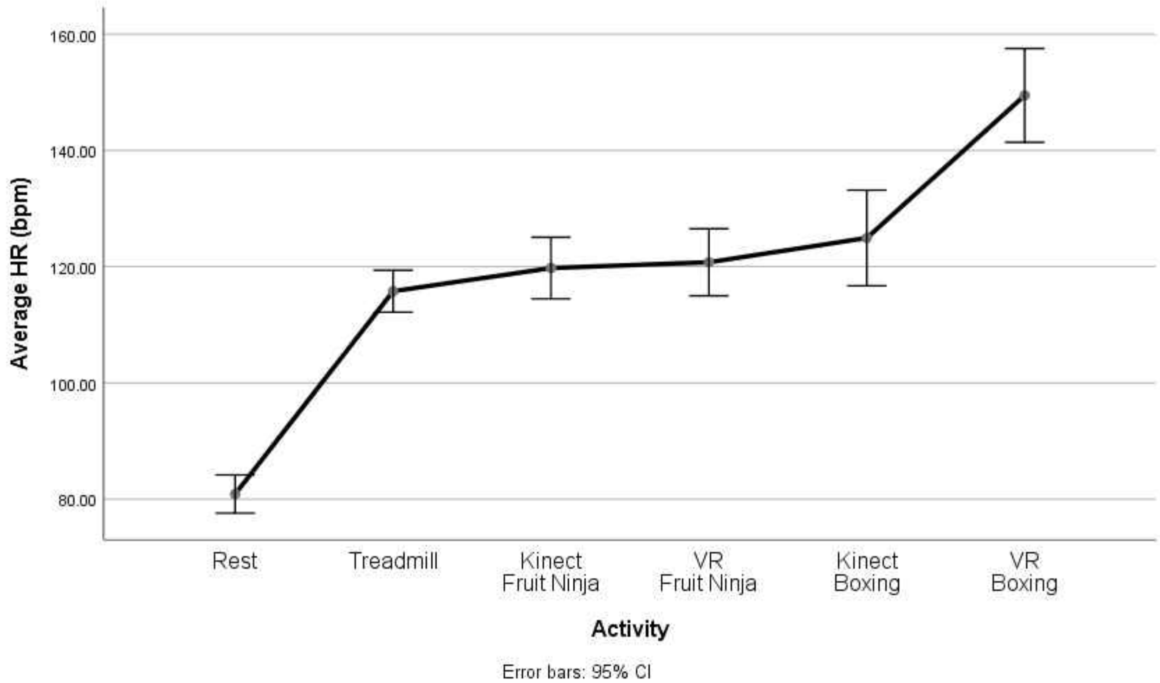


Figure 10: Graphical representation of HRmean for Activity Conditions.

Post hoc analysis with a Bonferroni adjustment revealed that HR_{mean} was statistically significantly increased from Rest (M=80.24, 95% CI [77.02, 83.46], p <.001), to Treadmill Walking at 3.0 mph (M=115.32, 95% CI [111.87, 118.77], p <.001), Kinect Fruit Ninja (M=119.46, 95%CI [114.47, 124.44], p <.001), VR Fruit Ninja (M=119.60, 95%CI [113.95, 125.26], p <.001), Kinect Boxing (M=123.62, 95%CI [115.67, 131.57], p <.001), and VR Boxing (M=148.51, 95%CI [140.83, 156.19], p <.001).HR_{mean} was not significantly different for Treadmill Walking at 3.0 mph, Kinect Fruit Ninja, and VR Fruit Ninja. HR_{mean} was statistically significantly greater for VR Boxing than all other activity conditions: Treadmill Walking at 3.0 mph, Kinect Fruit Ninja, VR Fruit Ninja, Kinect Boxing, and Rest.

Table 9: HR_{mean} Pairwise Comparisons

(I) Activity	(J) Activity	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	2	-35.080*	1.902	.000	-41.277	-28.883
	3	-39.216*	2.685	.000	-47.966	-30.466
	4	-39.360*	3.045	.000	-49.282	-29.438
	5	-43.380*	3.933	.000	-56.194	-30.566
	6	-68.272*	3.938	.000	-81.104	-55.440
2	1	35.080*	1.902	.000	28.883	41.277
	3	-4.136	2.103	.913	-10.987	2.715
	4	-4.280	2.607	1.000	-12.775	4.215
	5	-8.300	3.172	.227	-18.636	2.036
	6	-33.192*	2.862	.000	-42.519	-23.865
3	1	39.216*	2.685	.000	30.466	47.966
	2	4.136	2.103	.913	-2.715	10.987
	4	-.144	2.567	1.000	-8.509	8.221
	5	-4.164	2.772	1.000	-13.196	4.868
	6	-29.056*	2.757	.000	-38.039	-20.073
4	1	39.360*	3.045	.000	29.438	49.282
	2	4.280	2.607	1.000	-4.215	12.775
	3	.144	2.567	1.000	-8.221	8.509
	5	-4.020	3.569	1.000	-15.649	7.609
	6	-28.912*	3.560	.000	-40.512	-17.312
5	1	43.380*	3.933	.000	30.566	56.194
	2	8.300	3.172	.227	-2.036	18.636
	3	4.164	2.772	1.000	-4.868	13.196
	4	4.020	3.569	1.000	-7.609	15.649
	6	-24.892*	2.932	.000	-34.444	-15.340
6	1	68.272*	3.938	.000	55.440	81.104
	2	33.192*	2.862	.000	23.865	42.519
	3	29.056*	2.757	.000	20.073	38.039
	4	28.912*	3.560	.000	17.312	40.512
	5	24.892*	2.932	.000	15.340	34.444

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

There was a statistically significant difference between the HR_{mean} for at least two activity conditions ($p < .05$). Therefore, we can reject the null hypothesis and can accept the alternative hypothesis.

HR_{peak}

A one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in HR_{peak} for five activity conditions. There were no outliers and the data were normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was not violated, as assessed by Mauchly's test of sphericity, $\chi^2(9) = 7.335$, $p = .603$. HR_{peak} was statistically significantly different for the activity conditions, $F(4, 96) = 44.328$, $p < .001$, partial $\eta^2 = 0.649$. Summary of the significant results for HR_{peak} are provided in Table 10 and depicted in Figure 11.

