HEALTH AND LEISURE TIME PHYSICAL ACTIVITY PROMOTION THROUGH EXERGAMING FOR INDIVIDUALS WITH SPINAL CORD INJURY

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HEALTH AND LEISURE TIME PHYSICAL ACTIVITY PROMOTION THROUGH EXERGAMING FOR INDIVIDUALS WITH SPINAL CORD INJURY

ABSTRACT

Individuals with spinal cord injury (SCI) face challenges in maintaining leisure time physical activity (LTPA) participation and adherence to exercise. LTPA is important for improving fitness, quality of life and cardiometabolic profiles. However, epidemiological data among community-dwelling SCI revealed low participation (29-53%) in "dose-potent" LTPA, defined as aerobic exercise of moderate-vigorous intensity for health benefits. The studies provided evidence that participation in LTPA is related to barriers due to wheelchair dependency. Recurrent themes often cited include expensive equipment, boring and monotonous exercises, issues with transportation and the inaccessibility of training facilities. The Physical Activity Scale for Individuals with Physical Disabilities and the Barriers to Exercise Scale questionnaires were used to collect descriptive information on LTPA and the associated barriers to exercise. Adaptation and translation of these questionnaires to fit Malaysian cultural competency were proceeded with validation of its Malaysian rendition (Chapter 3). Dose-potent LTPA participation (Chapter 4), assessed within the scenario of a non-western culture and Asian developing country revealed low participation (27%). The majority of respondents came from a lower socioeconomic bracket, 70% with a monthly household income of less than RM2500; including 27% of them earning less than RM1000. The top three barriers reported were costly exercise equipment (54%), pain while exercising (37%) and no access to facilities (36%). Significant predictors for dose-potent exercise participation were age more than 35 years old, ethnicity, reporting transportation difficulties and health concerns. A systematic review (Chapter 4) explored the exercise alternative, "exergaming" (a combination of active bodily movements with video gaming) for population with neurological disabilities. The review concluded that exergaming could provide moderate or vigorous intensity aerobic exercise as recommended by health guidelines. An exergaming pilot study (Chapter 4) in adult SCI demonstrated its feasibility to produce adequate "dose-potency" prescribed for health benefits. There were significant physiological differences ($p<0.05$) in the metabolic responses while exergaming using Move Tennis (unilateral, dominant upper limb movements) against Move Boxing and Move Gladiator Duel (bilateral upper limb movements). Move Kayaking was adapted for use among a study sample with SCI. In Chapter 4, physiological responses between Move Boxing and heavy-bag boxing revealed no significant differences ($p>0.05$), with only small to moderate effect sizes (Cohen's d, 0.02-0.49). However, Move Boxing was perceived to be more enjoyable, easier to assemble, comfortable to use, motivating for longer duration and for home training. The final study (Chapter 5) assessed three different exercise types (Move Boxing, Move Kayaking and arm cranking) that were conducted within similar training zones to compare the ratings of perceived exertion (RPE) and enjoyment. All three exercise types achieved vigorous intensity according to the peak heart rate. Move Boxing was the most significantly ($p<0.05$) enjoyable exercise compared to Move Kayaking and arm cranking. Exergaming's RPE was significantly ($p<0.05$) more than arm cranking owing to the complex arm movements during gameplay. Move Boxing reported higher RPE but was significantly more enjoyable than arm cranking.

Keywords: Exercise, Video Games, Boxing, Kayaking, Sports

KESIHATAN DAN MEMPROMOSIKAN AKTIVITI FIZIKAL WAKTU LAPANG MELALUI EXERGAMING UNTUK INDIVIDU YANG KECEDERAAN SARAF TUNJANG

