CORRELATING PHYSIOLOGICAL RESPONSES OF EXERGAMING BOXING IN DIFFERENT BODY POSITIONS AND DISABILITY

NOR AINA BINTI MOHD JAI

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CORRELATING PHYSIOLOGICAL RESPONSES OF EXERGAMING BOXING IN DIFFERENT BODY POSITIONS AND DISABILITY

Field of Study: Biomedical Engineering

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Senior Lecturer
Department of Biomedical Engineering
Faculty of Engineering
University of Malaya

ABSTRACT

Physiological responses during exergaming may be affected by the position of gameplay and physical disability. This study aims to validate the correlations between heart rate and rating of perceived exertion coefficients when playing a moderate-vigorous intensity exergame among the able-bodied and wheelchair-user populations to formulate a possible regression model based on confounding factors, such as the position of gameplay, disability, age, or body mass index. To do this, the Sony PlayStation 3® consoles, along with its two Move motion controllers; Sony Eye Camera and Sports Champion 2® software, were selected as the modality of choice. A total of 45 participants were recruited and divided into able-bodied (mean age of 25.1 (2.95)) and wheelchair-user (mean age of 30.3 (10.3)). The able-bodied participants performed the Move Boxing in sitting position for 10 minutes and standing position for 10 minutes, with at least a day gap. Wheelchair-users performed the Move Boxing while seated in their wheelchairs for 10 minutes. HR measurements were obtained at rest and during gameplay. RPE was assessed using Borg's modified (1−10) and original (6−20) scales. All data were expressed as mean (standard deviation) (SD). The significance level was set as a priority at P=0.05. SPSS (Version 25.0) was utilized to perform all statistical analyses. Normality tests and statistical tests were conducted, including paired-sample t-test, bivariate Pearson's correlation, and Spearman's rho correlation, to analyse the results. The mean HR was significantly higher when the able-bodied users performed exergaming in the standing position (130.79 (23.18) beats per minute (bpm)) compared to the sitting position (116.46 (19.08) bpm) ($p \leq 0.05$), and more similar to those obtained by wheelchair-users while playing on their wheelchairs (130 (14) bpm). There was a significant correlation between HR and RPE values while playing boxing exergame in the standing position. For wheelchair-users, HR elevation also correlated well with both Borg's RPE original and modified scales during exergaming while being seated in their wheelchairs. A regression model that can be fitted into an equation to predict HR from reported RPE was derived from the significant values of Pearson's correlation. The formula extracted from the linear regression models provided reliable predictions in estimating HR from reported RPE while boxing exergaming in a standing position and being seated in wheelchairs for future research works.

Keywords: Video games, boxing, exercise, sedentary, cardiorespiratory health, posture, intensity

ABSTRAK

Tindak balas fisiologi semasa menjalankan aktiviti 'exergame' mungkin dipengaruhi oleh kedudukan badan semasa bermain dan kecacatan fizikal. Kajian ini bertujuan untuk mengesahkan hubung kait antara kadar degupan jantung dan skala Borg: 'Rating of Perceived Exertion (RPE) ketika menjalankan aktiviti 'exergame' yang berintensiti sederhana-kuat dalam kalangan orang dewasa normal dan orang dewasa yang berkerusi roda, untuk membentuk satu rumus model regrasi berdasarkan faktor-faktor seperti kedudukan badan semasa bermain, kecacatan, umur, atau indeks jisim badan. Untuk melakukan kajian ini, sistem Sony PlayStation 3®, bersama dengan dua alat kawalan pergerakan Move, kamera Sony Eye, dan cakera padat Sports Champion 2® telah dipilih sebagai pilihan. Seramai 45 peserta telah dipilih dan dibahagikan kepada dua kumpulan iaitu kumpulan normal (min umur: 25.1 (2.95)) dan pengguna kerusi roda (min umur: 30.3 (10.3)). Peserta dewasa yang normal melakukan aktiviti Move Boxing dalam posisi duduk selama 10 minit dan posisi berdiri selama 10 minit, dengan jurang satu hari. Pengguna kerusi roda melakukan Move Boxing sambil duduk di kerusi roda selama 10 minit. Pengukuran kadar degupan jantung diperoleh pada waktu rehat dan semasa menjalan aktiviti. Sementara RPE dinilai menggunakan skala Borg yang diubah (1-10) dan asal (6-20). Semua data dinyatakan sebagai min (sisihan piawai) (SD). Tahap keertian ditetapkan pada $P = 0.05$ dan SPSS (Versi 25.0) digunakan untuk melakukan semua analisis statistik. Pemeriksaan normaliti dilakukan dan ujian statistik termasuk paired-sample t-tests, hubung kait bivariate Pearson dan Spearman rho digunakan untuk menganalisis data yang diperoleh. Dalam kalangan orang dewasa normal, purata kadar degupan jantung lebih tinggi semasa melakukan aktiviti 'exergame' dalam posisi berdiri (130.79 (23.18) degupan bagi setiap minit (bpm)) berbanding dengan posisi duduk (116.46 (19.08) bpm) ($p \leq 0.05$), dan lebih sama *dengan yang diperoleh oleh pengguna kerusi roda semasa bermain di kerusi roda mereka (130 (14) bpm). Terdapat hubung kait yang bererti antara nilai kadar degupan jantung dan RPE ketika melakukan aktiviti 'exergame' dalam posisi berdiri. Bagi pengguna kerusi roda, ketinggian kadar degupan jantung juga mempunyai hubung kait yang tinggi dengan skala Borg RPE yang asli dan yang diubahsuai semasa melakukan aktiviti 'exergame' sambil duduk di kerusi roda mereka. Model regrasi yang diperoleh daripada hubung kait bererti Pearson tadi dimasukkan ke dalam persamaan untuk merumuskan kadar degupan jantung dari RPE yang dilaporkan. Rumus yang diekstrak dari model regrasi lurus di dalam kajian kali ini membolehkan penganggaran kadar degupan jantung dari RPE yang dilaporkan sambil melakukan aktiviti 'exergame' dilakukan dalam kajian masa depan yang melibatkan orang dewasa normal dan pengguna kerusi roda.*

Kata kunci: Permainan video, tinju, senaman, tabiat tidak aktif, kesihatan kardiorespirasi, postur, intensiti

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As the opportunity present itself, I am also thankful that I have very supportive parents, Mohd Jai Bin Kadir and Rohayu Binti Abd Hadi, as well as cheerful siblings, who always encourage me to move forward and to preserve during the process of completing this project. Last but not least, thank you to all my closest friends who always inspire me with their support and motivational words upon my hardships throughout the journey.

Finally, I have put my best and sincere efforts into this project, and I surely hope this will be helpful as future references for researchers and/or professionals who shall study or work on this field of interest.

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LIST OF SYMBOLS AND ABBREVIATIONS

ACSM	:	American College of Sports Medicine
BMI	:	Body Mass Index
CAD	:	Coronary Artery Disease
CDC	:	Center for Disease Control and Prevention
CP	:	Cerebral Palsy
CPOE	:	Center of Prosthetic and Orthotic
DDR	:	Dance-Dance Revolution
EE	:	Energy Expenditure
ECG	:	Electrocardiogram
FM%	:	Fat Mass Percentage
HDL-C	:	High-Density Lipoprotein
HIE	:	High-Intensity Exercise
HR	:	Heart Rate
HRM	:	Heart Rate Monitoring
HR_{rest}	:	Resting Heart Rate
HRR	:	Heat Rate Reserve
HR_{max}	:	Maximum Heart Rate
$\%HR_{max}$	:	Percentage of Maximum Heart Rate
HR-based ML	:	Heart Rate-based Match Load
LIE	:	Low-Intensity Exercise
LDL-C	:	Low-Density Lipoprotein
MET	:	Metabolic Equivalent of Task
RPE	:	Rating of Perceived Exertion
SCI	:	Spinal Cord Injury

SD	:	Standard Deviation
VO_2	:	Oxygen Consumption
$\%VO_{2\ peak}$	:	Percentage of Oxygen Consumption Peak
WB	:	Wheelchair Basketball
WHO	:	World Health Organization
3D	:	Three-dimensional

LIST OF EQUATIONS

Body mass index;

$$BMI, kgm^{-2} = \frac{Body\ mass\ (kg)}{[Height\ (m)]^2} \qquad (3.1)$$

Tanaka's formula for age-predicted maximum heart rate (HR_{max}) quantification;

$$HR_{\max = 208 - (0.7\ \times age)} \qquad (3.2)$$

Percentage of maximum heart rate;

$$HR_{max}\% = \frac{HR_{(while\ playing)}}{HR_{max}} \times 100\% \qquad (3.3)$$

Extracting heart rate (HR) from rating of perceived exertion (RPE) values;

For able-bodied population

Standard RPE (6-20); $HR = (RPEx4) + 74$ (4.1)

Modified RPE (1-10); $HR = (RPEx5) + 107$ (4.2)

For wheelchair-users population

Standard RPE (6-20); $HR = (RPEx8) + 26$ (4.3)

Modified RPE (1-10); $HR = (RPEx8) + 101$ (4.4)

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

The first chapter introduces the research topic and explains the background and rationale for the current study. It provides a brief overview of the prevalence of disabilities worldwide and in Malaysia, as well as data on sedentary lifestyles led by people with disabilities and how these may affect their health. The chapter is followed by the study's objectives, significance, delimitations, and operational definitions of terms. The chapter concludes with a chapter-by-chapter overview of the thesis and a study flowchart.

1.1 Background

Recent data have shown that more than one billion people worldwide have disabilities, with nearly 200 million having significant functional difficulties and the prevalence is higher in developing countries. In Malaysia, the prevalence of disability among adults is 11.8% and comparable to the World Health Organization's (WHO) estimation and most developing countries (Ahmad et al. 2017). The number is expected to be higher as the existing data in Malaysia are reported to be understated. This is concerning as the number is increasing because of population aging and the rapid spread of chronic diseases (Kiau et al. 2013, Mustapha et al. 2014).

People with disabilities are more likely to lead sedentary and less active lifestyles. This is a perturbing health disparity, given the significant health benefits of an active lifestyle, which may be greater for those with disabilities than for the non-disabled population due to a higher incidence and prevalence of numerous chronic health conditions such as cardiovascular disease, obesity, and Type II diabetes (Owen et al. 2010, Paul et al. 2016). Physical activities are more difficult for those having mobility issues. They face numerous unique disability-related barriers such as lack of accessible transportation and facilities and knowledgeable health professionals, in addition to general exercise barriers such as lack of motivation and time. Those with severe mobility impairments include suffering from spinal cord injury (SCI) and experiencing additional equipment, resource, and environmental barriers to participating in activities (Johnson et al. 1990, Rimmer et al. 2008, Brinthaupt et al. 2010, Rosenberg et al. 2013).

Exergaming is a new technology that uses low-cost video games as an exercise activity in the form of a game, such as boxing, bowling, tennis, or golf. It is based on the movement-controlled interface technologies that track a player's body movement (exertion) and converts the signal into a game command, providing the players with both fun and exercise opportunities (Bosch et al. 2012, Burns et al. 2012, Barry et al. 2016). Previous studies have demonstrated the positive impacts of exergaming on health-related outcomes for people of different ages, from children to the elderly, as well as for people with different physical abilities or disabilities, rehabilitation needs, or special needs through heart rate (HR), oxygen consumption (VO_2), or energy expenditure (EE) measures (Kraft et al. 2011, Bosch et al. 2012, Burns et al. 2012, Taylor et al. 2012, Mackintosh et al. 2016, Mohd Jai et al. 2020).

As the use of exergaming has grown popular among regular users and healthcare providers, electronic sports (e-sports) are also becoming more well-known, and during e-sports, a heart rate monitor (HRM) is the most accurate and practical way to measure exercise intensity under any conditions. Wearing HRM during competition, on the other hand, can be extremely inconvenient and can affect a player's overall performance. The use of a rating of perceived exertion (RPE) will also be beneficial in assessing intensity in people who take medications that affect heart rate or pulse. There is a need to develop a more flexible approach to estimating HR solely based on reported RPE.

While strong evidence shows RPE is highly associated with HR during actual exercises, data regarding the correlation of HR and RPE have never been discussed during any exergaming studies before. Therefore, this study aims to validate the correlation between HR and RPE by considering factors such as different body positions during gameplay and different types of disabilities.

1.2 Problem Statement

People with physical disabilities needing prolonged use of a wheelchair include SCI, amputation, and cerebral palsy (CP). As movement is primarily restricted to the upper body, the energy cost of most exercises and activities of daily living performed by wheelchair users are significantly lower (27%) than those reported in the population without disabilities (Collins et al. 2010, Conger and Bassett 2011). However, studies show that people with severe disabilities can engage in moderate-to-vigorous intensity exercises by playing exergames. This is because it can be played in a sitting position for wheelchair users and provides a variety of exercise options.

Exergaming in a standing position produces more metabolic equivalents (METs) in adults than exergaming in a seated position, indicating more VO_2 when lower limb musculature is also recruited during gameplay. However, several exergames are designed to involve both the upper and lower extremities (Hurkmans et al. 2011). Previous researches have shown that moderate-to-intensity exergaming, particularly boxing, can be played in two different positions, sitting and standing, and using Wii, PlayStation Move, and Kinect hardware among adults with and without disabilities (Hurkmans et al. 2010, Jordan et al. 2011, Mackintosh et al. 2016, Mohd Jai et al. 2021).

Owing to the robust gyro and geomagnetic sensors, the PlayStation Move hardware is more likely to induce greater physiological impacts compared to other types of hardware (Tanaka et al. 2012). However, no data have been published on the physiological responses among able-bodied adults while playing boxing exergame using the PlayStation hardware. Studies involving wheelchair-users playing boxing exergame using PlayStation hardware are also still limited (Mat Rosly et al. 2017). Hence, the potential physiological responses of playing boxing exergame using PlayStation Move hardware in different positions among able-bodied and wheelchair-user adults (sitting on chairs, standing, and sitting on wheelchairs) have never been assessed.

Two general methods have been used to measure the EE obtained by the players during any physical activities or exercises, namely indirect estimation and direct measurement of oxygen uptake. The indirect estimation includes HRM, double labelled water, activity questionnaires, pedometers, and accelerometers (Keytel et al. 2005, Cardon and De Bourdeaudhuij 2007, Hills et al. 2014). Among the methods, HRM is relatively more practical, accurate, and can be used in most situations. However, sometimes, during training or e-sports day, wearing the HRM tools can be troublesome and may affect a player's performance capacity throughout the gameplay. A study by (Gillach et al. 1989) demonstrates that the RPE scale can be used to properly monitor changes in HR (as a measure of physiological strain) since each subject increases in RPE as HR increases.

Similarly, a study shows that RPE strongly correlates with HR and is not significantly influenced by factors such as gender, age, physical activity level, and exercise testing modalities (Scherr et al. 2013). The use of RPE is theoretically a more flexible approach for tracking changes in exercise intensity within a session which requires no form of HRM gadgets that may be uncomfortable for users when playing moderate-vigorous exergaming, such as Move Boxing. But to the best of our knowledge, the correlation between RPE and HR has never been made in any exergaming studies before.

1.3 Objectives

The aims of the present study are:

1. To validate the correlations between HR and RPE coefficients based on the intensity classifications when playing a moderate-vigorous intensity exergame (Move Boxing) among adults with and without a disability.
2. To formulate a possible regression model based on confounding factors such as the position of gameplay, disability, age, or body mass index (BMI).

1.4 Hypotheses

The two main hypotheses of the study are;

1. The significance of HR-RPE correlation when playing boxing exergame in a standing position is the same as the HR-RPE correlation when playing in a sitting position among the able-bodied.
2. The significance of HR-RPE correlation of wheelchair users when playing boxing exergame while being seated on their wheelchairs is equivalent to the HR-RPE correlation obtained in able-bodied when playing boxing exergame in sitting and standing positions.

1.5 Significance of Study

HR and RPE are the common measurements used to monitor the changes in exercise intensities during exercise activities including exergaming. Previously, the use of the only RPE to monitor the exercise intensity in traditional exercises has been proven to be valid and reliable by a strong association with HR. However, the HR-RPE correlation during exergaming has never been studied before. With the validation of the correlation between HR and both types of RPE scales during exergaming among able-bodied and wheelchair-user adults, it may lead to the following results;

i. A formula to estimate HR based on the reported RPE can only be formed to provide a more convenient and faster way for individuals to keep track of their HR when exergaming.

ii. The use of this formula is especially useful during exergaming competition where it eliminates the need of wearing HR monitor gadgets that can affect the player's performance during gameplay.

Through the analyses of this research, sedentary individuals can realize that it is easy to check their HR regularly and adjust the HR to a desired target heart rate zone and prevent overworking their heart during exergaming. The formula proposed may be incorporated by physiotherapists in the exergaming routines that they use with their patients, which can also be conducted in their homes. This will increase one's interest and participation in exergaming that can contribute to long-term adherence to exergaming routines and eventually increase their physical activity level. Finally, this study also benefits future researches to explore HR-RPE correlations during exergaming using other hardware, different age group, and population.

1.6 Delimitations of the Study

The main aims of this study are 1) to validate the correlations between HR and RPE coefficients when playing moderate-to-vigorous intensity exergames among adults with and without disabilities, and 2) to formulate a formula to estimate HR based on the reported RPE only. To achieve this, the delimitations of the study are categorised into population, intervention, comparison, outcomes, and generalisability.

- Population – the participation of this study is delimited to able-bodied and wheelchair-user young adults who are a) aged between 18 and 65 years old and b) have sufficient mobility for upper extremity exercise except for stroke.
- Intervention – the modality of choice in this study is limited to Sony PlayStation Move hardware and Move Boxing exergame. Subjective perception of participants is measured using both original Borg and modified RPE scales.
- Comparison – the study is delimited to only comparing two different body positions, sitting and standing, during gameplay. Other positions, for example, supine or lateral positions, are not assessed.
- Outcomes – the study only focuses on obtaining HR and RPE responses of participants to validate the HR-RPE correlation during exergaming.
- Generalisability – the results of the study will not be generalizable to other populations, for example, children (aged below 18 years old), older adults (aged above 65 years old), and stroke populations.

1.7 Operational Definitions of Terms

The operational definitions of this study were described as follows;

- Maximum heart rate (HR_{max}): The age-related number of beats per minute of the heart when working at its maximum, and calcutated by using Tanaka's formula.

$$HR_{max} = 208 - (0.7 \times age)$$

- Percentage of maximum heart rate (HR_{max}%): Target heart rate zone based on the age-related maximum heart rate. HR_{max}% is classified by the following intensity ranges established by ACSM (Garber et al. 2011): light (< 64%), moderate (64%-76%), vigorous (7695%), near-maximal to maximal (≥96).
- Perceived exertion: It is based on the physical sensations a person experiences during physical activity. The original Borg's and modified RPE scales are the common way to measure the exercise intensity level. Both modified RPE (1-10) and the original Borg's RPE (6-20) values are classified by the following intensity ranges; RPE (1-10); light (1-2), moderate (3-4.5), and vigorous (≥5) and RPE (6-20); light (9-11), moderate (12-13), vigorous (≥14).

1.8 Thesis Outline

The thesis is organised into five chapters. Chapter 1 begins with an introduction to the research followed by the research problem statements, hypotheses, and main objectives. This chapter also includes the significance, delimitation, operational term of the study, the thesis outline, and the flowchart of the study.

Chapter 2 discusses the literature motivating this research including the recommended level of physical activity among adults with and without disability, the challenges and barriers to physical activity, as well as the traditional exercise activity involving both populations. This chapter also reviews the existed supporting data on the subject matter and protocols employed in the present study.

Chapter 3 presents the methodology of the study including study design, selection of participants, material, and equipment used to conduct the experiment, experimental procedures, and data analysis method used in the study. Also, the ethical measures taken for the study are described in this chapter.

Chapter 4 bestows the results of the study followed by a discussion of the findings. The physical characteristics of all participants are presented followed by the results and discussions of the two research problem statements. Also, the findings of the study are discussed against the findings of previous studies on exergaming.