Table 10: HR_{peak} Descriptive Statistics

Activity	Mean	Standard Deviation	Std. Error	95% CI Lower Bound	95% CI Upper Bound
Treadmill 3.0	121.4000	10.47219	2.094	117.077	125.723
Kin Fruit Ninja	129.6800	16.70010	3.340	122.787	136.573
VR Fruit Ninja	126.3200	17.85758	3.572	118.949	133.691
Kin Boxing	136.3600	22.09804	4.420	127.238	145.482
VR Boxing	162.8800	19.23824	3.848	154.939	170.821

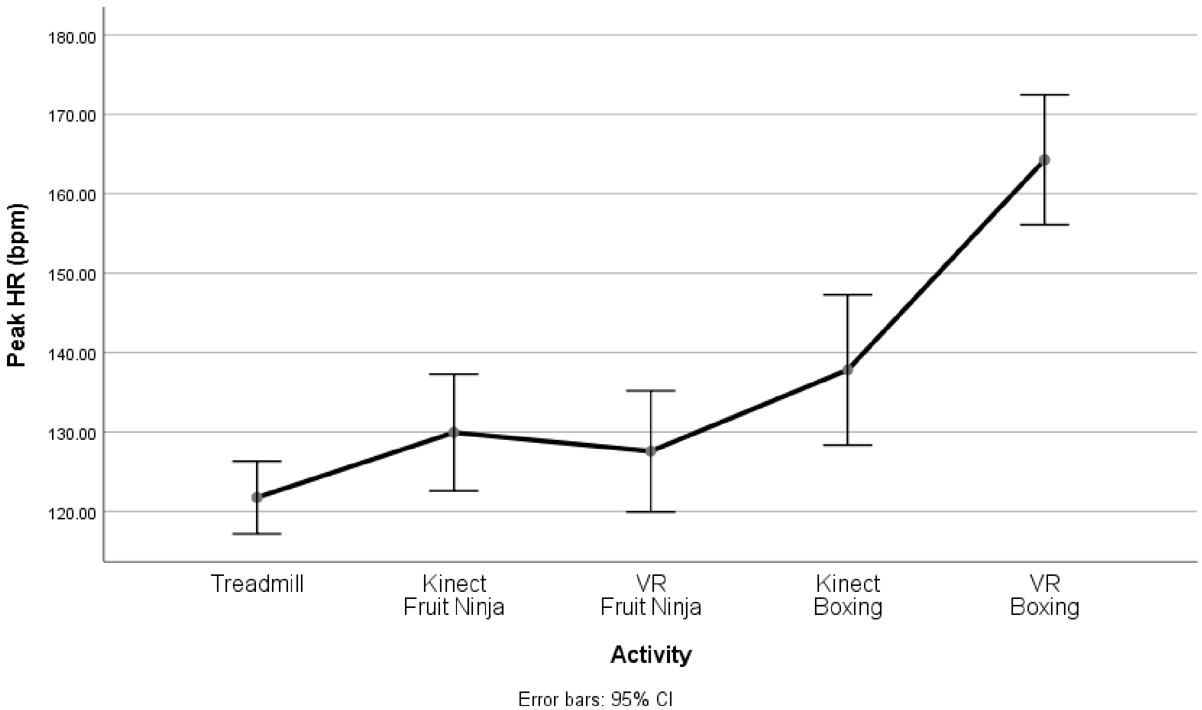


Figure 11: Graphical representation of HRpeak for Activity Conditions.

Post hoc analysis with a Bonferroni adjustment revealed that HR_{peak} was statistically significantly increased from Treadmill Walking at 3.0 mph (M=121.40, 95% CI [117.08, 125.72], p <.001) to Kinect Boxing (M=136.36, 95%CI [127.23, 145.48], p <.001), and VR Boxing (M=162.88, 95%CI [154.94, 170.82], p <.001). However, HR_{peak} did not statistically significantly differ from Treadmill Walking to Kinect Fruit Ninja (M=129.68, 95%CI [122.79, 136.57], p <.001) and VR Fruit Ninja (M=126.32, 95%CI [118.95, 133.69], p <.001), HRpeak was not statistically significantly different for Treadmill Walking at 3.0 mph, Kinect Fruit Ninja, and VR Fruit Ninja. HR_{peak} was statistically significantly greater for Kinect Boxing than Treadmill Walking at 3.0 mph, Kinect Fruit Ninja and VR Fruit Ninja. HR_{peak} was statistically significantly greater for VR Boxing than all other activity conditions: Treadmill Walking at 3.0 mph, Kinect Fruit Ninja, VR Fruit Ninja, and Kinect Boxing.

Table 11: HR_{peak} Pairwise Comparisons

(I) Activity	(J) Activity	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	2	-8.280	3.235	.172	-18.279	1.719
	3	-4.920	3.145	1.000	-14.639	4.799
	4	-14.960*	3.635	.004	-26.195	-3.725
	5	-41.480*	2.896	.000	-50.430	-32.530
2	1	8.280	3.235	.172	-1.719	18.279
	3	3.360	3.906	1.000	-8.710	15.430
	4	-6.680	3.673	.815	-18.032	4.672
	5	-33.200*	3.249	.000	-43.241	-23.159
3	1	4.920	3.145	1.000	-4.799	14.639
	2	-3.360	3.906	1.000	-15.430	8.710
	4	-10.040	3.981	.187	-22.342	2.262
	5	-36.560*	3.844	.000	-48.440	-24.680
4	1	14.960*	3.635	.004	3.725	26.195
	2	6.680	3.673	.815	-4.672	18.032
	3	10.040	3.981	.187	-2.262	22.342
	5	-26.520*	2.914	.000	-35.527	-17.513
5	1	41.480*	2.896	.000	32.530	50.430
	2	33.200*	3.249	.000	23.159	43.241
	3	36.560*	3.844	.000	24.680	48.440
	4	26.520*	2.914	.000	17.513	35.527

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

There was a statistically significant difference between the HR_{peak} for at least two activity conditions ($p < .05$). Therefore, we can reject the null hypothesis and can accept the alternative hypothesis.

RPE

A one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in rating of perceived exertion for five activity conditions. There were no outliers and the data were normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was not violated, as assessed by Mauchly's test of sphericity, $\chi^2(9) = 9.106$, $p = .429$. There was a significant main effect of condition for RPE, $F(4, 96) = 32.732$, $p < .001$, partial $\eta^2 = 0.577$. VR Boxing yielded the highest RPE (M=14.20, 95% CI [13.37, 15.03], p <.001), followed by Kinect Boxing (M=11.52, 95% CI [11.04, 11.99], p <.001), VR Fruit Ninja (M= 10.87, 95% CI [9.86, 11.88], p <.001), Kinect Fruit Ninja (M= 10.72, 95% CI [9.75, 11.70], p <.001), then Treadmill Walking (M= 10.04, 95% CI [9.33, 10.75], p <.001). Summary of the significant results for RPE are provided in Table 12 and depicted in Figure 12.