ABSTRAK

Individu yang mengalami kecederaan saraf tunjang (KST) menghadapi banyak rintangan dalam penglibatan kegiatan aktiviti fizikal waktu lapang (AFWL). AFWL penting bagi meningkatkan kesihatan ketahanan, kualiti hidup dan profil kardiometabolik. Walaubagaimanapun, data epidemiologi menunjukkan penglibatan rendah dalam kegiatan AFWL (29-53%) yang "dos-poten", iaitu senaman aerobik yang bersifat intensiti sederhana hingga lasak untuk tujuan manfaat kesihatan. Kajian-kajian berikut menunjukkan halangan penglibatan AFWL berkaitrapat dengan penggunaan kerusi roda. Halangan yang dilaporkan merangkumi alat-alat senaman yang mahal, aktiviti fizikal yang membosankan dan terlalu berulang-ulang, isu-isu pengangkutan dan masalah akses fasiliti-fasiliti latihan. "The Physical Activity Scale for Individuals with Physical Disabilities" dan "Barriers to Exercise Scale" digunakan untuk mengumpul informasi secara deskriptif mengenai AFWL dan halangan-halangan yang berkait dengan senaman. Adaptasi dan translasi soal selidik berikut telah dilakukan mengikut cara hidup dan budaya Malaysia, seterusnya divalidasikan (Bab 3). Penglibatan aktiviti yang dos-poten (Bab 4), dalam konteks negara Malaysia menunjukkan purata yang rendah (27%). Majoriti responden termasuk dalam kategori sosioekonomi yang rendah, iaitu 70% berpendapatan isi rumah bulanan kurang daripada RM2500, dimana 27% daripada mereka dalam lingkungan kurang daripada RM1000. Tiga halangan yang paling kerap dilaporkan adalah alat-alat senaman yang mahal (54%), rasa sakit semasa bersenam (37%) dan tiada akses kepada fasiliti (36%). Penglibatan senaman yang dos-poten bergantung kepada umur melebihi 35 tahun, jenis kaum, masalah pengangkutan dan rasa khuatir terhadap kesihatan. Kajian sistematik (Bab 4) dibuat dengan tujuan merumus alternatif kepada senaman, iaitu “exergaming” (kombinasi pergerakan badan secara aktif dan permainan video) diantara golongan yang kurang upaya akibat masalah neurologi. Kajian tersebut menunjukkan bahawa exergaming berpotensi untuk memberi senaman aerobik dalam intensiti yang sederhana hingga lasak, bersesuaian dengan panduan kesihatan yang digariskan. Kajian percubaan (Bab 4) di kalangan orang dewasa KST membuktikan exergaming mampu memberi intensi senaman yang dos-poten selaras dengan manfaat kesihatan. Dalam Bab 4, terdapat perbezaan fisiologi ketara ($p<0.05$) dilihat dari segi respon metabolik semasa exergaming menggunakan Move Tennis (unilateral, bahagian pergerakan tangan yang dominan) dengan Move Boxing dan Move Gladiator Duel (pergerakan tangan dwilateral). Seterusnya, Move Kayaking telah diadaptasikan untuk memberi senaman intensiti yang dos-poten kepada individu KST. Respon fisiologi di antara Move Boxing dan boxing menggunakan beg-berat, menunjukkan tiada perbezaan ketara dilaporkan ($p>0.05$, saiz efek Cohen’s d, 0.02-0.49). Namun begitu, Move Boxing dianggap lebih ($p<0.05$) menyeronokkan, mudah dipasang, selesa digunakan, memberi motivasi untuk penggunaan yang lebih lama dan sebagai latihan di rumah. Kajian terakhir di Bab 5, tiga jenis senaman berbeza (Move Boxing, Move Kayaking dan kayuhan lengan) dikendalikan dalam julat zon latihan yang serupa untuk tujuan perbandingan kadar persepsi penggunaan tenaga (KPPT) dan keseronokan. Ketiga-tiga jenis senaman berikut mampu mencapai intensiti lasak mengikut kadar degupan jantung yang tertinggi. Move Boxing didapati paling menyeronokkan ($p<0.05$) dibanding dengan Move Kayaking ataupun kayuhan lengan. Exergaming melaporkan KPPT yang lebih ketara ($p<0.05$) daripada kayuhan lengan disebabkan pergerakan tangan yang lebih kompleks sewaktu senaman. Golongan KST melaporkan Move Boxing lebih susah, tetapi lebih menyeronokkan daripada senaman kayuhan lengan.