Chapter 5 contains the conclusion of the findings obtained in the current study, including the limitations and potential future works on the HR-RPE correlations to be conducted using other types of exergames and platforms.

1.9 Thesis Flowchart

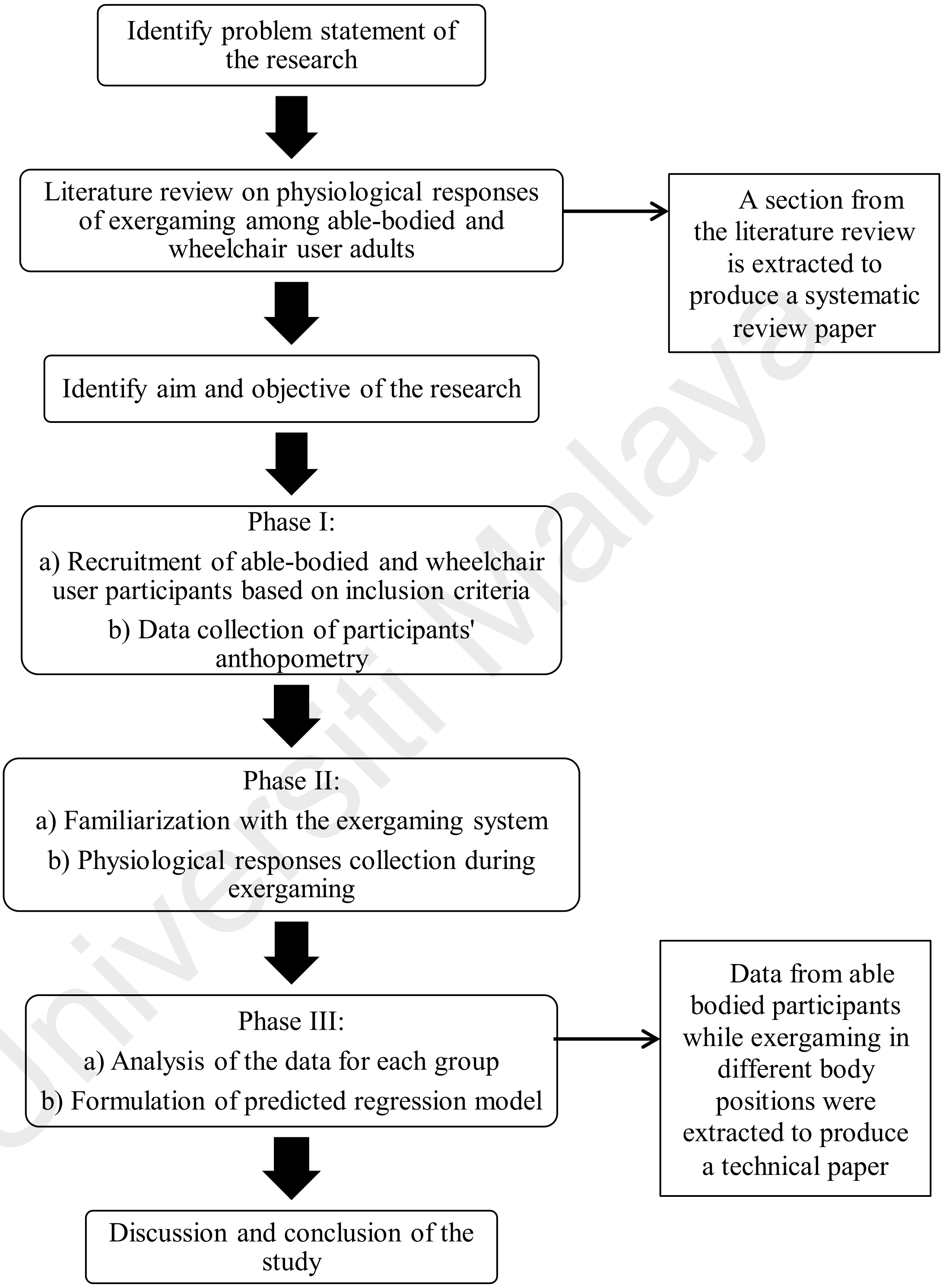

Figure 1.1: The flowchart of study

CHAPTER 2: LITERATURE REVIEW

The theoretical foundation and studies related to the background of this study are presented in Chapter 2. Specific sub-sections cover physical activity, exergaming, exergaming research, and the correlation of physiological responses with perceived exertion ratings. Finally, a summary of the research background is provided.

2.1 Physical Activity

Caspersen et al. (Caspersen et al. 1985) defined physical activity as any bodily movement that resulted from the contraction of muscle which elevates energy expenditure above the minimal level. According to the Center for Disease Control and Prevention (CDC), physical acticity is indeed crucial for overall health and prevention of premature death. Some physical activities are better than doing none but still less than the recommended activity level for good health. Several recommendations and guidelines were made differently based on age groups and specific population groups such as the WHO and the American College of Sports Medicine (ACSM) exercise guidelines.

Adults, including those living with a disability, aged from 18 to 64 years were recommended to at least perform 150 to 300 minutes of moderate-intensity aerobic physical activity or at least 75 minutes to 150 minutes of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate-vigorous-intensity throughout the week ((WHO) 2020). Similarly, the recent ACSM recommendations for adults are to engage in 30 minutes of moderate-intensity physical activity, five days per week, or 20 minutes of more vigorous physical activities, 3 days per week (Garber et al. 2011). For young adults, aged from 20 to 39 years, moderate-intensity exercise is that which results in an EE of 4.8 to 7.1 METs, or a percentage of maximum HR (HRmax%) of 64% to 76% (Garber et al. 2011). Examples of moderate-intensity for young adults include walking, dancing, or mowing the lawn, which demands major muscle involvement (Ainsworth et al. 2011).

A sufficient physical activity plays a major role in overall well-being and the prevention of chronic health conditions such as obesity, cardiovascular disease (CVD), type 2 diabetes, and other morbidities. Except for genetic CVD, a high correlation exists between CVD and physical activity. For an instance, results from an analysis study show that individuals who engage in physical activity either light, moderate, or vigorous, had a significantly lower risk for CVD mortality, dicounting of their metabolic risk factors (Reddigan et al. 2011) (Figure 2.1). Individuals with CVD who become physically active experience a reduction of risk, signs, and symptoms of CVD while increasing the functional capacity (Leon et al. 2005). The quality of life among CVD patients also increased when physical activity and exercise training were included in their medical programming (Schairer et al. 2003).

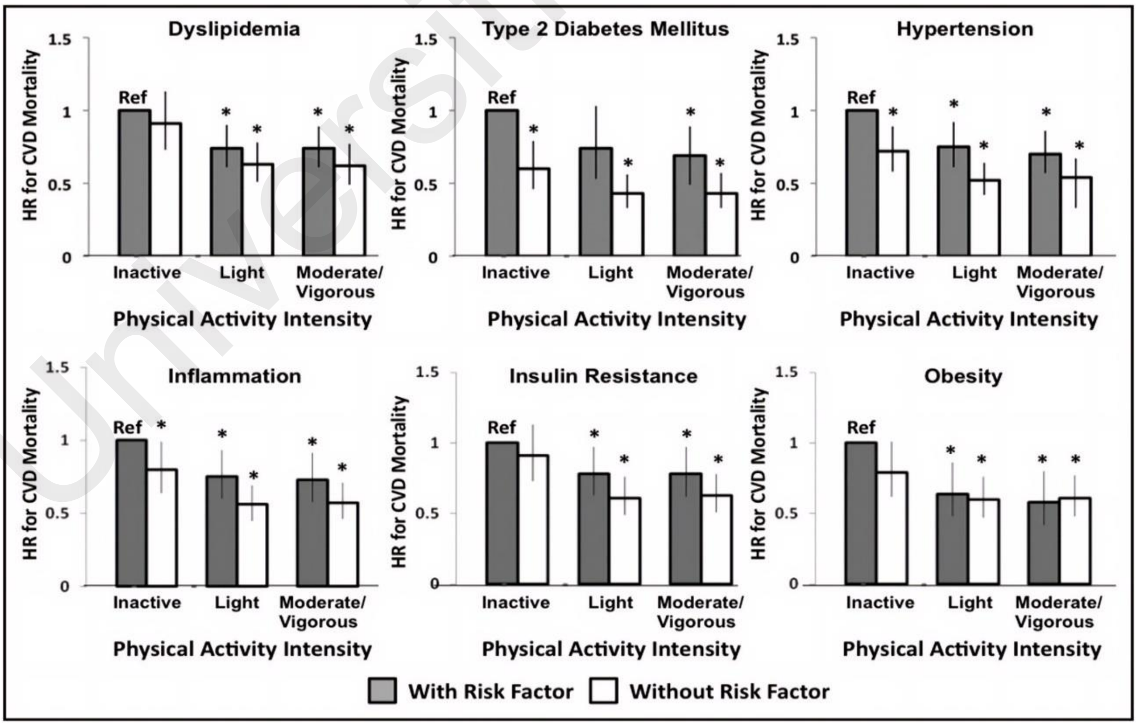

Figure 2.1: Reddigan et al., 2011 analysis of CVD mortality risk in subjects with and without a given metabolic risk factor across the three physical activity levels

Individuals with an insufficient level of physical activity are also at higher risk of developing type 2 diabetes, no matter what age, gender, ethnic group, or BMI (Sigal et al. 2004, Admiraal et al. 2011). In fact, obesity and physical inactivity are the two supreme risk factors linked with type 2 diabetes (Knight 2012). Conventionally, aerobic physical activity has been a key element in the prevention and management of type 2 diabetics. A week of moderate to vigorous aerobic physical activity provides positive impacts on overall body insulin (Colberg et al. 2010). An increase in daily physical activity increases the high-density lipoprotein (HDL-C) and improves blood low-density lipoprotein (LDL-C) as well as triglyceride levels, which promotes weight loss and reduces obesity rates (Wing and Hill 2001). Besides physical effects, a regular physical activity also good for emotional health including improving moods (Sexton et al. 2001), self-esteem (Sonstroem and Morgan 1989), vitality, and satisfaction with physical appearance (Babic et al. 2014). Studies also demonstrated that regular physical activity may protect against the development of depression (Dishman et al. 2012), or that insufficient PA may be a determinant condition for depressive symptoms (Farmer et al. 1988).

Recently, strong evidence shows that insufficient physical activity combined with sedentary behavior bestow to the development of non-communicable diseases (Pate et al. 2008). Sedentary activities are those where the required energy expenditure is very low and the dominant posture is sitting or lying such as television viewing, computer uses, and video gaming (Matthews et al. 2008, Pate et al. 2008, Matthews et al. 2012). Sedentary behaviors are associated with increased risks of CVD. For instance, men who drive for 10 hours and more per week had an 82% higher risk of CVD compared to those who spent 4 hours or less per week (Warren et al. 2010). An additional hour of sedentary activity could also elevate the chance of developing the two major factors of CVD which are being overweight (13%) and high abdominal fat (26%) (Byun et al. 2012).

The growing evidence suggests that there is a possible risk origin for health, which is related to the level of activity or inactivity. The association of physical inactivity to variety of health problems, and health benefits of physical activity were established (Warburton et al. 2006, Lee et al. 2012). Physical activity improves people's health and well-being, whereas physical inactivity is a serious public health problem and a major risk factor for chronic diseases. Several studies have also presented evidence of rising healthcare costs as a result of physical inactivity (Kohl 3rd et al. 2012, Ding et al. 2016). However, far too few people meet the recommended levels of physical activity. Thus, physical inactivity is not only an individual problem, but also a societal problem, and because of its importance in terms of public health and finance, it is critical to find new ways to motivate people to be more physically active, exercise more, and avoid physical inactivity.

2.2 Physical Activity Barriers

Being physically active will benefit the physiological, emotional, and social aspects of one's life. Yet, not all can easily enjoy the benefit of physical activity, particularly ones living with disabilities, due to the many personal and environmental barriers they encounter making PA difficult. According to WHO's recent data, 15% of global population or around 1 billion people experiences disabilities. This number is expected to rise due to the ageing population, advancements in medical and rapid spread of chronic health conditions (WHO 2011). In Malaysia, the prevalence of disability among adults was 11.8% and comparable to WHO estimates and most developing countries (Ahmad et al. 2017). The number is expected to be higher as the existing data in Malaysia was reported to be understated. This situation is concerning as the prevalence of leading sedentary and inactive lifestyles which eventually contribute to development of chronic diseases is higher in people with disabilities. For example, Rimmer and Wang mentioned that individuals with disabilities have a 66% greater rate of obesity compared to healthy peers (Rimmer and Wang 2005). However, adults with disabilities only do PA regularly about half as often as adults without disabilities (Figure 2.2).

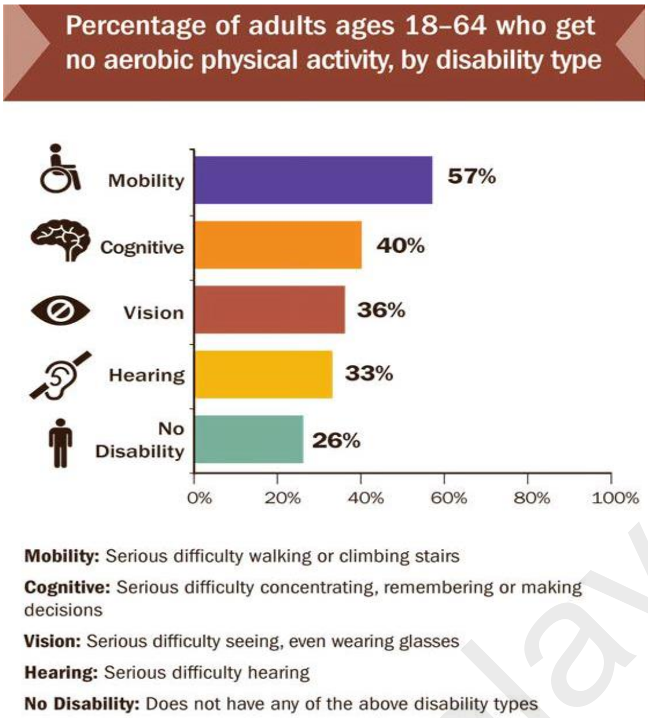

Figure 2.2: Source from the Centers for Diseases Control and Prevention (CDC) National Center for Health Statistics, National Health Interview Survey, 2009-2012

2.2.1 Personal Barriers

People are inactive for a variety of personal reasons. The most common reasons for adults not being active have been described, including a lack of time to engage in physical activity, a lack of motivation, the inconvenience of exercise, and so on (Sallis and Hovell 1990, Sallis et al. 1992, Arzu et al. 2006). These obstacles are typically shared by all people, both able-bodied and disabled (Johnson et al. 1990, Zhu et al. 2001).

People with disabilities, on the other hand, are more likely to suffer from factors such as injury and pain, as well as a fear of falling (Kars et al. 2009). In fact, according to one study, more than half of Australians (N=2298) cite injury and physical impairment as major "roadblocks" to getting physical activity (Finch et al. 2001). Fatigue and a lack of energy were also mentioned as personal barriers to sports participation among adults with various types of disabilities (Stroud et al. 2009, Beckerman et al. 2010).

Lack of knowledge about physical activity, has also been significant impediment to increasing physical activity among people with disabilities. For example, Scelza et al's study found that the majority of people with SCI had limited knowledge about where to get exercise, preventing them from being more active (Scelza et al. 2005). Furthermore, low confidence and self-efficacy in one's ability to be physically active, as well as negative exercise behaviour that can occur in both able-bodied and disabled people, have a significant impact on one's participation in physical activity (Brinthaupt et al. 2010, Brittain et al. 2011, Lox et al. 2016).

In addition to a lack of time and transportation, health issues and a lack of motivation were major barriers to exercise for people with disabilities in Malaysia. Approximately 9.8 percent of those polled believed that exercise would aggravate their situation (Manaf et al.). Whereas for the able-bodied population, tiredness after work, laziness, and a lack of discipline were the main perceived barriers by private office worker respondents (Jun et al. 2020).

2.2.2 Environmental Barriers

Environmental barriers that may influence an individual's participation in physical activity can be classified as physical or psychosocial. The physical barriers in the environment include a lack of access to gyms or workout amenities, a lack of wheelchair-friendly built-in environments for physical activity, a lack of parks or green spaces, insufficient sidewalk coverage, and a lack of safe and convenient walking or cycling trails (Humpel et al. 2002, Arbour-Nicitopoulos and Ginis 2011, Rosenberg et al. 2013).

Factors such as the distance between exercise facilities and the home, as well as weather conditions such as excessive heat or cold, have a significant impact on the frequency of exercise (Sallis and Hovell 1990, Chan and Ryan 2009). In temperate climates, for example, physical activity levels are significantly lower during the winter season, and both men and women tend to do more activities in the summer than in the winter (Dannenberg et al. 1989, Baranowski et al. 1993). Furthermore, the environment's psychosocial barrier includes a lack of supports and inspirations, social stigma, and the absence of companions. The aforementioned factors may have a disproportionate impact on people with physical disabilities, who are typically dependent on their parents, spouses, or siblings to assist them with physical activity participation, such as driving them to exercise facilities, holding up equipment, and other functional assistances (Rimmer et al. 2008).

According to Kang et al’s study, one of the most significant barriers to exercise among youth with physical disabilities is a lack of space to exercise with friends (Kang et al. 2007). In fact, a large body of research has demonstrated the importance of social contact in facilitating sports participation among adults with disabilities (Tasiemski et al. 2004, Shihui et al. 2007, Kars et al. 2009).

2.3 Body Position and Disability Impact to Exercise

Body positions during an exercise or physical activity are well-documented to have an effect on players' physiological responses. In theory, standing exercise or activity provides more benefits than sitting exercise or activity because more neuromuscular core activations are involved (Saeterbakken and Fimland 2012). In the standing position, the body works more muscles and burns more calories than in the sitting position. Similarly, Escamilla et al's study investigated the ability of eight Swiss ball exercises in various positions (such as roll-out, pike, knee-up, sitting march right, and decline push-up) and two abdominal exercises (crunch and bent-knee sit-up) to activate core musculature (Escamilla et al. 2010). The study suggested that pike, roll-out, knee-up, and skier exercises may produce more EE than bent-knee sit-ups and crunches due to increased muscle recruitment and core muscle activity (Figure 2.3).

However, different people have different needs and efficacies when it comes to exercising on a regular basis. Furthermore, body positions during exercises were determined by the individual's training needs as well as the exercise's requirements. For example, in weight lifting, someone who is just starting out may be advised to perform in a sitting position. In a seated position, one can avoid using momentum or the wrong muscle groups to perform and keep their balance while learning proper form and technique. Furthermore, shorter body dimensions correspond to a larger mean skeletal muscle cross-sectional area, which is beneficial to weightlifting performance (Storey and Smith 2012). Also, for someone looking to build muscle strength, a sitting position provides more balance than a standing position, allowing them to handle heavier weights (Hunter et al. 1998).