Table 12: RPE Descriptive Statistics

Activity	Mean	Standard Deviation	Std. Error	95% CI Lower Bound	95% CI Upper Bound
Treadmill 3.0	10.0400	1.71489	.343	9.332	10.748
Kin Fruit Ninja	10.7240	2.35271	.471	9.753	11.695
VR Fruit Ninja	10.8680	2.45318	.491	9.855	11.881
Kin Boxing	11.5160	1.15061	.230	11.041	11.991
VR Boxing	14.2000	2.01515	.403	13.368	15.032

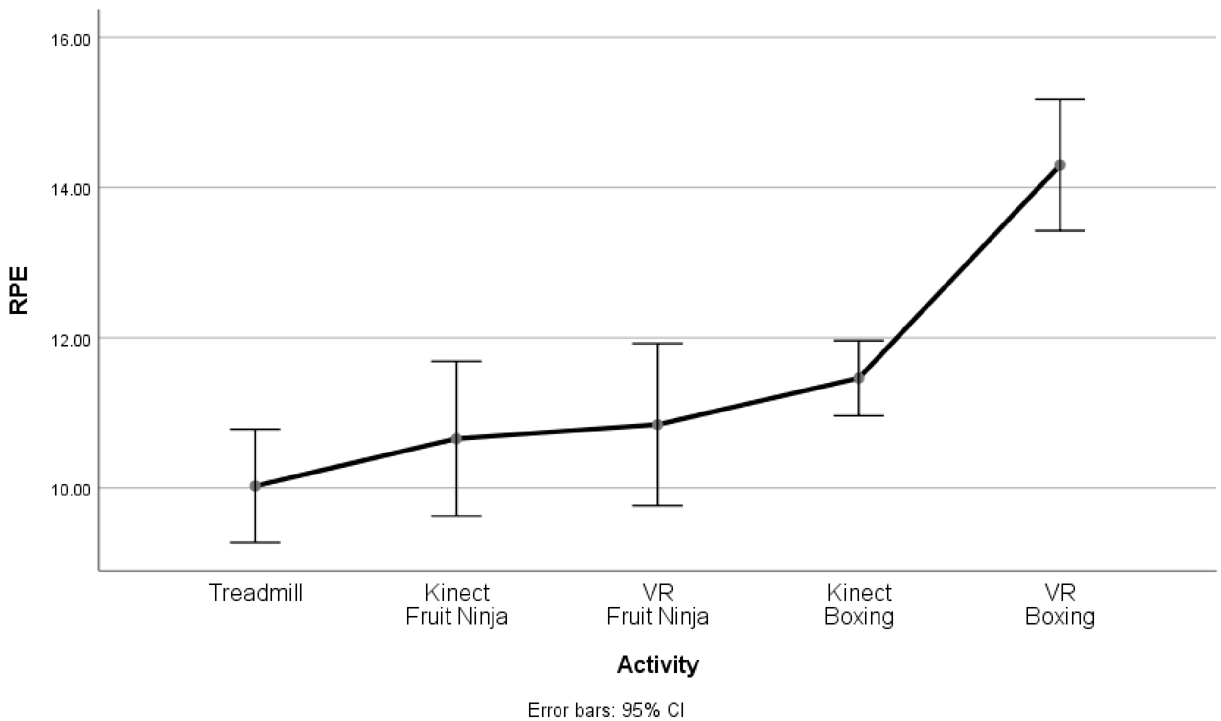


Figure 12: Graphical representation of RPE for Activity Conditions.

Post hoc analysis with a Bonferroni adjustment revealed that RPE was statistically significantly increased from Treadmill Walking to Kinect Boxing and VR Boxing. RPE did not statistically significantly differ from Treadmill Walking, Kinect Fruit Ninja, or VR Fruit Ninja.

Table 13: RPE Pairwise Comparisons

(I) Activity	(J) Activity	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	2	-.684	.456	1.000	-2.094	.726
	3	-.828	.455	.814	-2.235	.579
	4	-1.476*	.289	.000	-2.369	-.583
	5	-4.160*	.396	.000	-5.384	-2.936
2	1	.684	.456	1.000	-.726	2.094
	3	-.144	.426	1.000	-1.459	1.171
	4	-.792	.389	.527	-1.993	.409
	5	-3.476*	.404	.000	-4.726	-2.226
3	1	.828	.455	.814	-.579	2.235
	2	.144	.426	1.000	-1.171	1.459
	4	-.648	.427	1.000	-1.967	.671
	5	-3.332*	.385	.000	-4.520	-2.144
4	1	1.476*	.289	.000	.583	2.369
	2	.792	.389	.527	-.409	1.993
	3	.648	.427	1.000	-.671	1.967
	5	-2.684*	.332	.000	-3.710	-1.658
5	1	4.160*	.396	.000	2.936	5.384
	2	3.476*	.404	.000	2.226	4.726
	3	3.332*	.385	.000	2.144	4.520
	4	2.684*	.332	.000	1.658	3.710

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

There was a statistically significant difference between RPE for at least two activity conditions ($p < .05$). Therefore, we can reject the null hypothesis and can accept the alternative hypothesis.

Enjoyment

A one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in Liking for five activity conditions. There were no outliers and the data were normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was violated, as assessed by Mauchly's test of sphericity, $\chi^2(9) = 18.088$, $p = .035$. The Greenhouse-Geisser correction was applied, Epsilon (ε) = .735. There was a significant main effect of condition for liking, F (2.942, 70.6) = 32.675, $p < .001$, partial $\eta^2 = 0.577$. VR Fruit Ninja was the most liked (M=.958, 95% CI [.936, .980], p <.001), followed by VR Boxing (M=.915, 95% CI [.882, .948], p <.001), Kinect Fruit Ninja (M=..862, 95% CI [.820, .905], p <.001), Kinect Boxing (M=.846, 95% CI [.807, .884], p <.001), then Treadmill Walking(M=.737, 95% CI [.691, .782], p <.001). Summary of the significant results for Liking are provided in Table 14 and depicted in Figure 13.

Table 14: Liking Descriptive Statistics

Activity	Mean	Standard Deviation	Std. Error	95% CI Lower Bound	95% CI Upper Bound
Treadmill 3.0	.7368	.11052	.022	.691	.782
Kin Fruit Ninja	.8624	.10199	.020	.820	.905
VR Fruit Ninja	.9580	.05362	.011	.936	.980
Kin Boxing	.8456	.09332	.019	.807	.884
VR Boxing	.9148	.08001	.016	.882	.948

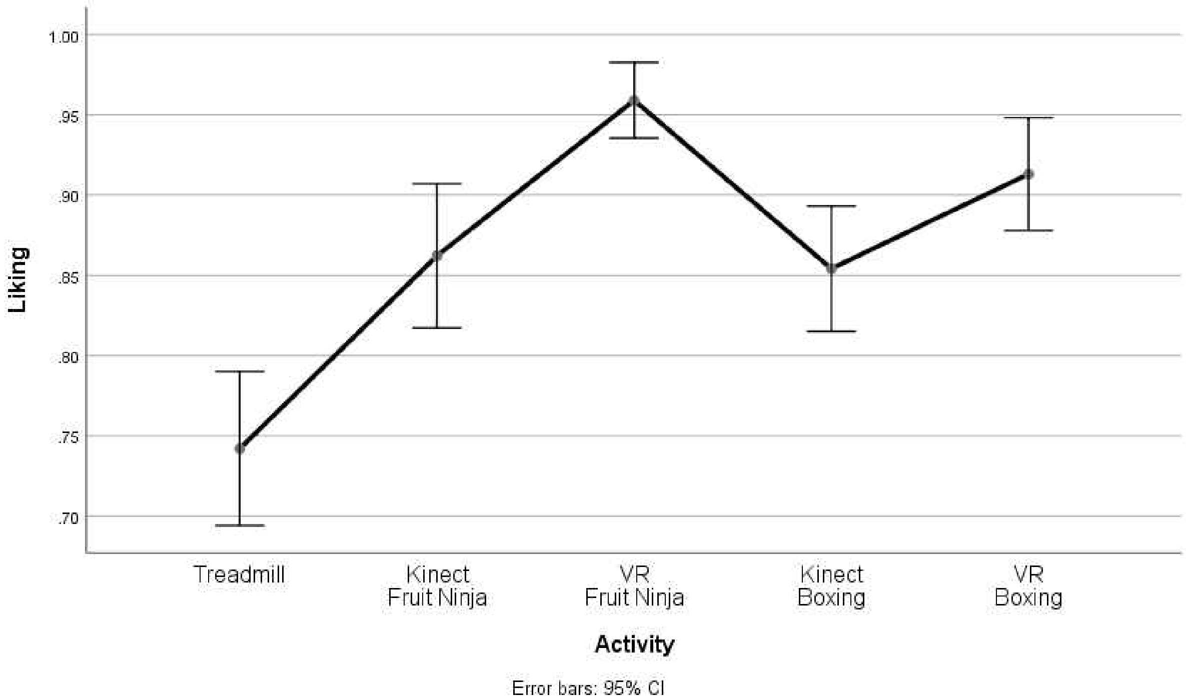


Figure 13: Graphical representation of Liking for Activity Conditions.