Kata kunci: Senaman, Permainan Video, Tinju, Kayak, Sukan

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Abbreviations:

ABT	:	Activity Based Therapy
AC	:	Abdominal Circumference
ACE	:	Arm Crank Ergometer
ADL	:	Activities of Daily Living
AIS	:	American Spinal Injury Association (ASIA) Impairment Scale
ANOVA	:	Analysis of Variance
BMI	:	Body Mass Index
BTES	:	Barriers to Exercise Scale
BWSTT	:	Body Weight Supported Treadmill Training
CO_2	:	Carbon Dioxide
FES	:	Functional Electrical Stimulation
FNS	:	Functional Neuromuscular Stimulation
HR	:	Heart Rate
HRpeak	:	Peak Heart Rate
LSD	:	Least Significant Difference
LTPA	:	Leisure Time Physical Activity
MET	:	Metabolic Equivalent of Task
OBA	:	Overground Bionic Ambulation
O_2	:	Oxygen
PA	:	Physical Activity
PACES	:	Physical Activity Enjoyment Scale
PAL	:	Physical Activity Level
PARASCI	:	Physical Activity Recall Assessment for Spinal Cord Injury

PASIPD	:	Physical Activity Scale for Individuals with Physical Disabilities
RPE	:	Rating of Perceived Exertion
SCI	:	Spinal Cord Injury
TSI	:	Time Since Injury
VO_2	:	Oxygen Consumption
VO_2peak	:	Peak Oxygen Consumption

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CHAPTER 1: INTRODUCTION

1.1 The spinal cord

1.1.1 Spinal cord injury – An introduction

The spinal column is a complex bony structure that protects the spinal cord and allows the exit of nerve roots to conduct sensory, motor and autonomic signals to target organs. It consists of 29 vertebral bodies divided into 3 segments consisting of the cervical spine (C1-C7), thoracic spine (T1- T12), lumbar spine (L1-L5) and sacral spine (S1-S5) (Manogue *et al.*, 2017). Damage to the neural elements (C1-C8) within the cervical spinal canal results in tetraplegia, causing impaired function of the arms, trunk, legs and pelvic regions (Kirshblum *et al.*, 2011; Maynard *et al.*, 1997). However, damage to the thoracic, lumbar or sacral neural elements within the spinal canal (T1-S5) causes paraplegia, where upper limb involvement is spared (Kirshblum *et al.*, 2011; Maynard *et al.*, 1997). Injuries to the spinal cord, whether traumatic or non-traumatic, can lead to devastating and catastrophic sequelae for individuals with a spinal cord injury (SCI). A case of SCI is defined by any lesion to neural elements in the spinal cord/cauda equine resulting in temporary or permanent motor or sensory deficit (Thurman *et al.*, 1995).

The neural cells enclosed within the spinal tract can die once severed by an external impact causing demyelination of the descending (for contractions) and/or ascending (for sensations) axons (Dimitrijevic *et al.*, 2015). Once this damage occurs, voluntary muscle contractions below the level of the lesion will become affected, either temporarily or permanently (Dimitrijevic *et al.*, 2015). Depending on the type and level of injury, sensory perceptions as well as autonomic function may also become affected (Dimitrijevic *et al.*, 2015). An incomplete injury refers to partial preservation of sensory and/or motor functions below the neurological level and is classified as complete injury when sensorimotor functions are absent in the lowest sacral segment (Hayes *et al.*, 2000).

The impact of autonomic nervous response following SCI is generally less well known, but could potentially cause serious consequences (Dimitrijevic *et al.*, 2015; Theisen, 2012). In the case of a complete SCI, sacral parasympathetic functions will always be involved, but sparing the cranial parasympathetic nervous system (Theisen, 2012).

The International Standards for Neurological Classification of SCI (INCSCI) is used for documentation of neurological examination for individuals with SCI. Classification in terms of completeness of the lesion and the level of injury uses the American Spinal Injury Association (ASIA) impairment scale (AIS). There are five classifications altogether, ranging from A to E that describes the sensory and motor preservation below the neurological level and sacral segments of the injury (Ditunno *et al.*, 1994; Maynard *et al.*, 1997). The grades are categorised as either of motor complete (AIS A) or motor incomplete in nature (AIS B/ C/D) (Maynard *et al.*, 1997). Motor incomplete status is graded if an individual has voluntary control of the anal sphincter (AIS C) or sacral sensory sparing (AIS B) with preserved motor function more than three levels below the motor level (Maynard *et al.*, 1997). In particular, an individual with prior neurological deficits but demonstrated normal sensory and motor function tested at a later stage is classified as grade E. Motor function grading is categorised based on muscle power ranging from 0 (total muscle paralysis) to 5 (full range of movement against gravity with sufficient resistance) (Ditunno *et al.*, 1994; Maynard *et al.*, 1997). Sensory function is tested based on light touch, pin-prick stimulation and deep pressure across the dermatome that each spinal nerve level innervates (Ditunno *et al.*, 1994; Maynard *et al.*, 1997). The drawback to the AIS however, is that assessment of autonomic completeness is not included and must be assessed separately (Kirshblum *et al.*, 2011; West *et al.*, 2013). The INCSCI recommends the use of the International Standards for Autonomic Function

(ISAFSCI) to document remaining autonomic functions after SCI (Krassioukov *et al.*, 2012).