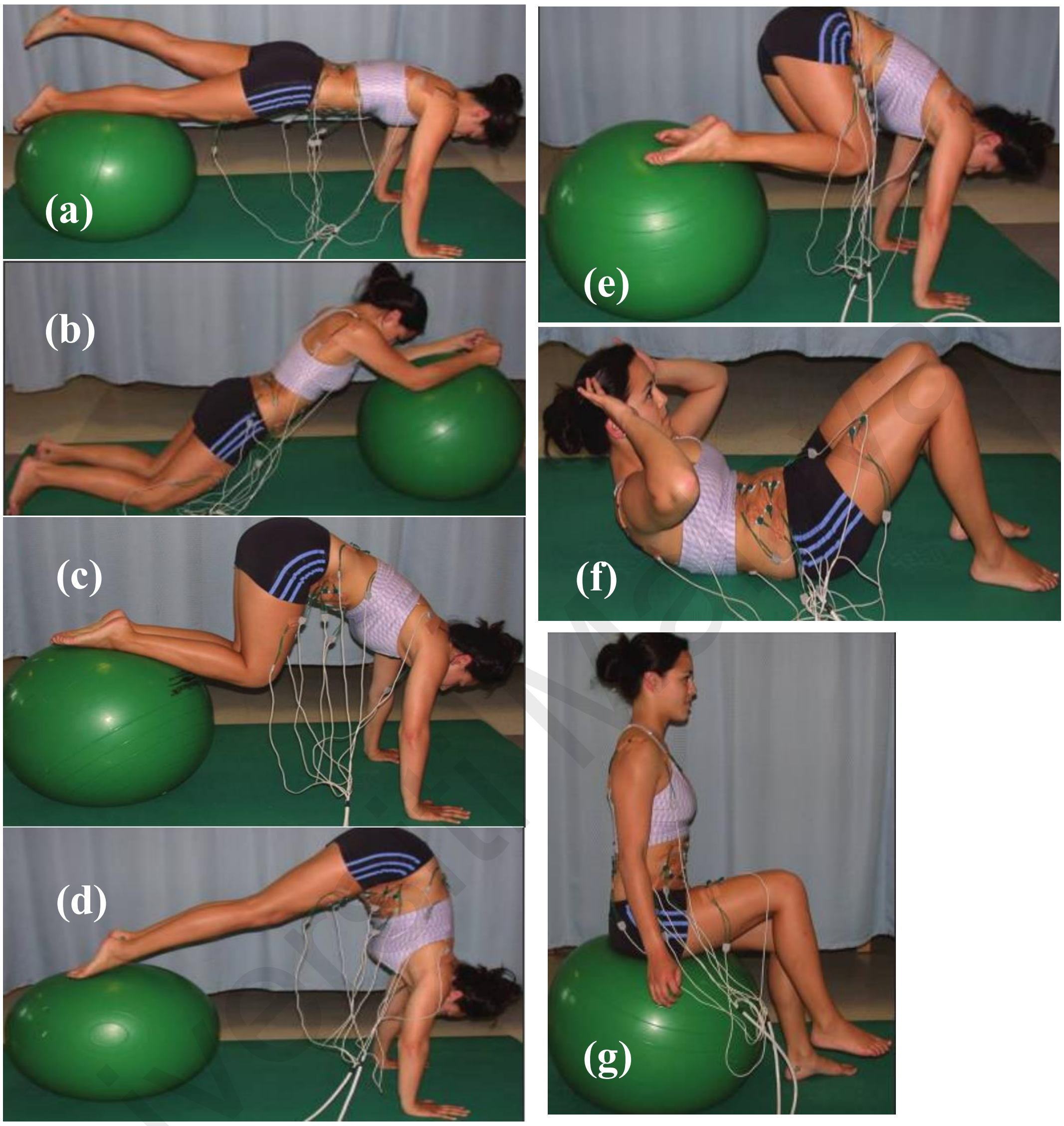

Figure 2.3: Escamilla et al's study demonstrated the core muscle activations in different positions namely (a) hip extension right (b) roll out (c) pike (d) knee-up up (e) skier (f) crunch (g) sitting march right

In the rehabilitation context, if one is recovering from a lower-body injury, particularly among people with lower body impairments, staying seated while performing exercises is a great option. Even while seated, one can work on his or her upper body without putting any additional strain on the body. Indeed, sports such as wheelchair basketball (WB) and tennis have been shown to significantly improve the player's physiological responses such as HR and VO_2. Conners et al's study, for example, found that one WB game participation contributes to the recommended weekly amount of at least 150 to 300 minutes of moderate-intensity aerobic physical activity among the youth population (Garber et al. 2011, Conners et al. 2020).

A low fat-mass percentage has a significant impact on performance in running basketball and, more broadly, able-bodied sports. According to Cavedon et al's s study (Cavedon et al. 2015), WB players may not be obstructed by extra body weight as in running basketball because they carry their body weight in a wheelchair during play and do not have to jump. They may even benefit from a more stable posture when throwing basketball due to extra body weight, reducing the direct impact of body fat on performance. Similarly, Croft et al's study showed that WB was more physiologically demanding than tennis; however, the average tennis values relative to percentage of oxygen consumption (VO2 percent) peak in 68 percent in the study, which was higher when compared to other studies investigating wheelchair players (49.9 percent), and more similar to that of able-bodied tennis players at 60 percent to 70 percent (Croft et al. 2010). This means that the intensity and energy expended during any exercise are not always determined by one's disabilities. With appropriate repetitive training, people in wheelchairs can meet the exercise guidelines on a regular basis and achieve the same physiological responses as their able-bodied peers.

2.4 Exergaming

Exergaming is a fusion of exercise and video games (Bogost 2010) that integrate the low cost video games into sport-like activity (Sinclair et al. 2007). It is also called activity-promoting video games due to its ability to encourage physical activity during screen time (Lanningham-Foster et al. 2006). While, Oh and Yang, 2010 define exergaming as an experiential activity that involves playing exergames or any video games that involve physical exertion or movements that are more than sedentary activities, it also includes strength, balance, and flexibility activities (Oh and Yang 2010).

2.4.1 Exergaming History and Technology

The origins of this genre can be traced back to the late 1980s, when video games became popular. Computrainer by Racer-Mate, released in 1986, is widely regarded as the first true exergame, allowing a user of a road bike to pedal through a virtual landscape while viewing cadence, speed, and other data generated to a projector screen (Davison et al. 2009, Clark et al. 2016, Sparks et al. 2016). Konami Corporation of Tokyo released the Dance Dance Revolution (DDR) video game in the late 1990s (Behrenshausen 2007). DDR became a phenomenon, selling over three million copies and popularising exergaming as a possible tool for exergame players to lose weight (Tan et al. 2002, Behrenshausen 2007, Warburton et al. 2007). Many of the problems that plagued earlier exergames were improved in newer iterations such as Cat-Eye Game Bike, Exertris Interactive Gaming Bike, EyeToy: Kinetic, Gamercize, and Wii Fit, resulting in an increase in exergaming usage in the 2000s (Warburton et al. 2007, Adamo et al. 2010).

The Nintendo Wii released a motion-sensitive controller in 2006 that detected three-dimensional (3D) accelerations, and the Wii 2010 version could detect a player's 3D hand posture using a three-axis gyro sensor. As a result of this, Nintendo has gained widespread recognition as the company that pioneered the development of movement-controlled interfaces in seventh-generation game consoles. Following that, Microsoft released Kinect in 2010, an exergaming device that used motion-sensing technology to control the game (Best 2015), without any need for controllers. Exergaming has come a long way since the late 1980s and has grown in popularity since the second half of the 2010s. This is because of improved video-game graphics and the addition of new games to mobile and tablet applications. As the genre continues to evolve and realistically meet the increasing demands from the players, the exergaming industry is expected to reach new heights in popularity.

Many exergaming consoles and interfaces have been developed over the years, with the Nintendo Wii, Sony PlayStation Move, and Microsoft Xbox 360 Kinect being among the most popular. The position and motion of the controller or player can be tracked by all three consoles. Controllers used as a marker by both PlayStation and Wii simplify the software required to collect the data, allowing for faster data collection. However, the Kinect's use of more complex vision-based software allows for more acquisition and frees players from the need to hold any device to mark themselves. Sensing devices, responses latency, advantages, disadvantages for each console are summarised in Table 2.1.

Table 2.1: Comparisons of three commonly used gaming consoles. Adapted from previous studies (Tanaka et al. 2012, Mat Rosly et al. 2017)

Criteria	Game consoles		
	Nintendo Wii	**PlayStation Move**	**Xbox 360 Kinect**
Controller	Single	Dual	None
Sensor interfaces	Detects 3D positioning (limited), 3D information of acceleration, and rotational angular of the controller	Detects 3D positioning, contains 3D accelerometers, 3D gyro sensor, and geomagnetic sensor	Detects 3D positioning and orientation of objects in the visual field
Average latency	143 milliseconds (moderate response)	115 milliseconds (fastest response)	218 milliseconds (slow response)
Advantages	The largest documented game console used in exergaming studies	High resolution of image processing, upper body motion estimation by inverse kinematics	Contain depth detection, whole-body motion recognition in 3D.
Disadvantages	Limited detection to hand motion Difficulty in the detection of 3D hand position	Upper body motion can only be estimated by inverse kinematics, but the estimation accuracy is low	Low image processing, slow latency response, limited recognition in motion due to the unchanged of depth information

2.5 Exergaming Boxing

Exergaming has transformed the perception of video games as a sedentary activity into an activity-promoting tool among players, particularly younger generations. Exergaming research findings vary depending on the age, background, and health conditions of participants, as well as the various types of game platforms and environments used in the studies.

Wii is the most commonly used platform in exergaming studies because it was the first company to produce movement-controlled interfaces. Several studies have looked into the intensity of exercise when playing the Wii exergame. The most popular game is Wii Sport, which typically comes with the console when purchased. The intensity of Wii Sports exergames was studied in people with and without disabilities (Hurkmans et al. 2010, O'Donovan et al. 2012, Perusek et al. 2014).

Baseball, bowling, and golf are just a few of the simulations that can be played with Wii Sports, and all of them require an energy expenditure of just under moderate intensity, 3 METs. However, regardless of population tested, healthy, or populations with specific injury or health conditions, Wii Boxing has consistently been shown to be the most active Wii Sports game when compared to the other games.

2.5.1 Physiological Effects of Exergaming Boxing in Healthy Adults

According to a recent study, boxing exergame exhibits a wide range of MET values among players without disabilities, ranging from light to vigorous activity intensities (Mohd Jai et al. 2021), as illustrated in Figure 2.4. This enables it to be adjusted to an individual's training requirements. A more sedentary individual, for example, can begin his training regimen with an easier mode that exerts less activity intensity. Furthermore, the MET values vary significantly depending on the user's playing motivation, study methodology (i.e., whether the study was conducted on the same or different days), and gaming environment (i.e competitive play or different difficulty level) (O'Donovan et al. 2012, Sanders et al. 2012, Scherr et al. 2013, McGuire and Willems 2015, Mohd Jai et al. 2021).

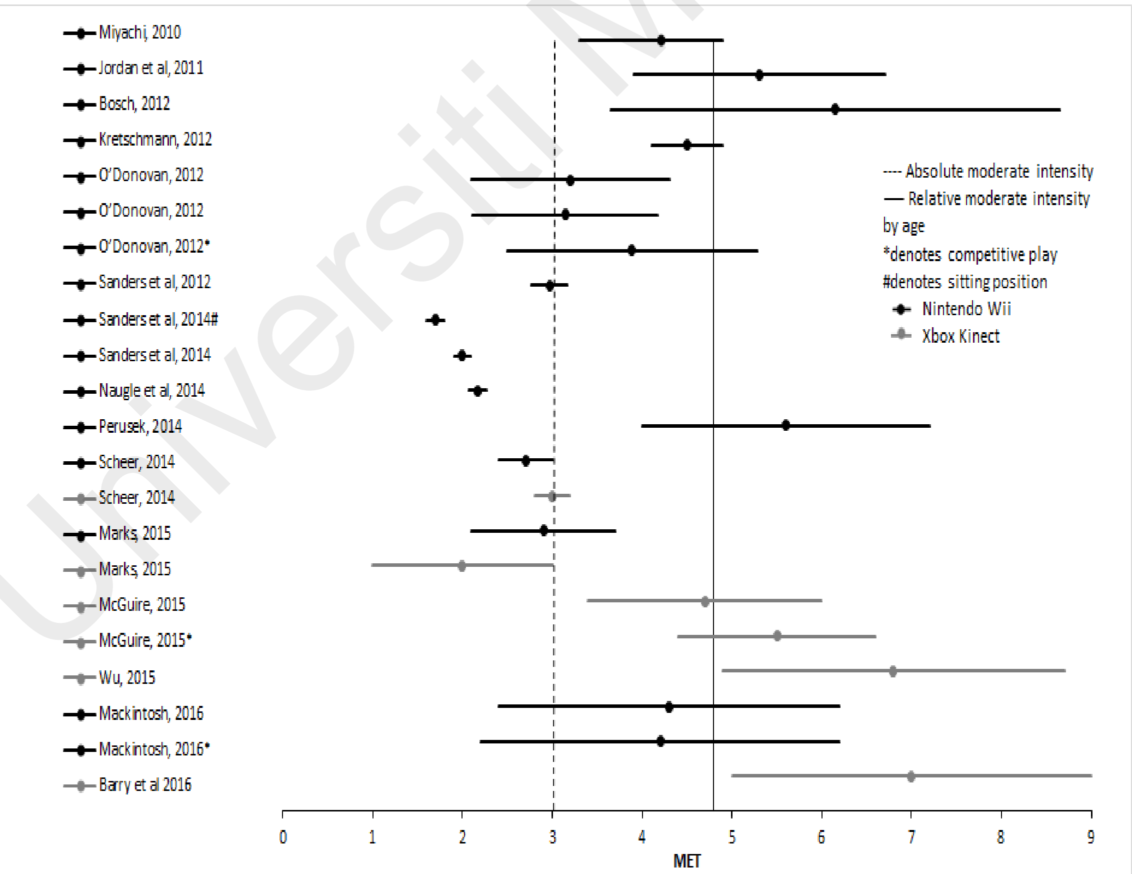

Figure 2.4: Forest plot of MET values (mean ± standard deviation) during exergaming boxing

According to Table 2.2, only one study reported physiological outcomes while participating in a boxing exergame among low-intensity (LIE) versus high-intensity (HI) exercisers (HIE). Naugle et al's study (Naugle et al. 2014) According to Naugle's research, HIE produced lower HR values despite their MET being nearly equal to that of LIE while playing a boxing exergame, as shown in Figure 2.5. This could be because their sympathetic cardiac acceleration has been adapted to high-intensity exercises, resulting in lower HR elevation (Berkoff et al. 2007).

Furthermore, one study found EE in sport science students while playing Wii Boxing. According to Kretschmann et al's study, Wii Boxing can provide moderate-intensity exercises for students (Kretschmann et al. 2009). The EE, on the other hand, did not correspond to the participant's perception of the game. Individuals, particularly sport science students, who participate in a variety of sports on a regular basis and have high fitness levels, rated their activities as less strenuous. This lends credence to the study's conclusion that Wii Boxing is sufficient for sedentary people to transition from sedentary to habitually physcically active (Perusek et al. 2014).

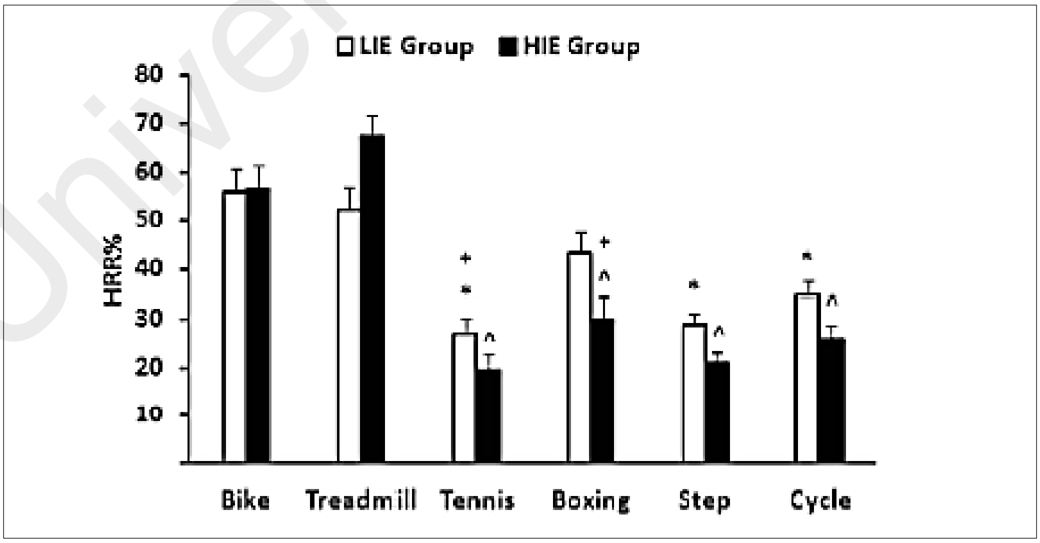

Figure 2.5: Naugle et al's mean percentage of the heart rate reserve (HRR) achieved for the LIE group and HIE group for each exercise activity tested.

There were only two platforms reported to be used to play the boxing exergames, the Nintendo Wii and the Xbox Kinect system, with Xbox Kinect Boxing platform producing higher MET (4.4 MET) than the Nintendo Wii Boxing (2.9 MET), according to Marks et al's study (Marks et al. 2015). Wu et al's and Barry et al's (Wu et al. 2015, Barry et al. 2016) study demonstrated that exergaming boxing with Xbox Kinect could produce moderate-intensity as recommended by the ACSM exercise guideline (Garber et al. 2011). The difference in physical exertion among the players may be explained by the differences in technical specifications between the Xbox Kinect system and the Nintendo Wii. Because of its more robust gyro and geomagnetic sensors, the PlayStation Move hardware can theoretically consume more energy than the other two more commonly used platforms (Table 2.1).

The amount of energy expended during exergaming boxing may also be affected by player's skill and experience levels (Figure 2.6). According to O'Donovan et al's study (O'Donovan et al. 2012), experienced players developed methods to reduce the effort required to exert force during exergaming boxing. This is accomplished by taking advantage of the user input-output mechanical loopholes while using the Nintendo Wii. Such a method involves using short, sharp movements by simple wrist flicking to produce the same input in-game, instead of performing a full forced punch swing. This is due to Wii controllers' poor 3D positioning and recognition information, which limits inverse kinematics of body motion (Tanaka et al. 2012, Mat Rosly et al. 2017).