Post hoc analysis with a Bonferroni adjustment revealed that Liking was statistically significantly increased from Treadmill Walking at 3.0 to all the active gaming conditions. The VR Fruit Ninja condition was statistically significantly greater than Treadmill Walking and the other active gaming conditions. Liking for VR Boxing was statistically significantly greater than Treadmill Walking, Kinect Fruit Ninja, and Kinect Boxing. However, Liking did not statistically significantly differ from Kinect Fruit Ninja to Kinect Boxing.

Table 15: Liking Pairwise Comparisons

(I) Activity	(J) Activity	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
1	2	-.126*	.023	.000	-.196	-.055
	3	-.221*	.024	.000	-.296	-.147
	4	-.109*	.022	.001	-.177	-.040
	5	-.178*	.026	.000	-.260	-.096
2	1	.126*	.023	.000	.055	.196
	3	-.096*	.017	.000	-.149	-.042
	4	.017	.021	1.000	-.048	.081
	5	-.052*	.017	.048	-.104	.000
3	1	.221*	.024	.000	.147	.296
	2	.096*	.017	.000	.042	.149
	4	.112*	.020	.000	.049	.175
	5	.043*	.012	.016	.006	.081
4	1	.109*	.022	.001	.040	.177
	2	-.017	.021	1.000	-.081	.048
	3	-.112*	.020	.000	-.175	-.049
	5	-.069*	.020	.021	-.131	-.007
5	1	.178*	.026	.000	.096	.260
	2	.052*	.017	.048	.000	.104
	3	-.043*	.012	.016	-.081	-.006
	4	.069*	.020	.021	.007	.131

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

There was a statistically significant difference between the Liking for at least two activity conditions ($p < .05$). Therefore, we can reject the null hypothesis and can accept the alternative hypothesis.

HR_{mean} vs RPE Relationship

A Pearson's product-moment correlation was run to assess the relationship between activity condition HR_{mean} and RPE for males and females aged 18 to 28. Twenty-five participants were recruited. Preliminary analyses showed the relationships to be linear with variables normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$), and there were no outliers.

There was no statistically significant correlation between Activity Condition HR_{mean} and RPE. Pearson Correlations and p-values are listed for each activity condition in Table 16.

Table 16. HR_{mean} vs RPE Pearson Correlation

Activity Condition	Pearson Correlation, r(23) =	p=
Treadmill Walking	-.16	.46
Kinect Fruit Ninja	-.05	.83
VR Fruit Ninja	.16	.45
Kinect Boxing	-.16	.44
VR Boxing	.20	.33

The relationship between activity condition HR_{mean} and RPE was not statistically significant. Therefore, we cannot reject the null hypothesis and cannot accept the alternative hypothesis.

Table 17: Research question and hypothesis testing summary

	Research Question	Hypothesis	Supported/ Not supported	Research Answer
1	Is there a significant difference in the average heart rate for activity conditions?	At least two of the HRmean of the activity conditions are significantly different (i.e., they are not all equal).	Supported	HR_{mean} was significantly different due to activity conditions. HR_{mean} VR Boxing> HR_{mean} Treadmill, Kinect Fruit Ninja, VR Fruit Ninja, Kinect Boxing, and Rest HR_{mean} Treadmill = HR_{mean} Kinect Fruit Ninja= HR_{mean} VR Fruit Ninja= HR_{mean} Kinect Boxing
2	Is there a significant difference in peak heart rate for activity conditions?	At least two of the HRpeak of the activity conditions are significantly different (i.e., they are not all equal).	Supported	HR_{peak} was significantly different due to activity conditions. HR_{peak} VR Boxing> HR_{peak} Treadmill, Kinect Fruit Ninja, VR Fruit Ninja, Kinect Boxing HR_{peak} Kinect Boxing> HR_{peak} Treadmill HR_{peak} Treadmill = HR_{mean} Kinect Fruit Ninja= HR_{mean} VR Fruit Ninja
3	Is there a significant difference in RPE for activity conditions?	RPE for the activity conditions is not all equal.	Supported	RPE was significantly different due to activity conditions. RPE VR Boxing> RPE Treadmill, Kinect Fruit Ninja, VR Fruit Ninja, Kinect Boxing RPE Kinect Boxing> RPE Treadmill RPE Treadmill = RPE Kinect Fruit Ninja= RPE VR Fruit Ninja
4	Are AVG activities more enjoyable than treadmill walking?	Liking for the activity conditions are not all equal.	Supported	Liking was significantly different due to activity conditions. Liking VR Fruit Ninja> ALL AVG and Treadmill Liking Treadmill< Liking ALL AVGs Liking VR Boxing> Liking Treadmill, Kinect Fruit Ninja, Kinect Boxing Liking Kinect Fruit Ninja= Liking Kinect Boxing
5	Is there an association between the subject's perceived exertion and actual physiological response?	There is significant correlation between RPE and HRmean.	Not Supported	There was no significant correlation between RPE and HR_{mean}.

CHAPTER 5: CONCLUSION

Introduction

This is the first study to assess physiologic effort, hedonics, and perceived exertion for playing two different types of active video games (Sports-Boxing, Casual-Fruit Ninja) on two different AVG systems (Xbox Kinect, Oculus Rift). This is also the first experiment to compare the Oculus Virtual Reality active video games and Kinect AVGs with Treadmill walking and resting conditions.

According to the CDC, a person's physical activity level can be measured by heart rate (CDC, 2011b). The age-predicted maximal heart rate, HR_{max}, is obtained by subtracting the subject's age from 220. For this study, the average age of the participants was 20.31 years. Thus, the age-predicted maximal heart rate would be calculated as 220 - 20, or 199.69 beats per minute (bpm). An individual's heart rate should be 50 to70% of his or her maximum heart rate to qualify as a moderate-intensity physical activity, or between 99.84 and 139.78 bpm. For vigorous-intensity physical activity, the target heart rate should be 70 to 85% of his or her maximum heart rate. Thus, vigorous-intensity physical activity would require that the subject's heart rate averages at least 139.78 to 169.74 bpm. Many participants did reach peak heart rates of over 170, which exceeds criteria for vigorous-intensity activity.