1.1.2 Spinal cord injury – The epidemiology

The global incidence of SCI is estimated to be around 3.6 to 246 cases per million per year, depending on the prevailing socioeconomic and demographic factors of each country (Furlan *et al.*, 2013; Jazayeri *et al.*, 2015; Ning *et al.*, 2012; van den Berg *et al.*, 2010). The common causes of SCI are largely dependent on the socioeconomic milieu of each country, which varies between motor vehicle accidents, falls, medical or surgical complications, sports-related injuries or gunshot wounds (Ibrahim *et al.*, 2013; Lee *et al.*, 2014; New *et al.*, 2014; Ning *et al.*, 2012). Reviews of the literature estimated that the incidence of traumatic SCI is much lower in developing countries compared to developed countries and this is largely attributed to different socioeconomic background or sociocultural structures (Chiu *et al.*, 2010; Ning *et al.*, 2012). However, poorer recognition of SCI, incomplete registration data and inadequate health care systems may have caused lower incidence reporting in developing countries (Jazayeri *et al.*, 2015).

North America and European countries continue to have well recorded data on SCI from traumatic injuries (Jazayeri *et al.*, 2015), with African and Asian regions, including Malaysia, demonstrating marked limitations in depicting accurate SCI epidemiology (Ning *et al.*, 2012; Ibrahim *et al.*, 2013). Some of these limitations include retrospective studies that are not representative of national trends, reporting of prevalence instead of incidence and poorly defined case criteria and definitions (Jazayeri *et al.*, 2015; Lee *et al.*, 2014; Ning *et al.*, 2012). In developing countries, approximately two-thirds of SCI are of paraplegia (injuries between the levels of thoracic and sacral segments of the spinal cord), whilst the remaining one-third involved the cervical spine that leads to tetraplegia

(Chiu *et al.*, 2010; Ibrahim *et al.*, 2013; Lee *et al.*, 2014; Moshi *et al.*, 2017; Wang *et al.*, 2016). This proportion is seen in reverse in developed countries due to the different aetiologies leading to SCI (Chiu *et al.*, 2010; Lee *et al.*, 2014; Majdan *et al.*, 2017). An estimated 50% of SCI are classified as sensorimotor complete, indicating concurrent sensory and motor deficits below the level of injury (Chiu *et al.*, 2010; Ning *et al.*, 2012). The mean age of individuals at the time of injury is 35 years old with triple the incidental rate among males compared to females (Chiu *et al.*, 2010; Ning *et al.*, 2012; Ibrahim *et al.*, 2013). The Malaysian population with SCI spectrum is reflective of a typical Asian developing country's epidemiology, where incidence is higher among younger aged males coming from a lower income group.

1.1.3 Mortality, recovery and rehabilitation after spinal cord injury

Approximately 10-30% of deaths, secondary to traumatic SCI, occur within the first year after injury (Cripps *et al.*, 2011; Radovanovic *et al.*, 2017; Yang *et al.*, 2017). Mortality rates at the cervical SCI level were four times more likely than at the thoracic or lumbar levels (Majdan *et al.*, 2017). Most SCI related mortalities occurred in the older age groups (65 years old and above) and males were 50% more likely to be at risk than females (Majdan *et al.*, 2017). However, the mortality risk based on neurological or completeness of SCI reduces within 5-10 years after injury and secondary complications become the determinants of later mortality (Garshick *et al.*, 2005). SCI have reported the highest recovery costs among traumatic injuries, with an estimated median expense of USD264,103 (RM1,026,000) incurred for living related expenditures (Mitchell & Bambach, 2016). Aggregated data showed that depending on the age of the patient, severity, and level of SCI, the lifetime cost of health care and other injury-related expenses for an individual with SCI can reach up to USD4.5 million (RM17.4) (DeVivo *et al.*, 1999).