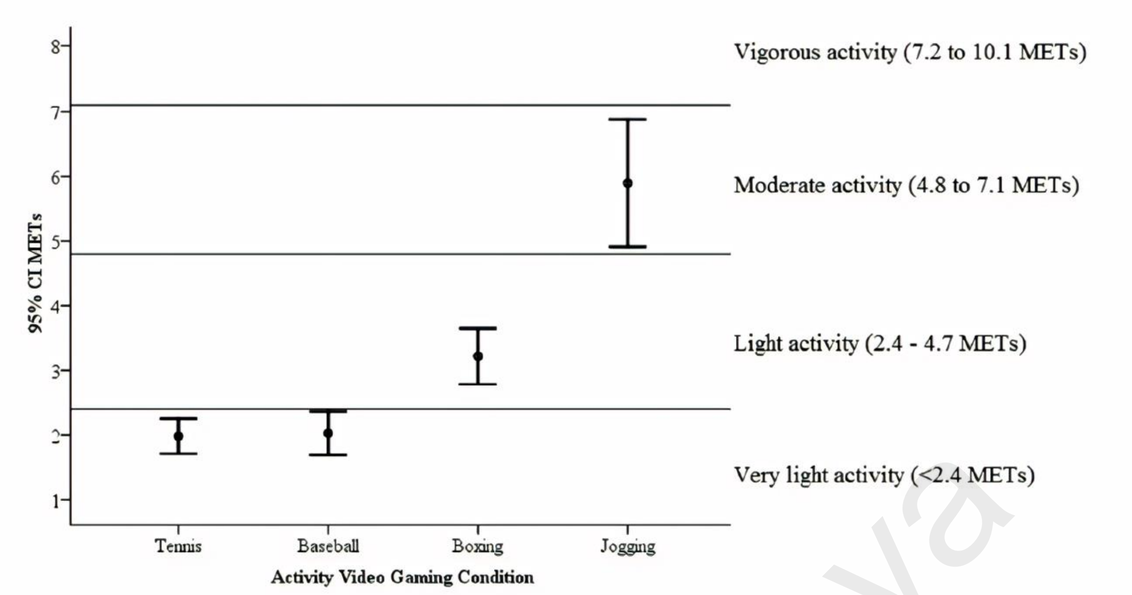

Figure 2.6: O'Donovan et al., results of lower MET values involving experienced gamers playing Wii Sports and Wii Fit

Table 2.2: Summary of previous exergaming studies investigating physiological responses of boxing exergame among healthy young adults

Author, year	Platform	Mean age (SD), Total participant (N)	Time play, position, environment	HRrest /HRmax	Outcome Intensity Parameter (Value, Intensity)		
					(HRmax%)/ Intensity	RPE (6-20)/ Intensity	EE in MET/ Intensity
(Miyachi et al. 2010)	Wii	34 ± 6, (N=12)	8 min, Stand	n/a	n/a	n/a	4.2 ± 0.9 / L
(Jordan et al. 2011)	Wii	29 ± 4, (N=15)	12 min sub-maximal , Stand	195 ± 11	(65.5% ± 10.1%)/M	n/a	5.3 ± 1.4/ M
(Bosch et al. 2012)	Wii	25.4 ± 1.3, (N=20)	30 min, Stand	186 ± 9	143 ± 15 (76.8%)/M	13.0 ± 1.6/ M	6.15±2.5/ V
(Kretschmann et al. 2009)	Wii	24 ± 1.69, (N=15)	10 min, Stand, athletes	191.2	110.98 ± 28, (58%) ($p < 0.001$)/L	n/a	4.5±0.4/ M
(O'Donovan and Hussey 2012)	Wii	23 ± 1, (N=12)	15 min, Stand	191.9	112.4 ± 24.4 (58%± 13%)/L	n/a	3.2 ± 1.1/ L
(O'Donovan and Hussey 2012)	Wii	21 ± 3, (N=14)	10 min, Single VS Dual	193.3	S= 107± 28 (55%); D=119 ± 28 (61.5%)/ L	n/a	S= 3.14 ±1.0; D= 3.89 ± 1.4/ L
(Sanders et al. 2012)	Wii	23 ± 2.4, (N= 24)	10 min, Stand	79.1 ± 2.5/ 191.9	105.4 ± 5.3 (55%)/L	11.3 ± 0.4/ L	2.97± 0.2 / L
(Sanders et al. 2014)	Wii	22.4 ± 1.95, (N=25)	10 min, Sit VS Stand	n/a	n/a	Sit= 8.1 ± 0.4[a]; Stnd= 8.9 ± 0.4[a], ($p <0.05$) / L	sit:1.7 ± 0.1 stand:1.9 ± 0.1/ L
(Naugle et al. 2014)	Wii	LIE: 20.72 ± 1.19, n=11; HIE, 20.18 ± 0.87, N=11	20 min, Stand, self-selected pace, LIE VS HIE	n/a	LIE=35.44–54.01%; (42.88±3.8%) HIE= 20.61–39.19% (29.69 ±3.84%) (% of HRR)/ LIE=M, HIE=L	LIE= 9.61–12.30[b], (14.61-17.3%); HIE= 8.84–11.53[b], (13.84-16.53%)/ LIE=V, HIE=M-V	HIE=2.17 LIE=2.1/ L

Table 2.2, continued

Author, year	Platform	Mean age (SD), Total participant (N)	Time play, position, environment	HRrest /HRmax	Outcome Intensity Parameter (Value, Intensity)		
					HR (HRmax%)/ Intensity	RPE (6-20)/ Intensity	EE in MET/ Intensity
(Perusek et al. 2014)	Wii	25.6, no SD (N=29)	30 min, Stand		138 ± 23.7 (72.6%), P=0.001/ M	11 ± 2, P(0.001)/ L	5.6 / M
(Scheer et al. 2014)	Wii	19.9 ± 1.35, (N=19)	8 min, Stand, Opponent: Human & Computer	194	(H) 117.6 ± 4.3 (60%) (C) 114.5 ± 4.6 (58%) /L	n/a	(H) 2.6± 0.2 (C) 2.7± 0.3/ L
	Kinect				(H) 119.6 ± 4.4 (61%), (C) 119.0 ± 4.3 (61%)/ L	n/a	(H) 3± 0.2 (C) 3± 0.2/L
(Marks et al. 2015)	Wii	21.3 ± 1.4 (N=15)	10 min, Stand	193	115.4 ± 12.8 (59%)/ L	n/a	2.9±0.8/ L
	Kinect				124.9 ± 13.0 (64%) (p < 0.05)/ M	n/a	4.4±1.3/ L
(McGuire and Willems 2015)	Kinect	23 ± 5, (N=10)	10 min, Single VS Dual	191.9	S= 120 ±28 (63%) D= 147 ± 18 (77%) (p<0.05)/ S=L, D= V	n/a	S= 4.7 ±1.3 D= 5.5 ± 1.1/ S=L, D= M
(Wu et al. 2015)	Kinect	22 ± 2.9, (N=17)	10 min, Stand	192.6	140.83±19.0 (73%)/ M	n/a	6.8±1.9/ M
(Mackintosh et al. 2016)	Wii	22 ± 4.2, (N=36)	18 min, Single VS Dual	n/a	n/a	n/a	S= 4.3 ± 1.9 D= 4.2 ± 2.0/ L
(Barry et al. 2016)	Kinect	23 ± 3, (N=19)	15 min, Stand	142 ± 18	(68% ± 11 %)/ M	12± 2/ M	7 ± 2/ M

SD: Standard Deviation; HR: heart rate; HRrest, Resting heart rate; HRmax, Maximum heart rate; HRmax%, Percentage of maximum heart rate; RPE: Rating of perceived exertion; %V02max: Percent of maximal oxygen uptake; EE: Energy expenditure; MET: Metabolic Equivalent of Tasks; LIE: Low-Intensity Exercisers; HIE: High-Intensity Exercisers; %HRR: percentage of heart rate reserve; n/a: not available; H: Human; C: Computer; S: Single; D: Dual; L, light; M, moderate; V, vigorous a: BORG20 point;b: uses 1-15 point scale, +5 conversion

2.5.2 Physiological Effects of Exergaming in Adults with Disabilities

Differences in EE while playing exergame boxing can also be affected by player's body positions (Sanders et al. 2014) or athletic background (Naugle et al. 2014). When playing in a standing position, METs were higher than in a sitting position, indicating that more oxygen is consumed when lower limb musculature is also recruited during gameplay. This is opposed to upper body movements only in a sitting position. Taylor et al's study, on the other hand, found that the EE and RPE of older adult participants (70.7 ± 6.4 years) while playing Nintendo Wii and Xbox Kinect, showed no significant difference between the equivalent games, regardless of body position (standing or sitting) (Taylor et al. 2012). However, it should not be generalised on other groups of participants, especially since RPE has been found to frequently overestimate the intensity classification compared to MET, especially in different positions (Naugle et al. 2014), disabilities (Mat Rosly et al. 2019), or in high-intensity activities (Malik et al. 2018).

Several studies had demonstrated that boxing exergame could provide adequate exercise intensities prescribed by exercise guidelines to a population with SCI, stroke, and CP (Table 2.3). There were only two different platforms of boxing exergame reported, Wii and PlayStation. Exergaming boxing using PlayStation hardware produced higher MET values in Mat Rosly et al's study (Mat Rosly et al. 2017) (MET= 4.3) compared to Wii hardware in Gaffurini et al's study (Gaffurini et al. 2013) (MET= 3.25) when both investigated SCI populations playing in sitting position. The robust gyro and geomagnetic sensors of PlayStation hardware may cause the difference.

The intensities when playing exergaming boxing also could be affected by the fact if the study used competitive play or not. For instance, Howcroft et al's study (Howcroft et al. 2012) had compared the energy levels and HR intensity between solo and multiplayer exergaming play. Multiplayer exergaming increased the player's HR more compared to solo play. The fun and competitiveness of multiplayer exergames may explain an increase in the motivation and participation of the players (Borra et al. 1995).

However, in the rehabilitation context, the solo play was more encouraged than multiplayer gameplay. In both gameplay, the dominant arm punching frequency was significantly greater than that of the hemiplegic arm, but during the multiplayer play, hemiplegic arm activity decreased, which understand as "developmental disregard" (Sutcliffe et al. 2009). The increased motivation to play and win against a real opponent explains the increased reliance on their more "reliable" limb, therefore minimize the rate of rehabilitation of the hemiplegic arm (Figure 2.7) (Howcroft et al. 2012).

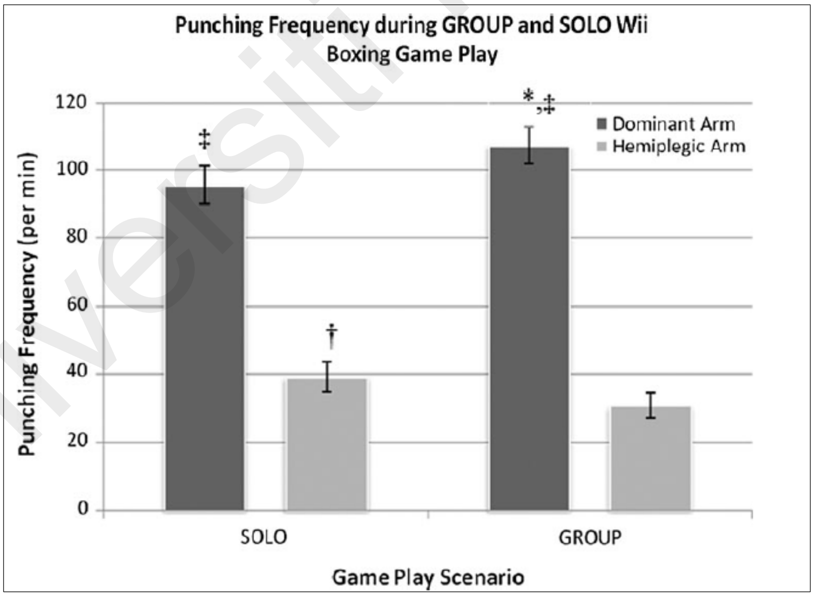

Figure 2.7: Howcroft et al's findings on the punching frequency during multiplayer and solo Wii Boxing gameplay

HR responses and MET values obtained when playing exergaming boxing using PlayStation hardware were comparable when compared either to other types of exergaming modalities (Wii Boxing) or different positions (sitting and standing) positions as well as in different populations (healthy, stroke, SCI, and CP). However, no related data had used PlayStation hardware to conduct the exergaming studies among normal population and studies that had investigate the potential of PlayStation hardware among wheelchair-users also are limited. Hence, there is a need for study to investigate the potential of PlayStation hardware to increase exercise intensities among both normal population and wheelchair-users.

Table 2.3: Summary of boxing exergames studies in populations with injury/health conditions (predominantly use wheelchairs)

Author, year, injury	Platform	Mean age (SD), Total (N)	Time play, position, environment	Outcome Intensity Parameter (Value, Intensity)		
				HR (HRmax%)/Intensity	RPE(20)/ (10) Intensity	EE in MET/ Intensity
Cerebral palsy						
(Hurkmans et al. 2010)	Wii	36 ± 7, N=8	15 mins, standing vs sitting rest	133.7 ± 20.7	5.4 ± 1.9 [a]use modified 11-point	5.0 ± 1.1
(Howcroft et al. 2012)	Wii	9.43 ± 1.5, N=17	8 mins	137.12 ± 19.11	-	3.36 ± 1.50 METs, M
(Howcroft et al. 2012)	Wii	9.77 ± 1.78, N= 15	8 mins, solo vs multiplay	Solo: 137.04 ± 19.96 Multiplay: 142.48 ±13.44	Solo: 4.25 ± 5.25 Multiplay: 6± 2 *OMNI scale	Solo: 3.32 ± 1.57 Multiplay: 3.37 ± 1.28
Stroke						
(Hurkmans et al. 2011)	Wii	56 (33-74), N= 8	Standing	106 ± 20	5.3 ± 2.7 (RPE (10)	4.1 ±0.7
(Kafri et al. 2014)	Wii	49.5 ± 12.2, 46.8 ± 6.7, N=19	8-10 mins, post-stroke, standing vs sitting	Stand: 63% of HRmax% Sit: 59.2 % of HRmax%	Stand: 13 Sit: 13	Stand: 3.08 Sit: 2.73
Spinal cord injury						
(Gaffurini et al. 2013)	Wii	40.0 ± 8.52, N= 10	10 mins, sitting	141.37	-	3.25 ± 0.93
(Mat Rosly et al. 2017)	PlayStation	32 ± 11, N=6	10 mins, sitting	120±19	6.7 ± 2.2 * RPE (10)	3.9 ±1.0
(Mat Rosly et al. 2017)	PlayStation	35.6 ± 10.2, N=17	Sitting	143±17	7.7 ± 1.7	4.3 ± 1.0
(Mat Rosly et al. 2019)	PlayStation	37 ±12	Sitting, Tetraplegia & Paraplegia	Tetraplegia: 100 ±8 Paraplegia:121± 18	Tetraplegia: 7.5 ± 1.3 Paraplegia: 64 ± 1.3	-
(Gail Nelson PT 2014)	Wii	18-23, N= 2	3 trials	146 ± 7 (48% HRmax%)- 174 ±7 (73% HRmax%)	-	-
Abbreviations: EE, energy expenditure; HR, heart rate; HRmax%, percentage of maximum heart rate; MET, metabolic equivalent of task; RPE, rating of perceived exertion						

2.6 Correlation of Heart Rate Responses and Rating of Perceived Exertion Methods during Physical Activity

HR is the common outcome measure used in evaluating the exercise intensity during any physical activity (Levine 2008). It can be an indicator of the cardiovascular system's challenge that the exercise represents. Furthermore, when compared to other indicators of exercise intensity, HR is relatively simple to monitor, inexpensive, and applicable in most situations. HRMs have evolved and become a popular training companion for a variety of sports activities over the last two decades (Achten and Jeukendrup 2003). HRMs have an electrocardiogram (ECG) transmitter that sends signals to the receiver which calculates average HR within 5 to 15 seconds interval and displays it as beats per minute (Karvonen and Vuorimaa 1988). Although HRMs are more expensive than pedometers and accelerometers, data collected from HRMs can be transmitted to a computer and used to estimate EE and physical activity in observational and intervention studies.

Borg's RPE, on the other hand, is a well-established psychophysical assessment tool for measuring the subjective perception of effort during any physical activity. Borg's RPE is a low-cost, practical, and reliable tool for measuring and prescribing exercise intensity. Scherr et al's study (Scherr et al. 2013) investigated the relationship between Borg's RPE and physiological exercise parameters in a large population and discovered that factors such as gender, age, coronary artery disease (CAD), physical activity status, and exercise testing modality had no significant influence on RPE values (all $p>0.05$). Furthermore, RPE has been shown to be highly correlated with HR. ($r = 0.74$, $p < 0.001$).

In a study, a relationship between session HR based match load (HR-based ML) and RPE based match load (RPE-based ML) during WB games among trained WB players was determined. The study shows that the RPE-based ML methods could be used as an indicator of global internal match load in highly trained WB players. The method was relatively cost-effective and a practical tool where any coach could administer as long as that the players had been familiarized with the RPE scale (Iturricastillo et al. 2016). Similarly, an earlier study that investigated the correlation between HR and RPE in 193 children and 188 adults during submaximal cycle ergometry demonstrated that the RPE scale can be used to properly monitor changes in exercise intensity since each subject reported increases in RPE as exercise intensity increased over several powers (Gillach et al. 1989). Also, the study indicated that the type of statistical method of calculating correlations for each subject and then generating a group mean produced high correlations because as power and HR increase, RPE also increases (Figure 2.8).

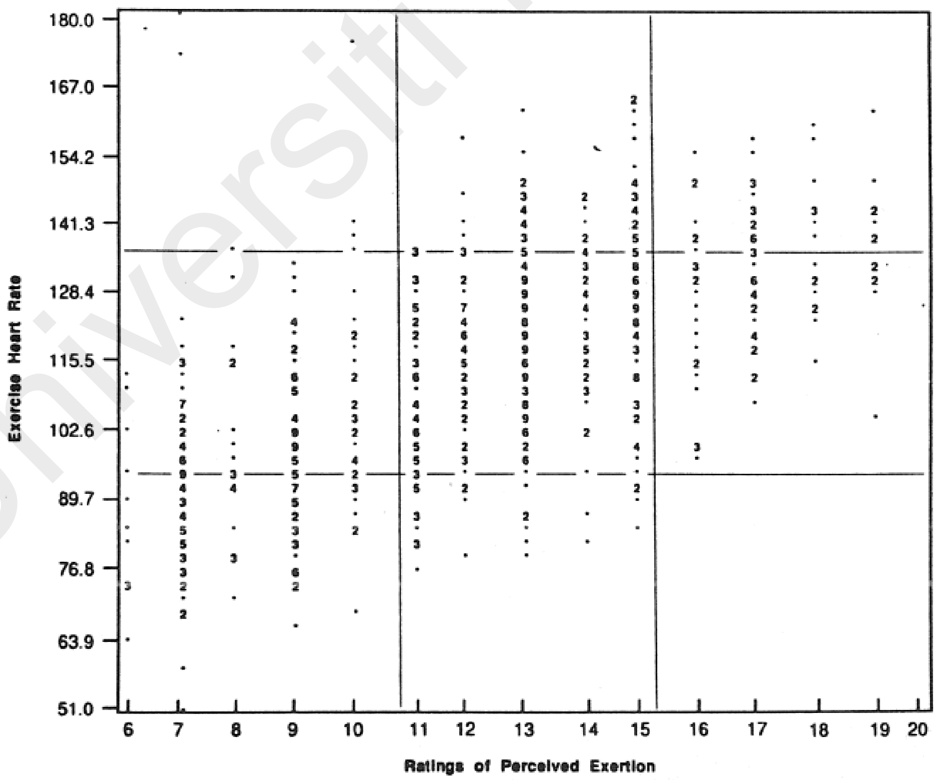

Figure 2.8: Relationship between heart rate and rating of perceived exertion in adults and children during cycle ergometry. Adapted from Gillach et al., 1989 (Gillach et al. 1989)

Researchers used real-time HR data to control an interactive biathlon game and design a fitness exergame in which users can perform various boxercise movements at high, moderate, and low intensity levels in exergaming studies (Masuko and Hoshino 2006, Nenonen et al. 2007). The results of the boxing fitness game revealed that HR elevations above the targeted HR zones were effective in increasing players' sense of accomplishment (Masuko and Hoshino 2006). Such HR-RPE correlations have never been observed in exergaming studies, to the best of the author's knowledge. Many previous studies may have overestimated the associations between RPE and physiological strain (HR), and using the RPE 0-10 scale to estimate HR may be misleading. However, the use of RPE is a more flexible approach for tracking changes in exercise intensity within a session that does not necessitate the use of HR monitoring gadgets that may be uncomfortable for users to wear when participating in moderate-vigorous exergaming. As a result, research is required to validate the HR-RPE correlations in order to develop a formula to estimate HR based on RPE.

2.7 Summary

During the past years, academic researchers have become increasing interested in exergaming. Most studies aiming to produce new evidence on how exergaming can increase the level of physical activity across various populations by utilising both physiological and psychological measurements. Although psychological measurements such as subjective's perception of participant, liking and motivation during traditional exercises are shown to have strong association with physiological measures such as HR, EE, METs, and VO_2, the validity and reliability to use psychological measurements only to monitor exercise intensity in exergaming studies have never been discussed. Such validations is therefore greatly needed to allow the use of psychological measurements only to estimate physiological responses such as HR in a faster and reliable way in a case of where the use of HRM gadgets are not recommended or in a home-based setting training program without the need~~s~~ of supervision. In order to design a practical approach to self-monitor exercise intensity during exergaming studies, relevant studies are carried out by using research methods, presented in the following research methodology section.

CHAPTER 3: METHODOLOGY

Chapter 3 contains the methodology of the current study. The chapter presents the study design, selection of participants including inclusion and exclusion criteria as well as how the sample size was determined, equipment and the modality of choices to conduct the experiment, experimental procedures, and data analysis method used in the study. This chapter also describes the ethical measures taken for the study.