Discussion

It is imperative to empirically establish effective mechanisms to increase levels of physical activity for many reasons including the potential to combat sedentary behaviors, obesity, health conditions associated with overweight/obesity, and healthcare costs. Due to the obesity epidemic and the search for options for improvement or maintenance of cardiorespiratory fitness, research on AVGs and PA are of great importance. A summary of the significant findings of this study is provided in Table 18.

HR_{mean}

The VR Boxing condition yielded the highest HR_{mean} (148.51 bpm). According to the classification of Vigorous PA, the VR Boxing game was the only condition to produce an average heart rate at vigorous-intensity physical activity levels. Vigorous Activity requires 139.52 bpm and Moderate Activity requires 99.66 bpm. The Treadmill (115.32 bpm), Kinect Fruit Ninja (119.46 bpm), VR Fruit Ninja (119.60 bpm), Kinect Boxing (123.62 bpm) qualify as moderate-intensity physical activity. The VR Boxing condition was significantly different from the treadmill and other AVG conditions. However, there was no significant difference in HR_{mean} for the Treadmill, Kinect Fruit Ninja, Kinect Boxing, and VR Fruit Ninja. Therefore, it is demonstrated that the Kinect and VR active video game conditions are at least comparable to the physical activity level required by treadmill walking at 3.0 mph. This study supports other experiments that find that the active video games elicited moderate-intensity physical activity levels (Jacob E. Barkley & Amanda Penko, 2009; Graf et al., 2009; L. Graves et al., 2008; Sanders et al., 2015; Smallwood et al., 2012). The Boxing game required a great deal of upper body movement and some lower body movement for both the VR and the Kinect. However, the head-mounted display in the VR boxing condition may have added to the realistic effect of the visual display and audio of the gameplay and engaged players more than the Kinect Boxing. On the other hand, the VR and Kinect condition for the casual game, Fruit Ninja, required similar body movements, primarily the upper limbs, yet the HR_{mean} was not statistically significant from Kinect Fruit Ninja to VR Fruit Ninja or to Kinect Boxing. In the future, it could be worth exploring the factors of AVGs that are attributed to the HR_{mean} for various game types, systems, and levels of gameplay.

HR_{peak}

VR Boxing achieved VPA with a peak HR of 162.88 bpm, which was significantly greater than all other conditions: Treadmill (121.40 bpm), Kinect Fruit Ninja (129.68 bpm), VR Fruit Ninja (126.32 bpm), and Kinect Boxing (136.36 bpm). Recalling that Vigorous Activity requires 139.52 bpm and Moderate Activity requires 99.66 bpm, Kinect boxing HR_{peak} did not quite reach the threshold or VPA, but it was very close. A previous study did find that the Kinect Boxing AVG elicited peak HR in the VPA range (Sanders et al., 2015). Although Kinect Boxing did not qualify as VPA in term of peak heart rate, it did show to be significantly higher than the treadmill condition. Moreover, the Treadmill, Kinect Fruit Ninja, and VR Fruit Ninja did not yield statistically significantly different HR_{peak} results. These findings further support the Hypothesis that at least one of the AVG activities would yield peak heart rates would be statistically significantly different from the others.

RPE

The American College of Sports Medicine (ACSM) classifies physical activity intensity in regards to the Borg Rating of Perceived Exertion (RPE) scale as Very light (<10), Light (10-11), Moderate (12-13), Hard (14-16), Very hard (17-19), and Maximal (20) (M.

L. Pollock et al., 1998). The Borg scale was visually presented to the participants during all activities, except during VR gaming, as it was not possible to view in the head-mounted display. The subjects were asked to review the scale prior to placing the VR headset on.

The RPE for VR Boxing (14.20) was statistically significantly greater than RPE for Treadmill (10.04), Kinect Fruit Ninja (10.72), VR Fruit Ninja (10.87), Kinect Boxing (11.52). Kinect Boxing RPE was significantly greater than Treadmill. However, Treadmill, Kinect Fruit Ninja, and VR Fruit Ninja were not statistically significantly different.

VR Boxing was the only condition to elicit Hard physical activity intensity. The Kinect boxing RPE was the only condition that was rated by the subjects as moderate physical activity intensity. VR Fruit Ninja, Kinect Fruit Ninja, and Treadmill Walking are classified as light physical activity intensity, according to the classification based on subjective RPE responses.

Enjoyment

Liking can be a valuable predictor of one's behavior (Barkley et al., 2014; Dishman et al., 2005). The VR Fruit Ninja (.958) was rated the highest and liked significantly greater than Treadmill Walking (.737), Kinect Boxing (.846), Kinect Fruit Ninja (.862), and VR Boxing (.915).

It is worth noting that although the Virtual Reality Boxing game elicited the greatest physiological cost (HR_{mean} and HR_{peak}) and had the highest rating of perceived exertion among all conditions, it was also ranked the second (after VR Fruit Ninja) most enjoyed activities of all five conditions. The VR Boxing was significantly more enjoyable than the Treadmill, Kinect Boxing, and Kinect Fruit Ninja, despite the physiological cost and perceived exertion. All the AVG conditions were liked significantly greater than the treadmill walking condition. Kinect Fruit Ninja and Kinect Boxing did not show a significant difference in liking between the two conditions.

Specifically, when assessing physically-intensive activities, enjoyment may be a determining factor for participating in MVPA as prescribed by the CDC. The results provide further support that AVGs that may elicit MVPA and may be a viable option for enjoyable and sustainable physical activity for some adults.

HR_{mean} vs RPE Relationship

There was no statistically significant correlation between Activity Condition HR_{mean} and RPE. The failure to reject the null hypotheses regarding the relationship between RPE vs HR_{mean} reveals the need for further exploration of this topic.

In the RPE discussion, it was noted that VR Fruit Ninja, Kinect Fruit Ninja, and Treadmill Walking are classified as light physical activity intensity, according to the classification of physical activity intensity based on subjective RPE responses (M. L. Pollock et al., 1998). These findings are not consistent with the physiological data of the mean heart rate. According to the HR_{mean}, VR Fruit Ninja, Kinect Fruit Ninja, and Treadmill Walking are classified as moderate-intensity physical activity (CDC, 2011b; M. L. Pollock et al., 1998). This contradiction in intensity classifications suggested that the subjects perceived exertion is underestimated compared to HR_{mean} and HR_{peak}. This difference may be explained by the existence of distracters during activities.

The Borg Ratings of Perceived Exertion (RPE) has been employed in several active video game studies (Jacob E. Barkley & Amanda Penko, 2009; Graf et al., 2009; Penko & Barkley, 2010; B. S. Pollock et al., 2013). Pollock et al. validated RPE as being positively associated with heart rate. However, it was purported that the association between RPE and physiological measures of effort may be affected by the presence of distracters, such as video and music, as examined in Wii Fit Active Videogame. In this study, it was not found that RPE and physiological measures were correlated. It would be imperative to explore the factors that affect one’s perception of exertion during active gaming, especially as it relates to Virtual Reality. In terms of distracters, the VR active gaming experience has a head-mounted display that offers 360-degree visual environments, 3D graphics, and integrated audio. VR is designed to give the user an immersive experience that would be greater than screen-based gaming. Thus, it would be greatly beneficial to further explore the factors that may contribute to the user’s experience or underestimation of perceived exertion during VR gameplay. This information could prove valuable to the gaming experience as well as considerations for safety.