Acute management following SCI emphasizes reducing further neuronal damage to the spinal cord and optimising recovery. Neuroprotective strategies include early decompression of the spinal cord to reduce mechanical pressure on the vascular circulation and pharmacological interventions (Rouanet *et al.*, 2017). The first year following SCI is the most critical period for individuals afflicted with the injury, wherein intensive inpatient rehabilitative training is aimed at maximising functional recovery (Stillman *et al.*, 2017). Repeated motor training and sensory stimulation in both physical and occupational therapeutic exercises target specific areas to activate the muscles affected (Houle & Côté, 2013; Rank *et al.*, 2015). Rehabilitative therapies during this critical period requires careful attention by health care providers to limit complications, improve functional independence and performance.

1.1.4 Community reintegration and quality of life after spinal cord injury

Following SCI, individuals affected most often face significant hurdles affecting participation in Leisure time physical activity (LTPA) or productive community engagement. LTPA comprise of activities that require physical exertion, where an individual partakes in during their free time, covering the domains of sports, exercises and going for walks or wheeling for pleasure (Bouchard & Shephard, 1994). Free time, defined as time spent away from work, education, training, domestic chores and necessities, may vary among individuals with SCI who are under paid and unpaid employment. The World Health Organization's International Classification of Functioning, Disability and Health provided integrative frameworks that described the domains related to health condition, physical functioning and proposed areas of interventions (World Health Organization, 2001). The classification is used to describe the difficulties adults with SCI face, in relation to personal, environmental and body functions/structures to support engagement in social activities, return to work or continue education. Participation in such activities have contributed significantly in improving the quality of life and general well-being for the population with SCI (Ditor *et al.*, 2003). Therefore, it is important that LTPA activities geared for adults with SCI be directed towards functional recovery and independence.

1.2 Rationale of this thesis

The rationale behind this thesis was to investigate domains in LTPA participation among community-dwelling individuals with SCI, assess their rate of participation, identify barriers associated with the participation and explore alternative exercise training programs. These can be directed towards improving compliance, enjoyment, as well as being intensity adequate for health benefits. Individuals with SCI who face difficulties in transportation, accessing facilities and have poorer financial means for LTPA participation may benefit from the introduction of alternative exercise modalities that are relatively more affordable.

Reduced participation in LTPA among adults with SCI could happen following discharge after the early phase of inpatient rehabilitation. However, epidemiological studies describing activities of daily living (ADL) engaged by the population with SCI within developing regions have not been reported. The domains investigated in this thesis represented critical and constructive approaches to improve LTPA participation among community-dwelling individuals with SCI. The current thesis sought to analyse the scenario of low participation rates in LTPA that are "dose-potent" and the main perceived barriers among adults with SCI. It also aimed to establish the feasibility of exergaming for individuals with SCI in tackling physical inactivity once they have been discharged from rehabilitation services. Overall, an attempt to identify and potentially find solutions to the barriers they face in adhering to exercise that meet the recommended health guidelines constitute the core body of this thesis. The objectives presented, explored the dynamics of partaking in exergaming type of exercise that are intensity adequate as a physical training platform. This thesis also sought to investigate ways to determine exercise intensity classification that can be implemented for exergaming.

This thesis addressed three key objectives concerning individuals with SCI:

(1) Document the leisure time physical activity participation rates among community-dwelling population with SCI and the associated barriers to moderate-vigorous intensity exercise participation.

(2) Explore alternative types of moderate-vigorous intensity exercises that can improve participation and enjoyment whilst being feasible for the population with SCI.

(3) Investigate the effectiveness of exergaming compared to conventional exercises among a population with SCI.