3.1 Study Design

This observational cross-sectional study was conducted in the laboratory setting of Universiti Malaya, Kuala Lumpur and two rehabilitation centres and one support organization from central, northen, and east coast regions of West Malaysia. The study population included able-bodied individuals aged 18 years and older, who lives in the urban area and wheelchair users registered under *Pusat Latihan Perindustrian dan Pemulihan Orang Kurang Upaya (PLPP),* Bangi, the Department of Rehabilitation, Hospital Sultanah Bahiyah, Kedah, and from *Persatuan Spinal Pantai Timur (PSPT)* respectively.

From advertisement and collaboration with the respective rehabilitation centres and support organization, the eligible young adults, both able-bodied and wheelchair users, were contacted and were informed of the research objectives. Those who agreed to participate signed the informed consent form, underwent a face-to-face interview to obtain anthropometric measurements and health informations, and participated in one to two exergaming sessions.

The main data collection were conducted between August 2019 and June 2020, including two months of recruitment periods. The study design was summarised in a flowchart as shown in Figure 3.1.

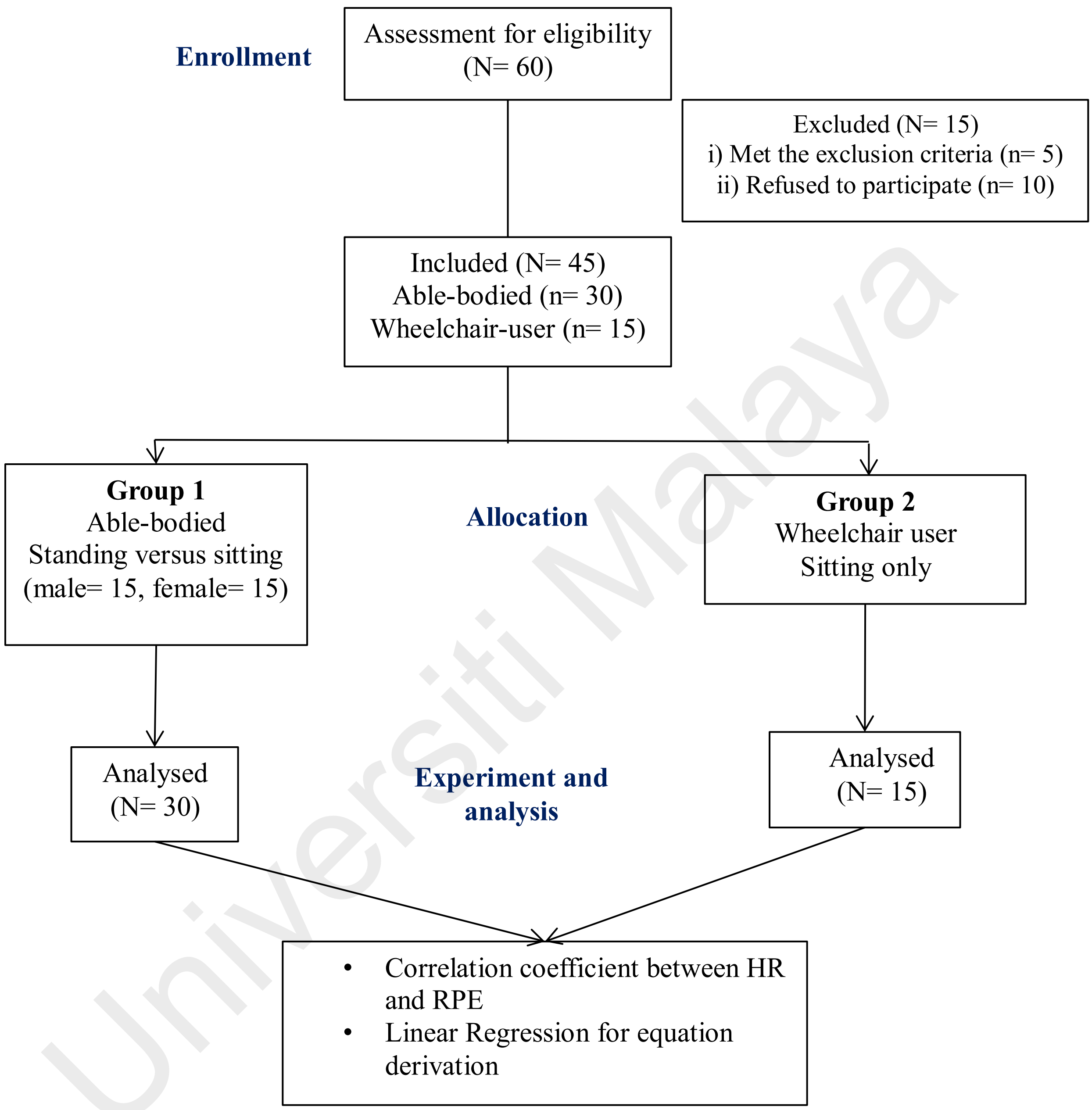

Figure 3.1: Flowchart of study design

3.2 Participants

The sample size was determined based on cohen formulation, on the primary outcomes (HR and both types of RPE responses within 10 minutes) to achieve 80% power, significance criterion, $\alpha = 0.05$, an effect size of 0.25 and 0.35 respectively (large) and within a large sample size populations (population proportion= 0.5 and 0.6) (Cohen 1992). From a total of 60 participants who were assessed for eligibility, 45 participants, consisting of 30 able-bodied adults and fifteen wheelchair-user adults were included for the study.

The methods of selection of participants were convenience. Able-bodied participants were selected based on the inclusion and exclusion criterias in Table 3.1. Wheelchair-user participants were included if they have sufficient upper extremity mobility for upper body exercise. Those who were included were mostly SCI (paraplegia) and the rest were spina bifida, poliomyelitis, amputee, and cerebral palsy. The inclusion and exclusion criterias for wheelchair-user participants were described in Table 3.2.

The exclusion criterias were assessed by utilising American Heart Association (AHA)-ACSM Health/Fitness Facility Preparticipation Screening Questionnaire (Balady et al. 1998) and the tests were performed by certified physician, Dr Maziah Binti Mat Rosly (MBBS). She underwent her medical training at the University of Malaya Medical Center and received her Ph.D degree in exergaming for individuals with spinal cord injury.

Table 3.1: Inclusion and exclusion criteria for the selection of able-bodied participants

Inclusion criteria	Exclusion criteria
✓ Aged between 18 to 60 years old ✓ No history of heart attack, heart surgery, heart transplant, severe lung diseases, uncontrolled diabetes, stroke, muscloskeletal problems, or asthma. ✓ Able to speak, write, and read either Malay or English	✓ Body mass index ≥ 50 ✓ Cognitive impairment precluding self-direct daily activities ✓ Current or planned pregnancy ✓ Heavy smoker

Table 3.2: Inclusion and exclusion criteria for the selection of wheelchair-user participants

Inclusion criteria	Exclusion criteria
✓ Aged between 18 to 60 years old ✓ No history of heart attack, heart surgery, heart transplant, severe lung diseases, uncontrolled diabetes, stroke, muscloskeletal problems, or asthma. ✓ Able to speak, write, and read either Malay or English ✓ permanent mobility impairment for ≥ 6 months that necessitated manual wheelchair use outside of the home ✓ sufficient upper extremity mobility for upper body exercise ✓ physician consent to exercise	✓ Body mass index ≥ 50 ✓ Cognitive impairment precluding self-direct daily activities ✓ Current or planned pregnancy ✓ Heavy smoker ✓ Has medical conditions their physician identified as contraindicated for unsupervised exercise (i.e., certain cardiac problems, and chronic obstructive pulmonary disease ✓ Under prescription of beta-blockers

3.3 Research Ethics

The research proposal containing the research purposes, experimental procedure, possible risks to the participants, recruitment of participants, consent from the participants, confidentiality for the participants, and data handling, was submitted and approved by the Universiti Malaya Research Ethics Committee (UMREC) (UM.TNC2/UMREC – 579) (APPENDIX A).

The consent form contains the following information (APPENDIX B);

1. An explanation of the purposes of the study, the expected duration of participation, experimental procedures, foreseeable risks, and potential benefits.
2. Participants' personal information such as name, personal or guardian's (for participants below 18 years old) contact number
3. A statement of confidentiality of records and consent for any medias publication
4. A statement of voluntariness from the participants

All participants were asked to sign the consent form before participating in the study.

3.4 Anthropometric Measurements

After the completion of recruitment, physical characteristics including age, weight, and height of each able-bodied participant was collected (Table 3.3). Due to position difficulties for obtaining the physical measurements of wheelchair-user participants, their demographic data including age, height, and weight were obtained through a self-report method or from their respective physiologists. The body mass index, BMI for all participants were calculated by the following equation.

$$BMI, kgm^{-2} = \frac{Body\ mass\ (kg)}{[Height\ (m)]^2} \tag{3.1}$$

Table 3.3: Physical characteristics of able-bodied participants

Participant	Gender	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m^2)
1	M	23	63.0	177	20.11
2	M	23	66.0	167	23.67
3	M	23	64.0	165	23.51
4	M	25	67.0	163	25.22
5	M	23	62.0	165	22.77
6	M	26	65.0	158	26.04
7	M	26	51.0	166	18.51
8	M	36	79.0	173	26.40
9	M	24	55.0	165	20.20
10	M	30	91.0	176	29.38
11	M	18	52.0	170	17.99
12	M	24	90.0	170	31.14
13	M	24	100.0	166	36.29
14	M	25	62.0	175	20.24
15	M	25	76.0	185	22.21
16	F	25	87.0	157	35.30
17	F	25	57.0	150	25.33
18	F	29	51.7	164	19.22
19	F	29	47.0	144	22.67

Table 3.1, continued

Participant	Gender	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m^2)
20	F	25	51.0	151	22.37
21	F	28	63.0	160	24.61
22	F	24	53.0	152	22.94
23	F	23	62.0	142	30.75
24	F	25	45.0	150	20.00
25	F	25	48.0	150	21.33
26	F	25	82.0	154	34.58
27	F	24	53.0	154	22.35
28	F	25	46.0	156	18.90
29	F	23	52.0	157	21.10
30	F	23	63.0	162	24.01
Abbreviations: M, male; F, female; BMI, body mass index					

Table 3.4: Physical characteristics of wheelchair-user participants

Participant	Gender	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m^2)
1	M	21	30.0	142	14.88
2	M	21	44.7	157	18.13
3	M	28	96.7	174	31.94
4	M	22	114.0	174	37.65
5	M	24	53.7	161	20.72
6	M	29	50.0	170	17.30
7	M	22	49.0	170	16.96
8	M	44	58.2	130	34.44
9	M	25	76.0	162	28.96
10	M	33	80.0	165	29.38
11	M	45	85.0	170	29.41
12	M	56	68.0	167	24.38
13	M	30	87.0	170	30.10
14	M	27	48.0	158	19.23
15	M	28	90.0	176	29.05
Abbreviations: M, Male; F, female; BMI, body mass index					

3.5 Study Setting

Exergaming sessions for the able-bodied and wheelchair-user participants were conducted separately at the Center for Prosthetic and Orthotic Engineering (CPOE), Universiti Malaya, and the respective rehabilitation centers (i.e., PLPP, Kedah, PSPT). The room areas used to conduct the study were measured about 4 m by 4 m.

The distance between participants and the 40-inch screen was also fixed at 150 cm. This distance is estimated according to the terrestrial magnetic field sensor of the PlayStation Move feature to be best set 150 to 213 cm from the player (Parry et al. 2014, Oh et al. 2017). A standard size metal chair with the dimensions as follows: height, 75cm; width, 37cm, was used.

The game was set to a moderate level, and the avatar for all participants was fixed to ensure the standardization of the game challenge between all participants (O'Donovan and Hussey 2012). Games were set in continuous loops for 10 minutes duration to ensure the achievement of steady-state. This period is sufficient to demonstrate a steady-state in adults (Kafri et al. 2014, Mat Rosly et al. 2017).

3.6 Equipment and Materials

The Sony PlayStation 3® console, along with its Move controllers and Sony Eye Camera were selected as the hardware platform for the study. To make sure participants experienced the moderate-vigorous exergaming, Move Boxing was selected as the modality of choice for the study.

Move Boxing sessions and the collection of physiological responses while playing the game were conducted using the following types of equipment, and their descriptions were elaborated in Table 3.5. Features and technical specifications of the Sony PlayStation 3® console are as shown in Appendix D. Also, the technical specifications of the Polar HR monitor (RS400) and the Polar chest strap's care and maintenance are as shown in Appendix E and F respectively.

Due to the high reliability and validity for monitoring and prescribing exercise intensity for a variety of population (r = 0.47-0.95, good to excellent correlation with HR) except for stroke, both original Borg's scale and modified RPE scale were utilised in this study (Gillach et al. 1989, Chen et al. 2002, Groslambert and Mahon 2006, Scherr et al. 2013). Detailed and standardised instructions were given to each participant regarding both type of RPE scales before participating in exergaming sessions.

Table 3.5: Lists of equipment used to conduct the study.

Types of equipment	Descriptions
 **Figure 3.2: PlayStation 3 (PS3) console**	PlayStation 3 (PS3) console was the hardware used to conduct the Move Boxing. A HDMI and a power cable were required to connect the console to the LED screen.
 **Figure 3.3: Two Move motion controllers**	Two Move motion controllers were required to play Move Boxing.

Table 3.4, continued

Types of equipment	Descriptions
 **Figure 3.4: The Sony Eye camera**	Sony Eye Camera was attached and calibrated to the PS3 console to detect the motion made while playing.
 **Figure 3.5: The Sports Champion 2®**	Sports Champion 2® software (Sony Interactive Entertainment, Inc.) was used to run the Move Boxing.
 **Figure 3.6: A 40-inch LED screen**	A 40-inch high-definition light-emitting diode (LED) television (Panasonic Viera LED TV, TH-40CS620, Malaysia) was utilised to project the game.
 **Figure 3.7: Polar HR monitor (RS400) (right) with its Polar chest strap (left)**	Polar Heart Rate (HR) monitor (RS400, Polar Electro, Kempele, Finland), along with its Polar chest strap (WearLink + transmitter) were utilised to continuously measure the participant's heart rate during resting and exergaming sessions.

Table 3.4, continued

<table>
<tr><th>Types of equipment</th><th>Descriptions</th></tr>
<tr><td>
<table>
<tr><th>Perceived</th><th>Description</th></tr>
<tr><td>0</td><td>Nothing at all</td></tr>
<tr><td>0.5</td><td>Extremely weak</td></tr>
<tr><td>1</td><td>Very weak</td></tr>
<tr><td>2</td><td>Weak (light)</td></tr>
<tr><td>3</td><td>Moderate</td></tr>
<tr><td>4</td><td>Somewhat Strong</td></tr>
<tr><td>5</td><td>Strong (Heavy)</td></tr>
<tr><td>6</td><td></td></tr>
<tr><td>7</td><td>Very Strong</td></tr>
<tr><td>8</td><td></td></tr>
<tr><td>9</td><td></td></tr>
<tr><td>10</td><td>Extremely Strong</td></tr>
<tr><td>*</td><td>Maximal</td></tr>
</table>
Figure 3.8: The modified RPE (1-10)
</td><td rowspan="2">Both modified RPE (1-10) and the original Borg's RPE (6-20) were utilised to measure the participant's subjective perception of effort during exergaming</td></tr>
<tr><td>
<table>
<tr><th>Rating</th><th>Perceived Exertion</th></tr>
<tr><td>6</td><td>No exertion</td></tr>
<tr><td>7</td><td>Extremely light</td></tr>
<tr><td>8</td><td></td></tr>
<tr><td>9</td><td>Very light</td></tr>
<tr><td>10</td><td></td></tr>
<tr><td>11</td><td>Light</td></tr>
<tr><td>12</td><td></td></tr>
<tr><td>13</td><td>Somewhat hard</td></tr>
<tr><td>14</td><td></td></tr>
<tr><td>15</td><td>Hard</td></tr>
<tr><td>16</td><td></td></tr>
<tr><td>17</td><td>Very hard</td></tr>
<tr><td>18</td><td></td></tr>
<tr><td>19</td><td>Extremely hard</td></tr>
<tr><td>20</td><td>Maximal exertion</td></tr>
</table>
Figure 3.9: The original Borg's RPE (6-20)
</td></tr>
</table>

3.7 Data Collection

All participants were constrained from eating for 2 hours and consuming caffeine for 12 hours before each exergaming session. The exergaming process for able-bodied and wheelchair-user participants were conducted according to Testing Procedure I and II, respectively.

3.7.1 Testing Procedure

A. TESTING PROCEDURE (I) FOR ABLE-BODIED PARTICIPANT

1. Upon arrival at the testing venue, each participant was briefed about the study and asked to sign the consent form.
2. The physical characteristics (i.e., weight and height) of each participant were measured and presented in Table 3.2.
3. After that, each participant was given about 10 to 15 minutes to get familiarized and practice with Move controllers and Move Boxing. Demonstrations on how to play and win the game were also provided during this time.
4. After confirming that the participant was comfortable with the system, the participant was asked to rest quietly in a sitting position with eyes closed for about 15 minutes to obtain the resting heart rate.
5. Then, the participant was asked to perform Move Boxing in a sitting position (Figure 3.10 (A)) for 10 minutes and was allowed to make any movement or strategies they wish while playing. Upon completion of 10 minutes exergaming in the sitting position, the participant was asked to rate their effort by pointing at the related number on the copy of the modified RPE (1-10) and the original Borg's RPE (6-20).

6. In the next testing session, with at least 1 and not more than 3 days gap, the participant was asked to perform the equivalent game in a standing position (Figure 3.10 (B)) (recommended position by the manufacturers) for 10 minutes.
7. Upon completion of the 10 minutes exergaming, the participant was again asked to rate their effort using both the modified RPE (1-10) and the original Borg's RPE (6-20).
8. The incoming participants were asked to follow the same testing procedures as above.

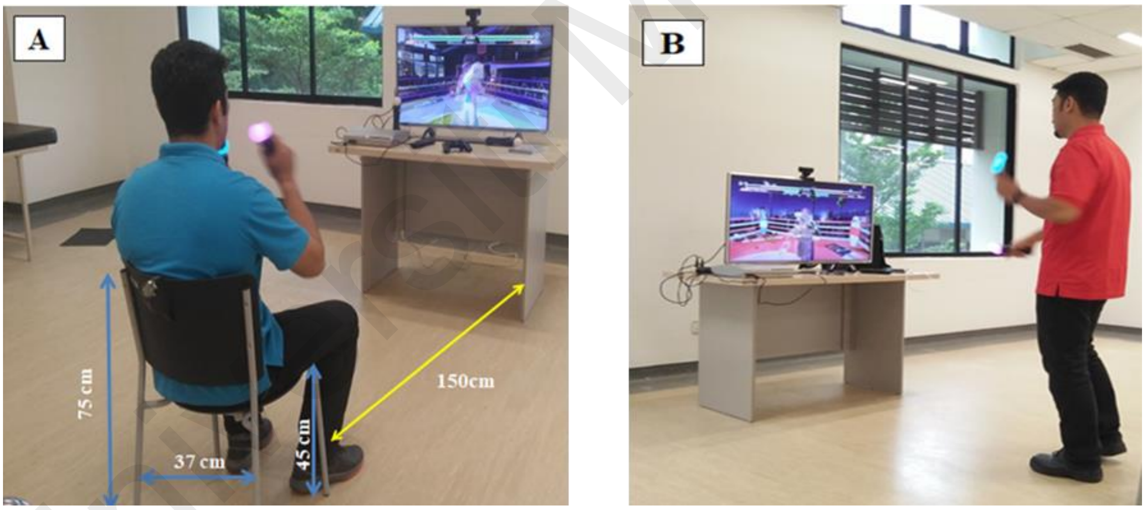

Figure 3.10: Exergaming boxing were performed in a (A) sitting and (B) standing position by an able-bodied participant

Figure 3.11: Exergaming boxing was performed in a sitting position by a wheelchair-user participant

B. TESTING PROCEDURE (II) FOR WHEELCHAIR-USER PARTICIPANTS

1. Steps 1 until 5 in the testing procedure (I) were repeated for each wheelchair-user participant.
2. Then, each participant was asked to perform Move Boxing while sitting on a wheelchair for 10 minutes. The wheelchair was locked and being held from behind by the researcher/volunteers to maintain the player's stability as shown in Figure 3.11.
3. Upon the completion of 10 minutes exergaming session, the participant was asked to rate their effort while playing using both modified RPE (1-10) and the original Borg's RPE (6-20).
4. The incoming participants were asked to follow the same testing procedures as above.