Safety Implications

Considering the advancements in active video gaming technologies and the availability of the systems and games to the public, it may be worthwhile to explore how factors and interaction of factors may affect the subjects RPE, and possibly the relationship to physiological response. While it can be a goal of the game developers to decrease the participant's perceived exertion with entertaining and distracting elements to increase the likelihood of prolonged participation in physically-intense activity, there are human factors and safety issues to consider, as well. Cardiovascular risks may occur when users underestimate the perceived exertion compared to actual physical performance (Muyor, 2013).

As motivating as it may be to discover gaming options that may elicit vigorous-intensity activity levels, it is just as important to realize issues with safety in prescribing or recommending physically-intensive activities. During the VR Boxing experience, users did experience vigorous-intensity heart rate mean. The data revealed that some participants experienced peak heart rates of up to 192 bpm. For the mean age of 21 years, the HR_{max} is 199 (220-21) bpm. This would qualify 192 bpm, as 96% of HR_{max}, well above the 70-85% threshold to be considered vigorous activity. VR activities such as the VR Boxing game may require some additional investigation. The population of subjects included in this study did not report any comorbidities. However, users should be aware of the intensity and risks of performing active gaming activities. Thus, it is highly important to empirically examine the AVGs for exercise recommendations and for mitigating safety issues.

Table 18. Summary of Significant Research Outcomes

Hypothesis Reference	Summary Data [95% CI], p <.001	Outcomes
HR_{mean}	Rest (M=80.24 [77.02, 83.46]) Treadmill (M=115.32, [111.87, 118.77]) Kinect Fruit Ninja (M=119.46, [114.47, 124.44]) VR Fruit Ninja (M=119.60, [113.95, 125.26]) Kinect Boxing (M=123.62, [115.67, 131.57]) VR Boxing (M=148.51, [140.83, 156.19])	VR Boxing> Rest, Treadmill, Kinect Fruit Ninja, VR Fruit Ninja, Kinect Boxing Treadmill = Kinect Fruit Ninja= VR Fruit Ninja= Kinect Boxing
HR_{peak}	Treadmill (M=121.40, [117.08, 125.72]) VR Fruit Ninja (M=126.32, [118.95, 133.69]) Kinect Fruit Ninja (M=129.68, [122.79, 136.57]) Kinect Boxing (M=136.36, [127.23, 145.48]) VR Boxing (M=162.88, [154.94, 170.82])	VR Boxing> Treadmill, Kinect Fruit Ninja, VR Fruit Ninja, Kinect Boxing Kinect Boxing>Treadmill Treadmill = Kinect Fruit Ninja= VR Fruit Ninja
RPE	VR Boxing (M=14.20, [13.37, 15.03]) Kinect Boxing (M=11.52, [11.04, 11.99]) VR Fruit Ninja (M= 10.87, [9.86, 11.88]) Kinect Fruit Ninja (M= 10.72, [9.75, 11.70]) Treadmill Walking (M= 10.04, [9.33, 10.75])	VR Boxing> Treadmill, Kinect Fruit Ninja, VR Fruit Ninja, Kinect Boxing Kinect Boxing>Treadmill Treadmill = Kinect Fruit Ninja= VR Fruit Ninja
Liking	VR Fruit Ninja (M=.958, [.936, .980]) VR Boxing (M=.915, [.882, .948]) Kinect Fruit Ninja (M=.862, [.820, .905]) Kinect Boxing (M=.846, [.807, .884]) Treadmill Walking (M=.737, [.691, .782])	VR Fruit Ninja> Treadmill, Kinect Boxing, Kinect Fruit Ninja, VR Boxing Treadmill< Liking ALL AVGs VR Boxing> Liking Treadmill, Kinect Boxing, Kinect Fruit Ninja Kinect Fruit Ninja= Kinect Boxing

Overall, the Kinect Fruit Ninja, Kinect Boxing, VR Fruit Ninja, and VR Boxing AVGs appear to be enjoyable activities for adults, stimulating moderate to vigorous-intensity activity through a medium that is traditionally sedentary. This study shows promise for Virtual Reality active video games as an alternative or supplemental method for maintaining cardiovascular health.

Research Contributions

The findings of this research support previous studies regarding physiological response, RPE, and hedonics for the Kinect active video games. This study further adds to the body of knowledge that the Virtual Reality active video games can also provide moderate-intensity physical activity levels in young adults. This study discovered vigorous-intensity physical activity levels can be achieved for average heart rate, for activities such as VR Boxing.

Table 19 compares the findings of this study to the study used as the framework for this research. The study compared the Xbox Kinect Boxing and Nintendo Wii Boxing games to treadmill walking (Sanders et al., 2015). Although the two studies cannot be directly associated, the comparison is useful to see that the Virtual Reality Boxing elicited higher heart rates than the Kinect and Wii AVG counterparts.

In addition to discovering that VR gaming is capable of eliciting VPA levels, it is found that the VR Fruit Ninja followed by the VR Boxing gaming conditions yielded the highest enjoyment ratings. This indicates that VR gaming conditions were liked greater than the Kinect gaming conditions and the treadmill walking conditions. The greater liking of an activity could be an indicator for the likelihood of participating in one activity over another.

Table 19: Comparison of VR/Kinect to Kinect AVG Previous Research

Researchers	***n=***	***Games***	***HR_{mean}***	***RPE***	***Other Subjective Measure***
Sanders, G. J., et al.	27	Rest	73.4 ±1.8	-	Liking-
		Treadmill 3.0	103.3 ±2.0	9.6 ±0.3	4.1 ±0.4
		Wii Boxing	104.5 ±2.2	10.0 ±0.4	6.2 ±0.3
		Kinect Boxing	126.4 ±3.0	12.6 ±0.4	8.2 ±0.2
Wooden	25	Rest	80.2 ±1.6	-	-
		Treadmill 3.0	115.3 ±1.7	10.0 ±0.3	73%±2%
		Kinect Boxing	123.6 ±3.9	11.5 ±0.2	85%±2%
		Kinect Fruit Ninja	119.5 ±2.4	10.7 ±0.5	86%±2%
		VR Fruit Ninja	119.6 ±2.7	10.9 ±0.5	96%±2%
		VR Boxing	148.5 ±3.7	14.2 ±0.4	91%±2%

Another important finding of this study is that HR_{mean} and RPE were not found to have a significant correlation. This could potentially lead to underestimation of exertion by users of the system and pose cardiovascular risks. It was proposed that further research on VR gaming, perceived exertion, and physiological response is essential to verify AVGs as qualified MVPA-achieving activities and to identify and mitigate risks of active gaming. For instance, the VR Fruit Ninja, Kinect Boxing, and Kinect Fruit Ninja were classified as “light” intensity activities according to the user’s reported ratings of perceived exertion. However, the physiological data would purport those same activities to be of “moderate” intensity. For purposes of an individual seeking MVPA activities, the intensity ratings for active video games should be classified according to the cardiovascular criteria. However, it would be beneficial for the individual to interpret the population’s perceived effort for such activities. Perhaps this could lead to the classification of active games in terms of cardiovascular intensity-ratings and corresponding perception of the energy expended during activities. Essentially, this could be an AVG-specific rating system to assist the population in understanding, exploring, and making decisions for implementing physical activities.