3.8 Variables

The dependent variables of this study were HR responses, recorded continuously at 30 seconds interval within the 10 minutes exergaming sessions and the RPE scores, rated by participants at the end of each session. Independent variables include the body positions of player during gameplay, disability, age and BMI.

3.9 Data Analysis

All data were expressed in mean (standard deviation (SD)), and the level of significance was set at $P \leq 0.05$. Exercise intensity during the 10 minutes sessions of exergaming was characterised by the percentage of maximal heart rate (HR_{max}%) and RPE. All statistical analyses were performed using SPSS for Windows 10 (Version 25.0, IBM SPSS). The analyses used to analyse the data were illustrated in Figure 3.12 and elaborated in the following sub-chapters (i.e., 3.91, 3.92 and 3.93)

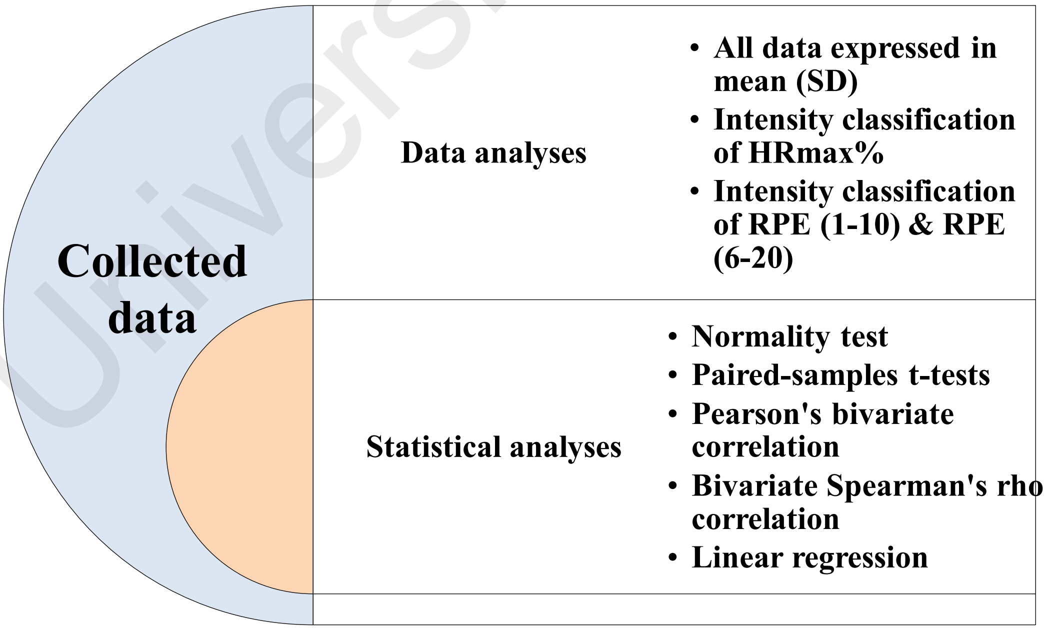

Figure 3.12: Data and statistical analyses used in the study

3.9.1 Percentage of Maximum Heart Rate (HR_{max}%)

The maximum HR (HR_{max}) of each participant was calculated by using Tanaka's formula (Tanaka et al. 2001) (3.2) based on their age. HR_{max} was required in order to calculate the percentage of maximum HR (HR_{max}%) achieved during 10 minutes sessions of exergaming as shown in Equation 3.3.

The individual's HR_{max}% was classified by the following intensity ranges established by ACSM (Garber et al. 2011): light (< 64%), moderate (64%-76%), vigorous (76-95%), near-maximal to maximal (≥ 96). Intensities were also categorised ordinally such as follows: 1= light, 2= moderate, and vigorous= 3.

$$HR_{\mathrm{max}=208-(0.7\times age)} \qquad (3.2)$$

$$HR_{max}\% = \frac{HR_{(while\ playing)}}{HR_{max}} \times 100\% \qquad (3.3)$$

3.9.2 Rating of Perceived Exertion (RPE)

Both individual's modified RPE (1-10) and the original Borg's RPE (6-20) values were also classified by the following intensity ranges; RPE (1-10); light (1-2), moderate (3-4.5), and vigorous (≥ 5) and RPE (6-20); light (9-11), moderate (12-13), vigorous (≥ 14). Intensities were categorised ordinally such as follows: 1= light, 2= moderate, and vigorous= 3.

3.9.3 Statistical Analysis

The data were analysed for normality using the Shapiro-Wilk test and visual inspection of the Q-Q plot. Data meet assumptions of normality with Shapiro Wilk $P > 0.05$ and an almost linear plotting of the Q-Q regression line. Assumptions 1) the dependent data which are HR responses and RPE were continuous data and 2) the differences between both dependent data were normally distributed, were meet to used paired-samples t-tests for assessing differences in HR and RPE responses based on positions during gameplay (i.e., sitting and standing).

The validity of HR-RPE correlation for both types of RPE scales was assessed with several test, 1) Pearson's bivariate correlation for continuous data 2) Spearman's rank correlation coefficient for ordinal data 3) linear regression models were fitted to predict HR as a) a function of RPE and other covariates and b) to estimate the percent variability (R^2) of HR. The covariates included in the model were age and BMI. All assessment methods utilized two-tailed significant testing.

The strength of the correlations were rated poor if $r < 0.3$, acceptable if $r = 0.3$-0.49, good if $r = 0.5$-0.79 and excellent if ≥ 0.8 (Cohen 2013). For r^2 variances, the strengths were rated $r^2 = 0.26$ (substantial), $r^2 = 0.13$ (moderate) and $r^2 = 0.02$ (weak) (Cohen 1988). A formula for estimating HR based on the available RPE was then derived from the linear regression equations.

CHAPTER 4: RESULTS AND DISCUSSIONS

This chapter consists of two subsections which are 4.1) Results and 4.2) Discussions. Section 4.1 presents the important findings of the study including the results of Shapiro-Wilk test, physical characteristics, HR and RPE responses, and HR-RPE correlation coefficient.

Next, section 4.2 presents the key findings and contribution of the study. The findings are discussed against the findings of previous exergaming studies and contributions for the scientific community and practitioners are presented. This section also discusses the limitations of the study and provides recommendations for future research.

4.1 Results

4.1.1 Shapiro-Wilk Test

The results of Shapiro-Wilk test and visual inspection of the Q-Q plot showed the data for HR and RPE in able-bodied and wheelchair-user participants were normally distributed.

The assumptions for normal distribution were meet in which the significant value of Shapiro-Wilk test is greater than 0.05 ($p > 0.05$) and almost linear plotting of the Q-Q regression lines as shown in Figure 4.1 and 4.2.

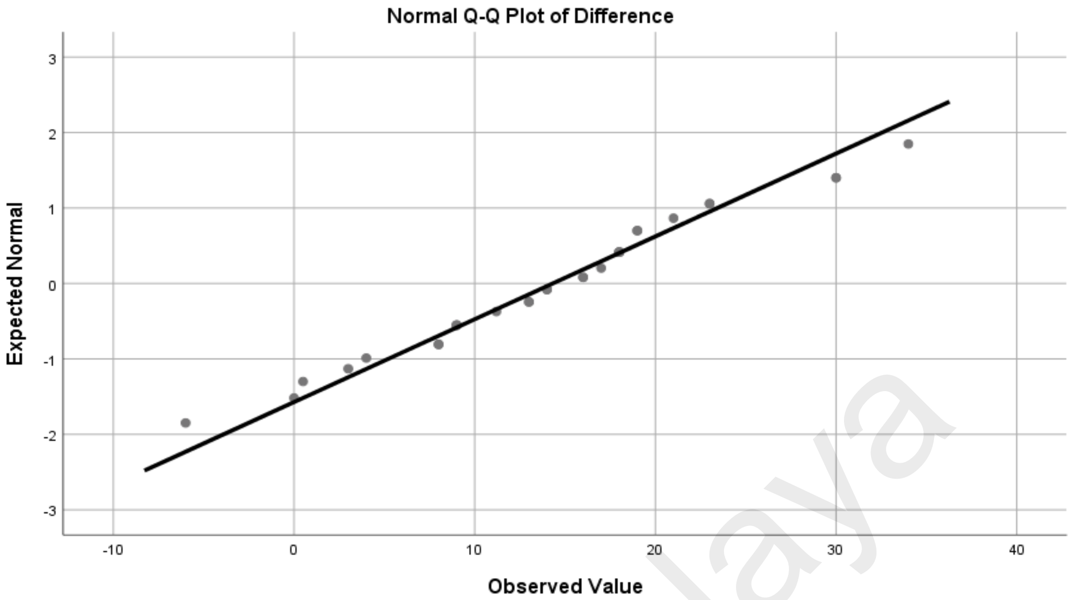

Figure 4.1: An almost linear plotting of Q-Q plot shows normally distributed data of HR and RPE for able-bodied

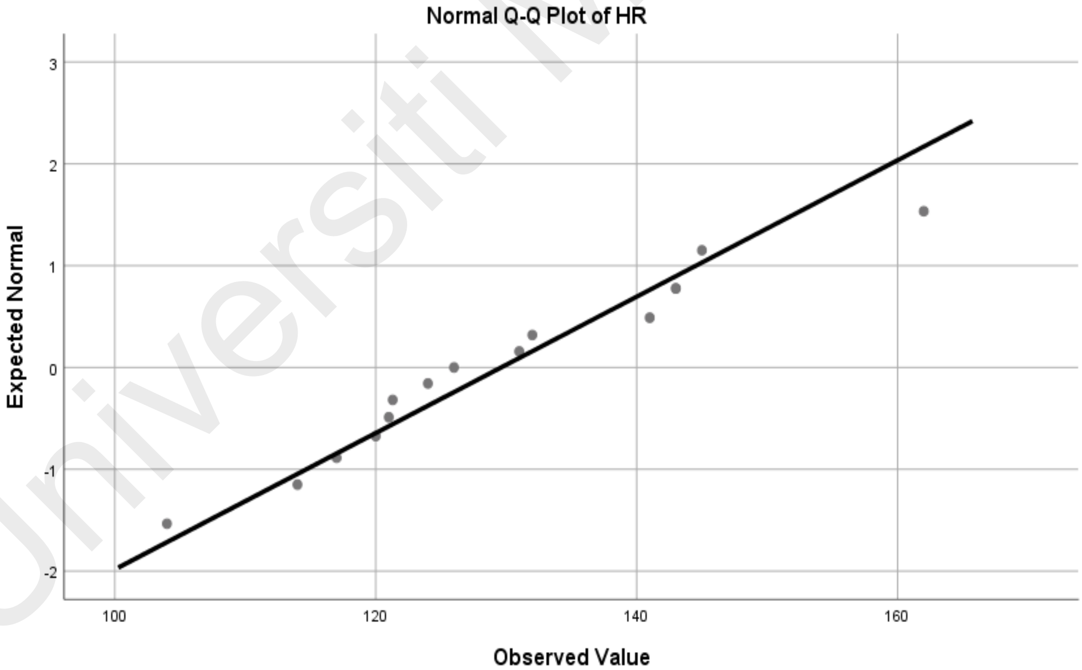

Figure 4.2: An almost linear plotting of Q-Q plot shows normally distributed data of HR and RPE for wheelchair-user participants

4.1.2 **Physical Characteristics of Participants**

Thirty able-bodied adults completed two sessions of Move Boxing that consists of 10 minutes playing in a sitting position and 10 minutes in the standing position without incidents. Both sessions were done separately with one day gap.

Also, fifteen wheelchair-user adults completed a session of Move Boxing while being seated in their wheelchair for 10 minutes. Participants' physical characteristics, categorised into able-bodied males and females, and wheelchair-user were summarised in Table 4.1.

Table 4.1: Physical characteristics of all participants

Characteristics	**Able-bodied male (n = 15)**	**Able-bodied female (n = 15)**	**Wheelchair-user (n=15)**
Age (years)	25.00 (3.93)	25.20 (1.97)	30.30 (10.30)
Weight (kg)	69.53 (14.71)	57.38 (12.50)	68.69 (23.37)
Height (cm)	169.00 (7.00)	154.00 (6.00)	163.06 (12.60)
BMI (kg/m^2)	24.24 (5.05)	24.36 (5.17)	25.50 (7.15)
HR_{rest} (bpm)	80.47 (11.63)	82.53 (12.26)	94.80 (11.03)
$HR_{max.pred.}$ (bpm)	190.50 (2.75)	190.36 (1.38)	186.77 (7.18)

Data are mean (SD). $p \leq 0.05$ Significantly different between sexes and disabilities. Abbreviations: BMI, body mass index; HR_{rest}, resting heart rate; $HR_{max.pred.}$, predicted maximal heart rate; bpm beats per minute

4.1.3 Heart Rate Responses during Exergaming

Figure 4.3 showed the overall mean (SD) HR responses to 10 minutes sessions of playing Move Boxing in the sitting position was 116.46 (19.08) bpm (61% of percentage of HR_{max}), and 130.79 (23.18) bpm (69% of percentage of HR_{max}) in the standing position among 30 able-bodied participants. While playing in the sitting position, 11 of 30 participants had a mean HR response in the moderate- to vigorous-intensity range.

Standing position gameplay, on the other hand, reported 17 of 30 participants with a mean HR response in the moderate-to-vigorous-intensity range. The paired-sample t-test revealed that playing in the standing position resulted in a significantly higher mean (SD) HR response than playing in the sitting position, t = -8.611, p = 1.74E^{-9}.

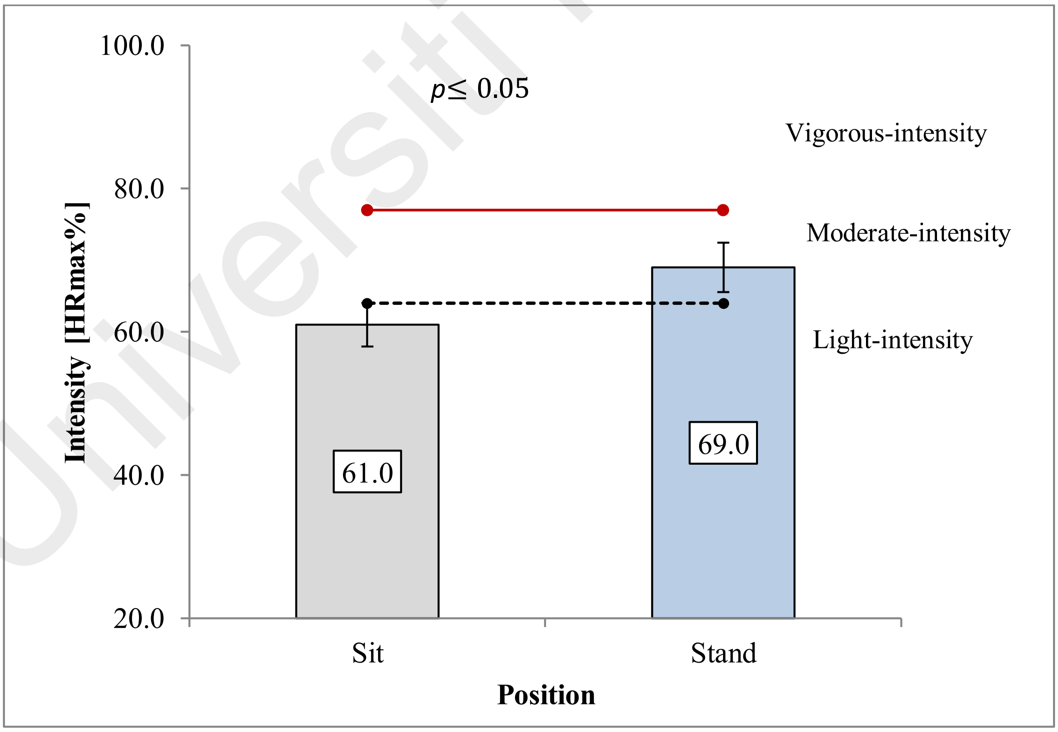

Figure 4.3: The overall mean (SD) HR responses (in sitting and standing position) and corresponding intensity classification based on HR_{max}% among the able-bodied adults

Figure 4.4 demonstrates the total mean HR responses of 30 able-bodied participants while playing Move Boxing in sitting and standing positions, respectively, when compared to the total mean HR responses of fifteen wheelchair-users playing Move Boxing while being seated in their wheelchairs. Wheelchair-user participants achieved the recommended moderate-intensity of 70% of percentage of HR_{max}, which is higher than those obtained by able-bodied while exergaming in both sitting and standing positions.

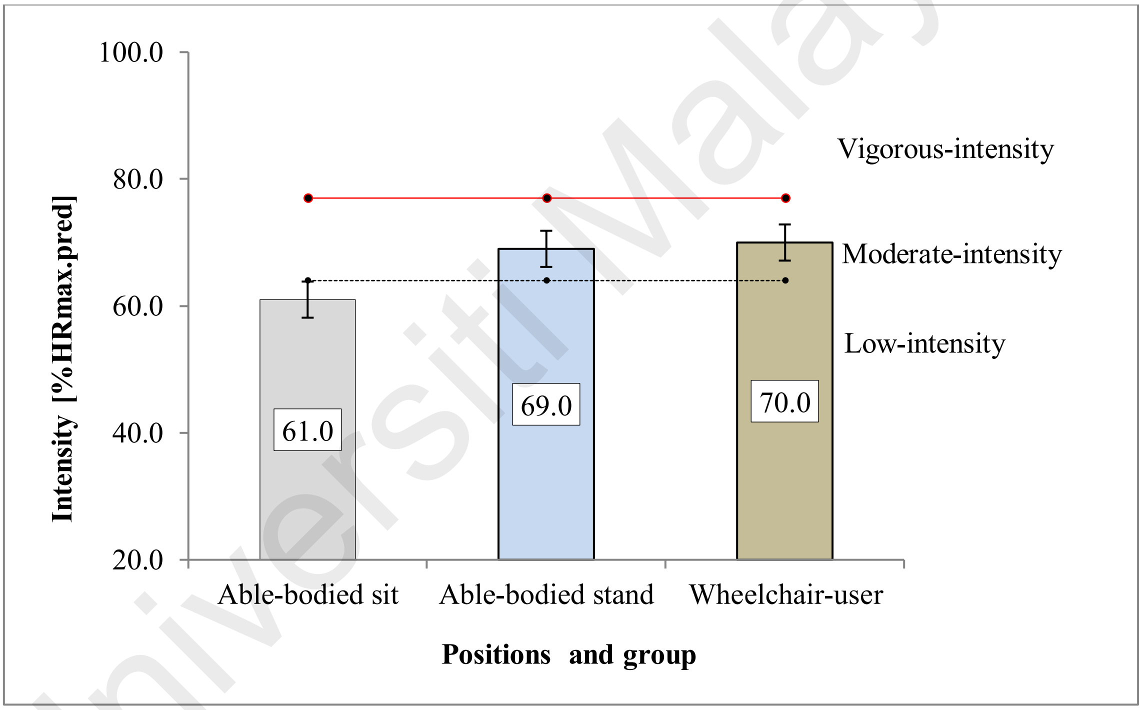

Figure 4.4: The overall mean (SD) HR responses in different positions and ability groups and corresponding intensity classification based on HR_{max}%

4.1.4 **Rating of Perceived Exertion Responses**

The mean (SD) scores for the modified RPE (1-10) for able-bodied participants during 10 minutes of playing Move Boxing in the sitting position was 4.0 (1.2), described as "somewhat strong" and within the moderate intensity. This value corresponded to the mean (SD) score for the original Borg's RPE scale (6-20) of 13.0 (2.1), described as "somewhat hard" and within the moderate intensity as well.

The mean (SD) scores of the modified RPE (1-10) for able-bodied participants during 10 minutes of playing Move Boxing in the standing position was 5.0 (2.3), described as "strong" and within the vigorous intensity.

The mean (SD) scores for original Borg's RPE (6-20) was 15.0 (2.8), described as "hard" and within the vigorous-intensity as well. Our findings showed that both modified RPE (1-10) and the original Borg's RPE (6-20) scores were in the moderate to vigorous-intensity for sitting and standing positions.

On the other hand, fifteen wheelchair-users reported the mean (SD) scores of modified RPE (1-10) of 3(0.8) which correlates to the mean (SD) of original Borg's RPE (6-20) of 13.3 (1.5). Both responses denoted the moderate-intensity levels and equivalent to those obtained by the able-bodied participants while playing in sitting positions.

The individual RPE scores for both original Borg and modified RPE scales during exergaming among able-bodied in sitting and standing positions and wheelchair-user participants in sitting positions were illustrated in Figure 4.5, 4.6, and 4.7 respectively.

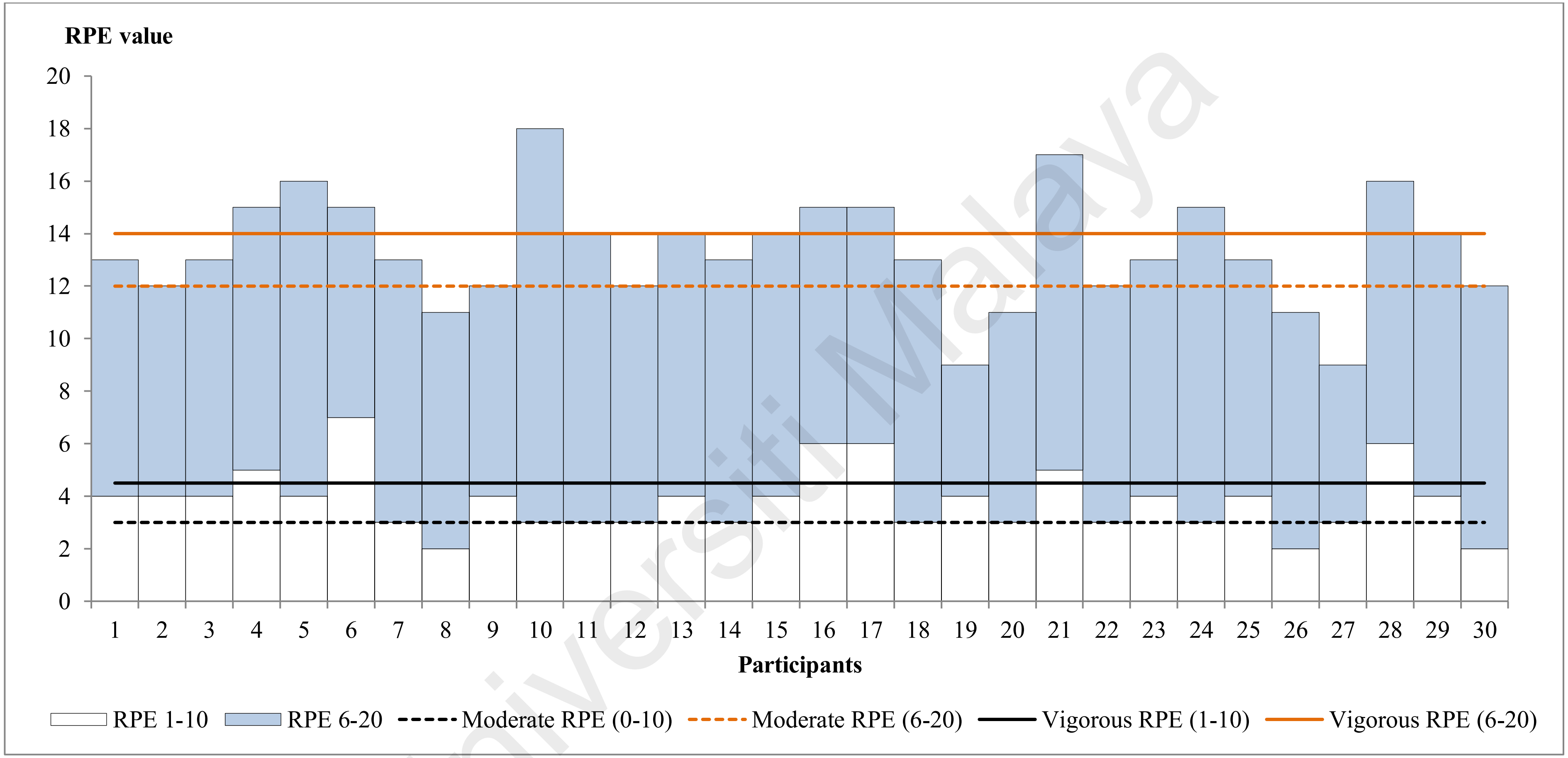

Figure 4.5: Individual RPE scores for both modified RPE scales (1-10) and the original Borg's scale (6-20) during exergaming (sitting position) among able-bodied participants.

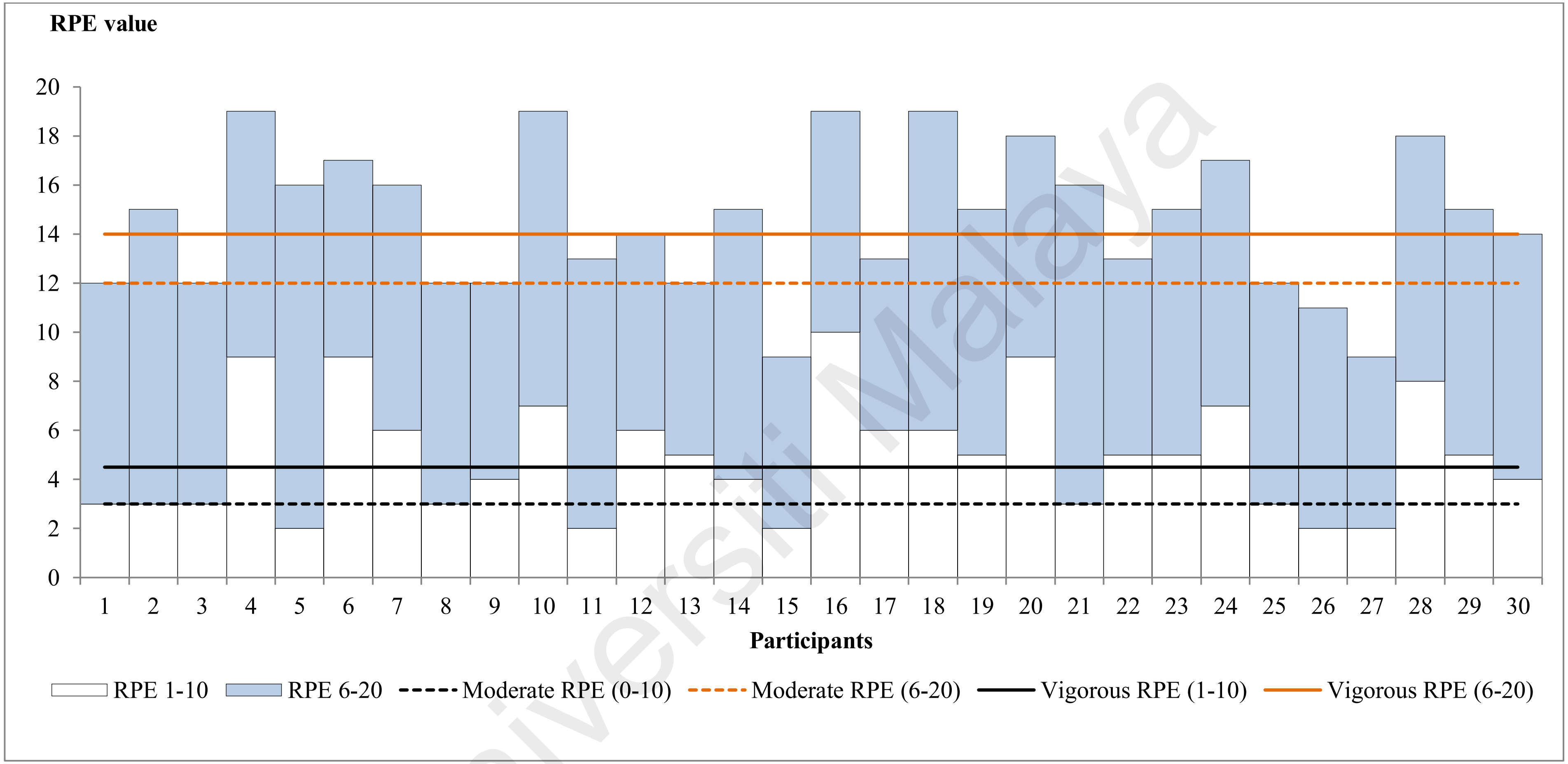

Figure 4.6: Individual RPE scores for both modified RPE scales (1-10) and the original Borg's scale (6-20) during exergaming (standing position) among able-bodied participants

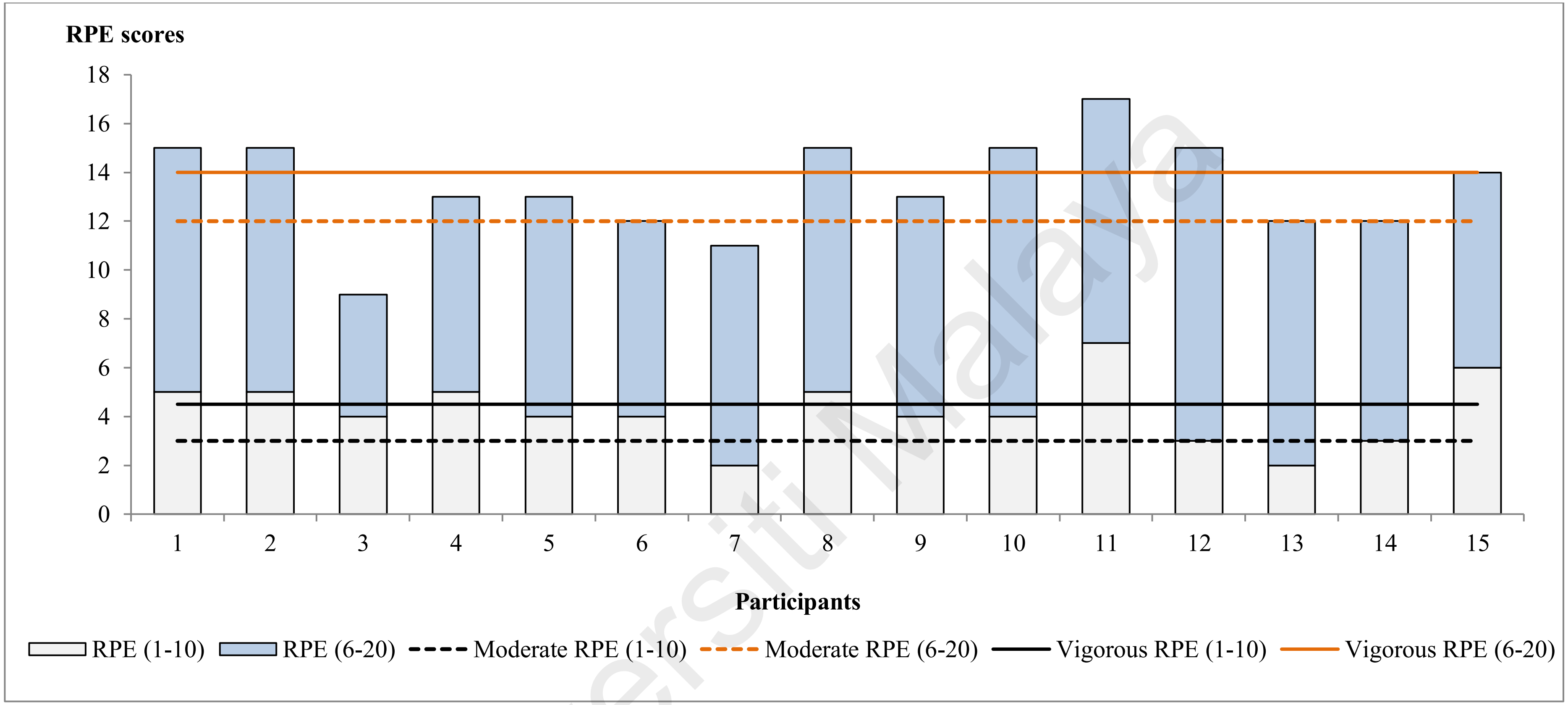

Figure 4.7: Individual RPE scores for both modified RPE scales (1-10) and the original Borg's scale (6-20) during exergaming in sitting position (on wheelchair) among wheelchair-user participants.

4.1.5 **The Correlation between Heart Rate and Rating of Perceived Exertion during Exergaming**

Pearson's correlation coefficients revealed significant ($P < 0.05$) findings with HR and RPE values while playing boxing exergaming in the standing position (Table 4.2). The correlation values are within acceptable to good ranges of between r = 0.48-0.77. Intensity classification between HR and the RPE reported also correlated well, as seen in Spearman's rho of r = 0.5-0.6 (Table 4.3). The linear regression analysis derived from significant values of Pearson's correlation revealed a regression model that can be fitted into an equation to predict HR from the reported RPE (Table 4.4).

However, HR and RPE values did not significantly correlate with each other during exergaming boxing in a sitting position. No significant correlations detected between HR or RPE with age in the sitting position (Table 4.2).

Table 4.2: Pearson correlation coefficient between heart rate and Borg's rating of perceived exertion among able-bodied

Position	Outcome measures (continuous data)	Correlation coefficient, r	P-value
Sitting	HR-RPE (6-20)	0.138	0.466
	HR-RPE (1-10)	0.222	0.239
	RPE(6-20)-RPE(1-10)	0.500	***0.005****
	HR-Age	-0.003	0.989
Standing	HR-RPE (6-20)	0.488	***0.006*****
	HR-RPE (1-10)	0.486	***0.006*****
	RPE(6-20)-RPE(1-10)	0.772	***0.000*****
	HR-Age	-0.054	0.776
*Correlation is significant at the P≤ 0.05 level **Correlation is significant at the P≤ 0.01 level			
HR: Heart rate; RPE: Rating of perceived exertion			

Table 4.3: Spearman's rho correlation coefficient between heart rate intensity classification and Borg's rating of perceived exertion intensity classification among able-bodied

Position	Outcome measures (ordinal data)	Correlation coefficient, r	P-value
Sitting	HR-RPE (6-20)	0.174	0.357
	HR-RPE (1-10)	0.223	0.237
	RPE(6-20)-RPE(1-10)	0.621	***0.000***
	HR-Age	0.246	0.189
Standing	HR-RPE (6-20)	0.507	***0.004***
	HR-RPE (1-10)	0.532	***0.002***
	RPE(6-20)-RPE(1-10)	0.597	***0.000***
	HR-Age	0.207	0.271
*Correlation is significant at the P≤0.05 level **Correlation is significant at the P≤0.01 level			
HR: Heart rate; RPE: Rating of perceived exertion			

Table 4.4: Linear regression analyses of heart rate and rating of perceived exertion model during exergaming boxing in a standing position among able-bodied

Regression Model	R^2 value	Correlation coefficients		P value	95% Confidence interval	
					Lower limit	Upper limit
HR-RPE (6-20)	0.238	Unstandardized B				
		constant	73.912	0.001	33.778	114.046
		RPE(6-20)	3.905	***0.006***	1.201	6.609
HR-RPE (1-10)	0.236	Unstandardized B				
		constant	107.535	0.000	89.616	125.453
		RPE(1-10)	4.714	***0.006***	1.435	7.993
HR-RPE(6-20)-RPE(1-10)	0.268	Unstandardized B				
		constant	85.357	0.001	39.381	131.333
		RPE(6-20)	2.228	0.304	-2.524^{γ}	7.784^{γ}
		RPE(1-10)	2.630	0.292	-2.027^{γ}	6.483^{γ}
**Correlation is significant at the P≤ 0.01 level γ95% confidence interval indicates no difference between types of RPE used						
HR: Heart rate; RPE: Rating of perceived exertion						

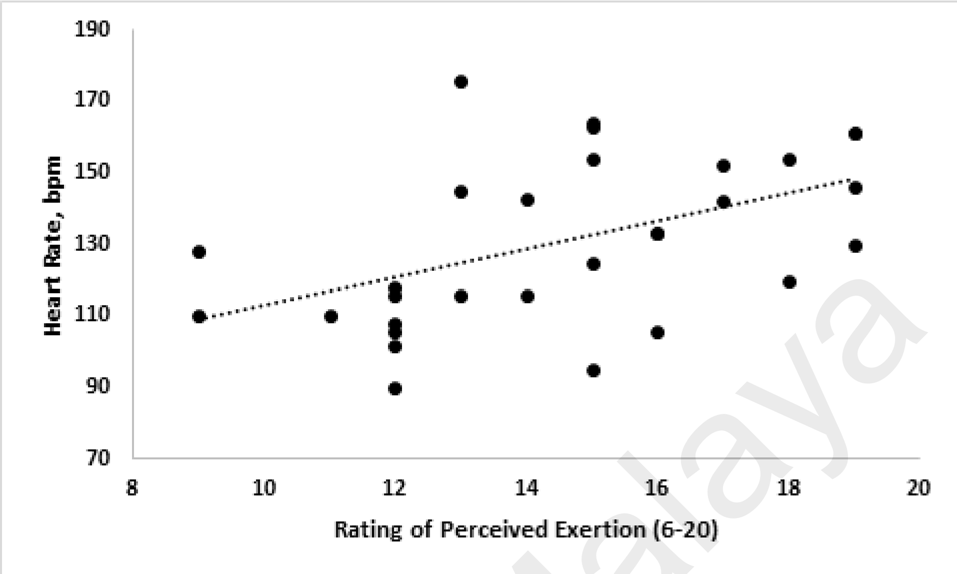

Figure 4.8: Scatter plot of HR and RPE scales (6-20) correlation with linear regression line during exergaming boxing (standing position) among able-bodied

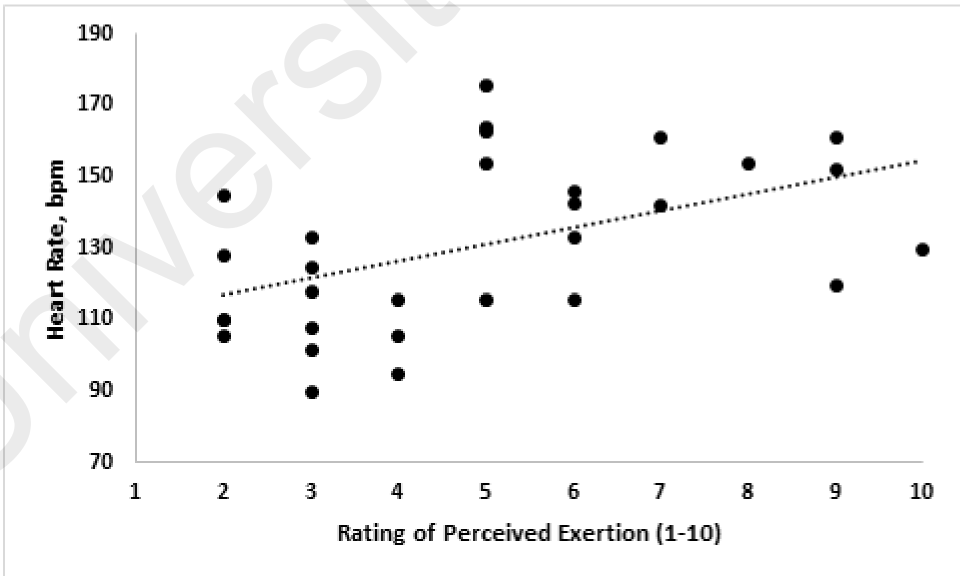

Figure 4.9: Scatter plot of HR and RPE scales (1-10) correlation with linear regression line during exergaming boxing (standing position) among able-bodied

Pearson's correlation coefficients revealed significant ($P < 0.05$) findings with HR and RPE values while wheelchair-users played boxing exergaming in their wheelchairs (Table 4.5). The correlation values are within good ranges of between r = 0.603-0.79 except for HR-age correlation which is relatively poor, r= 0.288 (Table 4.5). Intensity classification between HR and the original RPE (6-20) also correlated well, as seen in Spearman's rho of r = 0.5 (Table 4.6). However, the correlation between HR and the modified RPE (1-10) was found to be insignificant with (P= 0.076> 0.05).