In conclusion, playing virtual reality active video games like Oculus VR Thrill of the Fight boxing game can elicit and maintain vigorous-intensity physical activity response. Despite the VR boxing game requiring the highest physiological response and perceived exertion, it was ranked second highest in liking, above Treadmill Walking, Kinect Boxing, and Kinect Fruit Ninja. Overall, AVGs may be a better option in terms of physical intensity and liking than some traditional moderate exercise activities, such as treadmill walking. Kinect

AVG participation may help reduce the risk for cardiovascular disease and type II diabetes if performed activities meet the CDC recommendations for MPA. Center for Disease Control and Prevention recommends, weekly, at least 150 minutes of moderate to vigorous physical activity (MVPA) for adults (CDC, 2007). These results affirmatively support the research question “Could technology help us tackle the obesity crisis?” Virtual Reality and active video games like the games employed in this study can elicit MVPA and should be strongly considered as interventions to increase physical activity and combat the obesity crisis in adults.

Research Limitations

Some of the limitations of this study include that the sample was composed of University students. It would be beneficial to include children and adults of various ages and professional backgrounds. It is possible that different age groups may respond differently to the AVGs. Secondly, each condition was tested for 10 minutes. It would be most beneficial to see if the activities are likely to be sustained for longer sessions. Furthermore, a longitudinal study could be employed to assess the adherence of regular participation and long-term liking of the AVG activities. Another limitation of the study is that only heart rate was evaluated as the physiological response.

Future Research

Further research may improve the body of knowledge in active video gaming, as it relates to physiological costs and effectiveness. Ideally, advancing research in AVGs may lead to improving health and lowering healthcare costs through encouraging better health behaviors: more workouts, new habits, better adherence, and increase in participation of AVGs and other physical activities.

As mentioned in the limitations of this study, future research can be conducted to include a larger sample size, with greater variation of subject age and occupation, and incorporate energy expenditure and oxygen consumption data. It would also be beneficial to understand the physiological response, perceived exertion, and liking over an extended time of participation, i.e. 30-minute sessions, instead of 10-minute sessions or a 6-week trial versus the single-day trial.

In terms of safety, it would be worthwhile to explore how factors and interaction of factors of VR gameplay may affect the subjects RPE, and the relationship to physiological response. The participant may have the tendency to underestimate exertion increasing the likelihood of cardiovascular risks (Muyor, 2013). Muyor et. al reported that RPE scales (Borg and OMNI) are reliable but not valid instruments assessing activity intensity in cycling activities. In cases where the user's perceived exertion is not a valid indicator of actual intensity levels, it may be necessary to control the intensity of the activity with other means. These technologies might include heart rate monitors, heat sensors, skin conductance and speech recognition to identify and regulate the threshold of safe and MVPA-qualifying gameplay. Ultimately, the technologies might even be built into the AVG system as a safety protocol to mitigate the risk of over-exertion.

Essentially, the type of gaming interface (VR, Kinect, Wii, etc.), and the style of the game (Casual, Sport, Fitness, Dance, etc.), as well as other related, unidentified factors in this study (immersion, graphics, music, storyline, length of gameplay, etc.) may influence the user's perceived exertion and Heart Rate. Exploration of this topic may lead to a new gaming-specific exertion scale. The observations and analyses may provide insight into which factors influence one's perception of exertion during active video gameplay and help to develop guidelines for creating entertaining and MVPA-promoting active video games while considering user safety.

This information can provide additional insight into the motivations for immersion, fun, perception of physical exertion, and further add to the body of knowledge in VR active video gaming as it relates to the physiological as well as the Human-Computer Interaction fields of research.

APPENDIX A: UCF IRB APPROVAL

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Shanon Wooden**

Date: **November 02, 2017**

Dear Researcher:

On 11/02/2017 the IRB approved the following human participant research until 11/01/2018 inclusive:

Type of Review:	UCF Initial Review Submission Form Expedited Review Category #4, 6, & 7
Project Title:	Active Video Game Play Analysis
Investigator:	Shanon Wooden
IRB Number:	SBE-17-13447
Funding Agency:	
Grant Title:	
Research ID:	N/A

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 11/01/2018, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a signed and dated copy of the consent form(s).

All data, including signed consent forms if applicable, must be retained and secured per protocol for a minimum of five years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained and secured per protocol. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

Signature applied by Jennifer Neal-Jimenez on 11/02/2017 02:15:20 PM EDT

Designated Reviewer

APPENDIX B: UCF INFORMED CONSENT

Active Video Game Play Analysis

Informed Consent

Principal Investigator: Shanon Wooden, MS

Faculty Advisor: Pamela McCauley, PhD

Investigational Site(s): University of Central Florida,
Industial Engineering Department

Introduction: Researchers at the University of Central Florida (UCF) study many topics. To do this we need the help of people who agree to take part in a research study. You are being invited to take part in a research study which will include about 30 people at UCF. You have been asked to take part in this research study because you are an adult with abilities to participate in active video games. You must be 18 years of age or older to be included in the research study.

The person doing this research is Shanon Wooden of The University of Central Florida, Industrial Engineering Department. Because the researcher is a graduate student, she is being guided by Pamela McCauley, PhD, a UCF faculty advisor in Industrial Engineering.

What you should know about a research study:

- Someone will explain this research study to you.
- A research study is something you volunteer for.
- Whether or not you take part is up to you.
- You should take part in this study only because you want to.
- You can choose not to take part in the research study.
- You can agree to take part now and later change your mind.
- Whatever you decide it will not be held against you.
- Feel free to ask all the questions you want before you decide.

Purpose of the research study: The purpose of this study is to focus on the effects of active video games, namely the Xbox Kinect and the Oculus Rift, on heart rate, perceived exertion, and enjoyment. Recent research has revealed that interactive games can increase players' physical activity level and have the potential to combat overweight and obesity among adolescents and adults (Maddison et al., 2007; Peng, Lin, & Crouse, 2011; Straker & Abbott, 2007; Unnithan, Houser, & Fernhall, 2006). To date, there is no evidence of empirical research on Virtual Reality active video games relating the effects on one's physiological response, perceived exertion, and hedonics. This study aims to fill the gap in the literature by examining the effect of VR AVG play on heart rate (HR), rating of perceived exertion (RPE), and enjoyment during virtual reality active video gaming and controller-free reality active video gaming.

What you will be asked to do in the study:

Questionnaire:

The information that we ask for on the Questionnaire will be used to determine eligibility for physical activity, your perceived exertion ratings, your enjoyment, as well as some demographic information: height, weight, gender.

Steps in the testing:

1. When you sign-in, you will be given a random subject code. This code will be assigned to your demographic information (step 2). The sign-in logs and the Consent Statement are the only places in this study that your name will appear. The logs and the Consent Forms will be destroyed after five years.