The linear regression analysis derived from significant values of Pearson's correlation revealed a regression model that can be fitted into an equation to predict HR from the reported RPE (Table 4.7). Additionally, the HR was reported to be significantly correlated with BMI ($P < 0.05$), in this exergaming position (Table 4.5).

Table 4.5: Pearson correlation coefficient between heart rate and Borg's rating of perceived exertion among wheelchair-users

Position	Outcome measures (continuous data)	Correlation coefficient, r	P-value
Wheelchair -sitting	HR-RPE (6-20)	0.753	**0.01****
	HR-RPE (1-10)	0.619	0.014*
	RPE(6-20)-RPE(1-10)	0.790	***0.0005****
	HR-Age	0.288	0.298
	HR-BMI	0.603	0.017*
*Correlation is significant at the P≤ 0.05 level **Correlation is significant at the P≤ 0.01 level (2-tailed)			
HR: Heart rate; RPE: Rating of perceived exertion			

Table 4.6: Spearman's rho correlation coefficient between heart rate intensity classification and Borg's rating of perceived exertion intensity classification among wheelchair users

Position	Outcome measures (ordinal data)	Correlation coefficient, r	P-value
Wheelchair-sitting	HR-RPE (6-20)	0.671	0.006*
	HR-RPE (1-10)	0.472	0.076
	RPE(6-20)-RPE(1-10)	0.539	***0.038****
	HR-Age	0.526	0.044*
	HR-BMI	0.610	0.016*
*Correlation is significant at the P≤0.05 level **Correlation is significant at the P≤0.01 level			
HR: Heart rate; RPE: Rating of perceived exertion			

Table 4.7: Linear regression analyses of heart rate and rating of perceived exertion model during exergaming boxing of wheelchair-user (sitting position)

Regression Model	R^2 value	Correlation coefficients		P-value	95% Confidence interval Lower limit	95% Confidence interval Upper limit
HR-RPE (6-20)	0.567	Unstandardized B				
		constant	25.739	0.328	-28.953	80.432
		RPE(6-20)	7.714	0.01	3.675	11.753
HR-RPE (1-10)	0.190	Unstandardized B				
		constant	101.338	0.000	65.480	137.195
		RPE(1-10)	7.856	0.104	-1.867	17.579
HR-RPE(6-20)-RPE(1-10)	0.603	Unstandardized B				
		constant	22.214	0.400	-39.282	77.710
		RPE(6-20)	7.007	0.004	2.682 $^{\gamma}$	11.332 $^{\gamma}$
		RPE(1-10)	3.623	0.320	-3.989$^{\gamma}$	11.234$^{\gamma}$
**Correlation is significant at the P≤ 0.01 level γ95% confidence interval indicates no difference between types of RPE used						
HR: Heart rate; RPE: Rating of perceived exertion						

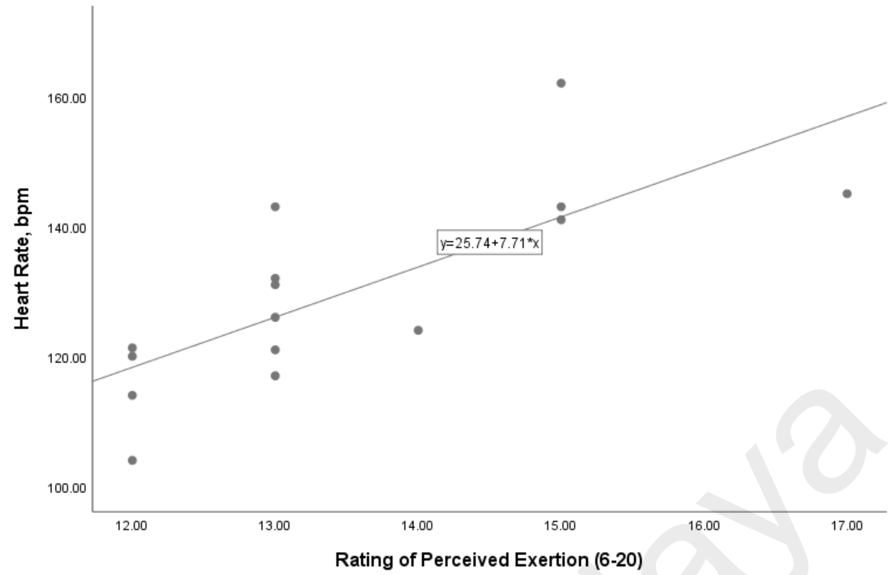

Figure 4.10: Scatter plot of HR and RPE scales (6-20) correlation with linear regression line during exergaming boxing of wheelchair-users (sitting)

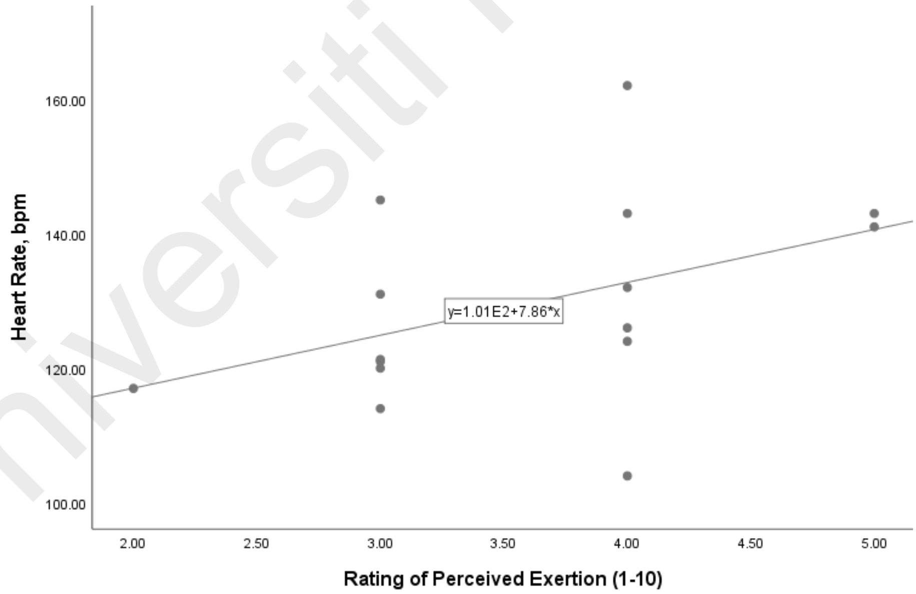

Figure 4.11: Scatter plot of HR and RPE scales (1-10) correlation with linear regression line during exergaming boxing of wheelchair-users (sitting)

4.2 Discussions

The study has successfully validated the correlations between HR and RPE coefficients based on the intensity classification when playing Move Boxing among able-bodied and wheelchair-user adults. To the best of our knowledge, this is the first study that has utilised Move Boxing to conduct exergaming in two different body positions, sitting and standing, and among different abilities/ disabilities. Apart from that, this is the first study to validate the HR-RPE correlations when able-bodied and wheelchair-user adults perform exergaming and the significant correlations are used to formulate a formula to estimate HR from the reported RPE only.

The findings indicate that able-bodied individuals playing Move Boxing in a standing position are more likely to raise the HR to the recommended exercise intensity for health benefits of moderate-intensity (>64% of $\%HR_{max}$) as prescribed by the ACSM exercise guidelines (Garber et al. 2011). Considering the health benefits, when a participant achieves the moderate-intensity range while playing Move Boxing, such activity results in the same benefits as those typically achieved while brisk walking (Willems and Bond 2009), such as decreased body fat, blood pressure, and cholesterol (Braun 1991).

Nine able-bodied participants in this study achieved vigorous intensity (>69% of $\%HR_{max}$) while playing Move Boxing in a standing position. Studies have shown that adults would typically be in the HR zone by running or cycling (Yoshiga and Higuchi 2002, Kraft et al. 2011). This indicated that exercising virtually with Move Boxing could also provide the same health benefits as the actual sports without having to go outside the house. Home-based exergames, such as Move Boxing that can be played solitarily, can provide an alternative interactive exercise as opposed to conventional sports, especially during the COVID-19 pandemic outbreak.

The current study also broadend the findings of previous studies investigating the HR responses in able-bodied adults during 10 minutes of exergaming sessions using other gaming consoles (Mohd Jai et al. 2021). For instance, the findings of this study are supported by (Sanders et al. 2014), which assess the EE in a similar age group while playing Wii Boxing and sedentary video games in both sitting and standing positions. The study found that both playing Wii Boxing and traditional, sedentary video games in a standing position resulted in a significantly higher EE than playing the same games in a sitting position.

(O'Donovan et al. 2012) investigated the HR responses in single and multiplayer modes during exergaming with Wii Sports in a standing position. The reported mean value of HR responses in both single (107 (28) bpm) and multiplayer (119 (28) bpm) modes during exergaming with Wii Boxing in a standing position produced lower HR compared to the current study (130.79 (23.18) bpm). The difference may be due to the bilaterality between Wii Boxing and Move Boxing, where Wii Boxing only uses one motion controller, while Move Boxing requires two motion controllers to play the game (Tanaka et al. 2012). The involvement of more movements from both hands may explain the difference in HR responses for both studies.

In contrast to the current findings and other studies for able-bodied adults playing Wii Boxing, (Wu et al. 2015) evaluated the EE and intensity of Xbox Kinect Boxing in seventeen healthy able-bodied adults (22.0 (2.9) years; 7 men) and reported that participants achieved higher mean (SD) HR response of 140.83 (19.0) (73% of cardiorespiratory responses). The difference might be relevant with the nature of Xbox Kinect systems that require whole-body movements to play the game rather than hand controllers in Move Boxing and Wii Boxing (Tanaka et al. 2012). There were some notable discrepancies in HR elevations during exergaming boxing in both standing and sitting positions. As opposed to the current findings, studies by (Sanders et al. 2014) and

(Taylor et al. 2012), reported no significant differences while playing in either position. Possible explanations for it may be due to the different technical specifications between game consoles.

The total mean (SD) value of HR responses for fifteen wheelchair-user participants was 130 (14) bpm denoted by a mean cardiorespiratory response of moderate-intensity (70% of HR_{max}%). These findings supported that boxing in a sitting position via exergaming achieved the recommended PA guidelines proposed by the ACSM (Garber et al. 2011). Also, this value was greater compared to HR_{max}% values obtained by able-bodied participants in the sitting position, and more similar to those obtained in standing position. (Mat Rosly et al. 2017) demonstrated a similar result where the HR obtained by the spinal cord injury (SCI) participants when playing Move Boxing in a sitting position was greater than those obtained by able-bodied playing Wii Boxing in standing position. The low HR responses of able-bodied participants when playing in a sitting position may be due to the lack of enjoyment and positive reactions towards the game (Pagulayan et al. 2002, Tamborini et al. 2010). Majority of them claimed that their movements while playing the exergames were constrained and limited to a seated position which caused them to feel less enthusiastic to play.

On the contrary, wheelchair-users are very dependent on their wheelchairs to perform daily activities. They feel that they do not have other options than to play the game in a sitting position, hence perceive self-efficacy, and give their best while playing. It has been well-documented that perceived self-efficacy and motivation have always been the major factors in facilitating adults with disabilities to perform PA and ensure the effectiveness of any rehabilitation programs (Johnson et al. 1990, Brinthaupt et al. 2010)

The results of RPE responses in this study are also supported by the existing findings involving RPE scores during exergaming among able-bodied participants. In studies by (Bosch et al. 2012, O'Donovan and Hussey 2012), the mean of RPE (6-20) scores of able-bodied participants when playing in a standing position (values= 13 and 11 respectively) is lower when compared to the current study's RPE (6-20) (value= 15), and more similar to the mean RPE (6-20) score when playing in a sitting position (value=13). The aforementioned factors such as the unilaterality and bilaterality between the hardware used in the previous (Wii) and the current studies (PlayStation Move), may explain the differences in the values.

The unique findings of this study could suggest that one can play exergaming with Move Boxing in any position (sitting or standing) without discriminating disability (able-bodied or wheelchair-users), and achieve the equipotent exercise intensity as proposed by the ACSM exercise intensity guidelines (Garber et al. 2011). This could also mean that during any exergaming or competition, able-bodied participants can play against wheelchair-users without worrying about the game being unfair or invalid.

The results of the correlation analyses indicated that only HR-RPE correlations of able-bodied participants in a standing position and wheelchair-users in a sitting position were reliable for estimation during exergaming. This led to an effective estimation that can be derived by having either variables of HR or RPE. The reliability of both the standard Borg RPE (6-20) and modified Borg (1-10) concerning the HR elevations while playing a boxing exergame was validated successfully in this study.

The RPE scale can also determine the intensity classification concerning HR elevations accurately, as seen from the significant findings of Spearman's rho correlation coefficients ($P<0.01$) for able-bodied standing and wheelchair-user sitting, with good reliability ($r = 0.4$-0.7). Only the correlation between HR and the modified RPE (1-10) intensity classification was found to be insignificant ($P= 0.076> 0.05$) (Table 4.6). This was most probably because Spearman's rho correlation test utilised the ordinal data which is less sensitive compared to continuous data (for Pearson's correlation) and more data points (larger sample) are needed to make an equivalent inference. However, the significant correlation between HR and the original RPE (6-20) intensity classification for the same sample sizes shows that if the number of the sample was bigger, then, we may see the correlation.

The regression model derived from the linear correlation coefficient plot can be used to estimate HR if the RPE is known. With this important information, future cohort or prospective intervention study designs can use RPE as a measure to (1) determine intensity classification while playing exergames, without the need of an HR monitor, and (2) estimate HR values derived from the reported RPE. Age is not significantly correlated to the regression model and thus can be used for all young adults. This allows the model to be more generalised among various groups of young adults. Considering the substantially strong r^2 value from the regression model, r^2=0.2-0.56, researchers can use the model to predict HR based on available RPE reports. A simplified formula for estimating HR from RPE of able-bodied in a standing position can be summarised in Equation 4.1 and Equation 4.2. The formula to estimate HR from RPE for wheelchair users is summarised in Equation 4.3 and Equation 4.4.

For the able-bodied population;

Standard RPE (6-20): $HR = (RPEx4) + 74$ (4.1)

For modified RPE (1-10): $HR = (RPEx5) + 107$ (4.2)

For the wheelchair-user population;

For standard RPE (6-20): $HR = (RPEx8) + 26$ (4.3)

For modified RPE (1-10): $HR = (RPEx8) + 101$ (4.4)

4.2.1 Limitations and Future Recommendations

It should be noted that the HR-RPE correlations and regression models cannot be generalised in instances where the exergaming is played in a sitting position, as displayed by the insignificant relationship. This finding is one of the limitations observed within this sample population while playing a boxing exergame. The formula is also derived from a young adult sample population (18−56 years old), and may be unreliable for use to generate HR values in children (<18), older adults (57-65 years old), or elderly individuals (>65). Future research designs could include sample populations from different age categories and within a larger sample size, N~300+, to detect better significant correlations.

Despite the acknowledged limitations, the results from the current study support the potential of using PlayStation Move Boxing for health benefits and could serve as a base for future studies. For instance, a longitudinal training effect of Move Boxing should be assessed, and the effect of Move Boxing on other populations with different disabilities, fitness levels and lifestyles should be investigated. Individuals with higher fitness levels and active lifestyles may not benefit much from playing Move Boxing in both positions (sitting and standing). However, less active individuals may find the exercise with Move Boxing in a standing position too exertive for them, and playing in a sitting position would be enough to elevate their HR to the moderate-intensity zone. As the relative intensity measures would be lower for the older age group, it is worth noting to see whether the exergames will produce lesser bias effects in the outcome measurement, should older groups be added into the analysis. Future studies could look into the suitability, feasibility, and enjoyment of high-intensity exergames such as Move Boxing in an older population, as games are most often synonymous with youth.

To date, no other similar studies have reported similar regression models for either boxing exergaming or exergames using the Sony PlayStation 3 Move hardware

(Mohd Jai et al. 2021). It is also unknown whether our findings only represent boxing exergames alone, or exergames played using a Sony PlayStation Move technology since the platform has better geomagnetic sensors (Tanaka et al. 2012) to detect exertive movements (Perusek et al. 2014) and lowered input-output delay time compared to Nintendo Wii or the Xbox Kinect (Tanaka et al. 2012). Future research could look into HR-RPE correlations when playing different types of exergames, game platforms, or other notable positions.

CHAPTER 5: CONCLUSION

The main objectives of this study are 1) to validate the correlations between HR and RPE coefficients based on the intensity classifications when playing a moderate-vigorous intensity exergame such as Move Boxing among adults with and without disabilities and 2) to formulate a possible regression model based on confounding factors such as the position of gameplay, disability, age, or BMI.

The results of this study show that the mean HR and RPE responses of all able-bodied participants while playing Move Boxing in a standing position is significantly higher ($p \leq 0.05$) than while playing in a sitting position, and more similar to those obtained by wheelchair users while playing in their wheelchairs. For the able-bodied population, the HR elevation correlates well with both the original and modified Borg's RPE scales while playing boxing exergame in a standing position, but not in a sitting position. For the wheelchair-user population, the HR elevation also correlates well with both the original and modified Borg's RPE scales during exergaming while being seated in their wheelchairs.

The formula extracted from the linear regression models provides reliable predictions in estimating HR from RPE for future research work. Future research is needed to investigate the training effects of playing Move Boxing for sustained periods by taking other factors (e.g., fitness level, lifestyle, and experience of the players) into account when measuring the responses. The regression model and subsequent formula allow a more flexible approach to monitoring required moderate-vigorous intensity activities while exergaming. This estimated formula requires no HR monitoring gadgets that may be uncomfortable for users to wear when playing moderate-vigorous exergames. The use of the RPE scale is especially useful during e-sports competitions, where the athletes are not distracted by the necessity to put on HR monitors, which may disrupt their gameplay or wear down their performance capacity.

Through the findings of this study, public interests towards exergaming and adherence to the exergaming routines also increase given that it eliminates the need to own the HR monitoring gadgets to track their heart rate while exergaming. They can directly monitor and adjust their performance to achieve the desired heart rate target zone and prevent overworking their heart during exergaming at the comfort of their homes. Adherence to regular physical activity such as moderate-to-vigorous exergames will increase the physical activity level, especially within the sedentary community. A positive attitude towards exergaming will also encourage a faster recovery or improvement in functional ability in rehabilitation. The formula proposed can be incorporated by physiotherapists in the exergaming routines that they use with their patients. Patients can perform exergaming and monitor their own heart rate intensity without the need for continuous supervision.

Additionally, the findings of this study will also benefit students and researchers to conduct exergaming studies outside the laboratory setting, such as during home-based program sessions and field-work data collection with limited resources. With correct instructions and training to the participants, the formula proposed in this study allows for intensity-based zone training or interventions without the need for an HR monitor.

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LIST OF PUBLICATIONS AND PAPERS

The research presented in this study has led to publications of the following:

Journal

1. **Mohd Jai, N. A**., Mat Rosly, M., & Abd Razak, N. A. (2020). Physiological Responses of Exergaming Boxing in Adults: A Systematic Review and Meta-Analysis. *Games for Health Journal*. (Published)
2. **Mohd Jai, N. A**., Mat Rosly, M., & Abd Razak, N. A. (2020). Correlating Psychophysiological Responses of Exergaming Boxing for Predictive Heart Rate Regression Models in Young Adults. *IEEE Transactions on Games*, *12*(4), 398-405. (Published)

Proceeding

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