3. We will be testing multiple games, and in order to be used for this study purposes, all 5 activities must be completed. Each activity is performed for 10 minutes. The entire study will take approximately 90 minutes to complete.

4. When assigned a game, you will go to the Game Play Analysis (GPA) station where you will be asked about your experience with this game and platform, and you may be asked to navigate through a "standard" exercise. You will be videotaped doing this task.

5. You will be asked to accomplish a number of tasks beginning at a specific point in the game. We will ask you to play this game according to some specific procedures that will assist our understanding of how you are playing the game. You will be videotaped doing these tasks.

6. During or following your game play, we will be asking you questions about your rating of perceived exertion and collecting heart rate data. You will be videotaped responding to these questions.

Location: The Study will be conducted in the Ergonomics Laboratory at the University of Central Florida, Engineering II Building, Room 321.

Time required: We expect that you will be in this research study for a single session of 90 minutes.

Audio or video taping:

You will be video taped during this study. If you do not want to be video taped, you will be able to be in the study. Discuss this with the researcher or a research team member. If you are video taped, the tape will be kept in a locked, safe place. The videotapes will be archived indefinitely. The participant's image and voice may be clearly evident in these recordings. Researchers may use these recordings in presentations and publications about game play.

Risks:

Your wellbeing is of the utmost importance to us as you play the games. Accordingly, there is very little physical or mental risks to you, as a participant in this study. You may experience increased heart rate due to the activity level, but if you feel tired, you may choose to stop participation to avoid over-exertion. There is a sligt possibility that you may experience discomfort or nausea from the Virtual Reality headset. Side effects of VE (virtual environment) use may include stomach discomfort, headaches, sleepiness, dizziness and decreased balance. However, these risks are no greater than the sickness risks participants may be exposed to if they were to visit an amusement park such as Disney Quest (Disney Quest is a VE based theme park), Disney World or Universal Studios parks and ride attractions such as roller coasters. You will be given 5-minute breaks during the exercise to lessen the chance that you will feel sick. If you experience any of the symptoms mentioned, please tell the researcher and remain seated until the symptoms disappear.

Benefits:

Our hope is that you will enjoy playing these games and trying to accomplish the tasks we assign. The information that we gain by observing your game play will give us insight into the physical requirements and hedonics of active video game play.benefits to you for taking part in this study.

Compensation or payment:

There is no compensation or other payment to you for taking part in this study.

Study contact for questions about the study or to report a problem:

If you have questions, concerns, or complaints, or think the research has hurt you, talk to Shanon Wooden, Graduate Student, Industrial Engineering Program, College of Engineering and Computer Science, (407) 476-8522 or by email: Shanon.wooden@knights.ucf.edu. Alternatively, you may contact Dr. Pamela McCauley, Faculty Supervisor, College of Engineering and Computer Science, (407) 823-6092 or via email: Pamela.McCauley@ucf.edu.

IRB contact about your rights in the study or to report a complaint: Research at the University of Central Florida involving human participants is carried out under the oversight of the Institutional Review Board (UCF IRB). This research has been reviewed and approved by the IRB. For information about the rights of people who take part in research, please contact: Institutional Review Board, University of Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246 or by telephone at (407) 823-2901. You may also talk to them for any of the following:

- Your questions, concerns, or complaints are not being answered by the research team.

- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You want to get information or provide input about this research.

Withdrawing from the study:
You habe the option to cease participation, at any time and withdraw from the study. There is no penalty or adverse consequences for doing so.

Your signature below indicates your permission to take part in this research.

DO NOT SIGN THIS FORM AFTER THE IRB EXPIRATION DATE (11/1/2018)

Name of participant

Signature of participant | Date

APPENDIX C: PACES SURVEY

ID #:	
Height	
Weight	
Age	
Gender	

VR Boxing

order #: ____

PACES items: Please rate how you feel *at the moment* about the physical activity you have been doing

1	2	3	4	5	6	7
* I enjoy it						I hate it
1	2	3	4	5	6	7
I dislike it						I like it
1	2	3	4	5	6	7
It's no fun at all						It's a lot of fun
1	2	3	4	5	6	7
* I feel good physically while doing it						I feel bad physically while doing it
1	2	3	4	5	6	7
I am very frustrated bv it						I am not at all frustrated bv it

	RPE	HR
min1		
min2		
min3		
min4		
min5		
min6		
min7		
min8		
min9		
min10		

VR Boxing

Kinect Boxing

order #: ____

PACES items: Please rate how you feel *at the moment* about the physical activity you have been doing

1	2	3	4	5	6	7
* I enjoy it						I hate it
1	2	3	4	5	6	7
I dislike it						I like it
1	2	3	4	5	6	7
It's no fun at all						It's a lot of fun
1	2	3	4	5	6	7
* I feel good physically while doing it						I feel bad physically while doing it
1	2	3	4	5	6	7
I am very frustrated bv it						I am not at all frustrated bv it

	RPE	HR
min1		
min2		
min3		
min4		
min5		
min6		
min7		
min8		
min9		
min10		

Kinect Boxing

VR Fruit Ninja

order #: ____

PACES items: Please rate how you feel *at the moment* about the physical activity you have been doing

1	2	3	4	5	6	7
* I enjoy it						I hate it
1	2	3	4	5	6	7
I dislike it						I like it
1	2	3	4	5	6	7
It's no fun at all						It's a lot of fun
1	2	3	4	5	6	7
* I feel good physically while doing it						I feel bad physically while doing it
1	2	3	4	5	6	7
I am verv frustrated bv it						I am not at all frustrated bv it

	RPE	HR
min1		
min2		
min3		
min4		
min5		
min6		
min7		
min8		
min9		
min10		

VR Fruit Ninja

Kinect Fruit Ninja

order #: ____

PACES items: Please rate how you feel *at the moment* about the physical activity you have been doing

1	2	3	4	5	6	7
* I enjoy it						I hate it
1	2	3	4	5	6	7
I dislike it						I like it
1	2	3	4	5	6	7
It's no fun at all						It's a lot of fun
1	2	3	4	5	6	7
* I feel good physically while doing it						I feel bad physically while doing it
1	2	3	4	5	6	7
I am very frustrated by it						I am not at all frustrated by it

	RPE	HR
min1		
min2		
min3		
min4		
min5		
min6		
min7		
min8		
min9		
min10		

Kinect Fruit Ninja

Treadmill Walk

order #: ____

PACES items: Please rate how you feel *at the moment* about the physical activity you have been doing

1	2	3	4	5	6	7
* I enjoy it						I hate it
1	2	3	4	5	6	7
I dislike it						I like it
1	2	3	4	5	6	7
It's no fun at all						It's a lot of fun
1	2	3	4	5	6	7
* I feel good physically while doing it						I feel bad physically while doing it
1	2	3	4	5	6	7
I am very frustrated by it						I am not at all frustrated by it

	RPE	HR
min1		
min2		
min3		
min4		
min5		
min6		
min7		
min8		
min9		
min10		

Treadmill Walk

APPENDIX D: PAR-Q SURVEY

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____

SIGNATURE ____ DATE ____________________

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

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