1.3 Objectives

1.3.1 Leisure time physical activity participation rates among community-dwelling population with spinal cord injury and the associated barriers to moderate-vigorous intensity exercise participation

The first objective of this thesis was to adapt, translate and validate two questionnaires, the Physical Activity Scale for Individuals with Physical Disabilities (PASIPD) and the Barriers to Exercise Scale (BTES) for use within a Malaysian setting. The PASIPD was originally intended to assess physical activity levels (PAL) and quantify energy expenditure among individuals with disparate physical disabilities (Washburn *et al.*, 2002). This questionnaire could be used to provide a description of LTPA participation among community-dwelling individuals with SCI, for large scale epidemiological studies. A second concurrent part of the questionnaire (BTES) investigated the barriers adults with SCI perceive from participating in LTPA after 1 year of injury. The BTES was first used for a population with stroke (Rimmer *et al.*, 2008) and was later adapted for the population with SCI (Roberton *et al.*, 2011). Both these survey questionnaires were used to identify important barriers to LTPA within a different sociodemographic background (Asian, developing country) such as Malaysia. This cross-sectional study determined the odds of participation against reported agreement to the barriers and analysed significant predictors of moderate-vigorous intensity LTPA. The results of this study provided alternative ways to promote moderate-vigorous intensity LTPA for individuals with SCI.

1.3.2 Explore alternatives to moderate-vigorous intensity exercises that are enjoyable and feasible for the population with spinal cord injury

The second objective explored the various types of exergaming activities among individuals with neurological disabilities (e.g: SCI, stroke, cerebral palsy) and the intensity of each exergaming type reported. A systematic search was conducted on 3 different types of search engines. Based on the findings from the systematic review, types of exergames available for use among the population with SCI was explored and assessed for feasibility. A pilot study on the feasibility of different exergaming types in achieving moderate-vigorous exercise intensity for individuals with SCI was conducted on a small sample of convenience. This pilot study also sought to determine the technical, mechanical, kinematic and positional difficulties of exergaming for adults with SCI that were predominantly wheelchair users. An exergaming console (PlayStation®) was chosen due to having specifications with the lowest latency period, in-depth precision, detailed visual kinematics and feasibility of capturing body motion even in a sitting position.

1.3.3 Investigate the effectiveness and perceived enjoyment of exergaming compared to conventional exercises among a study sample with spinal cord injury

The third objective analysed physiological responses of exergaming against conventional types of exercising for individuals with SCI. For this purpose, boxing and kayaking were chosen among the types of exergaming due to the nature of the exergame being physically exertive and the ability to produce moderate-vigorous intensity aerobic exercise. The studies sought to determine any significant difference in the physiological responses and perceived enjoyment between exergaming and conventional exercising. It was also useful to determine whether participants would be more encouraged and motivated to exercise longer and more frequently while exergaming. Additionally, directions for improvements in implementing exergaming as an exercise type were ascertained.

1.4 Hypothesis

In order to address objectives of the study, five hypotheses were proposed as described below. The first two hypotheses were proposed to ascertain the first objective in determining the exercise participation rates of moderate-vigorous intensity in a Malaysian population with SCI. Hypothesis number three sought to establish evidence that exergaming have the potential to provide exercise that is intensity adequate for health improvements. The last two hypotheses were developed to compare exergaming with other conventional exercise equipment in terms of dose-response and enjoyment.

H1 Moderate-vigorous intensity exercise participation rates are low among adults with SCI in Malaysia

H2 Barriers to moderate-vigorous intensity exercise are associated with expensive equipment, boring physical activities or no access to facilities

H3 Exergaming can achieve moderate-vigorous intensity exercise for the population with SCI

H4 Exergaming and conventional exercise types produce no significant difference in physiological response

H5 Exergaming is a more enjoyable alternative to conventional exercises

1.5 Summary of exergaming

"Exergaming" is a combination of video gaming with active body movements for video game control typically featured in sports-like motion games. The introduction of exergaming for commercial game consoles was first popularised by the Nintendo® Company in 2006 with the introduction of the Wii™ system (Miyachi *et al.*, 2010). Other major game console producers such as Sony PlayStation™, Microsoft Xbox™ and XaviX™ systems followed suit with their own versions of movement-controlled gaming interfaces (Tanaka *et al.*, 2012). Interfaces used as controllers for in-game control can range from having motion sensors (i.e Sony Eye Camera™ or Xbox Kinect™) to foot operated pads (Dance Dance Revolution™ by Konami®) or arm ergometry (GameCycle® or GameBike®). These exercise systems integrated to video gaming were originally designed with the goal of providing a fun and motivating exercise platform

(Fitzgerald *et al.*, 2004; Guo *et al.*, 2006). However, exergames commercially-available were designed for the able-bodied population and are rarely suitable for individuals with neurological or physical disabilities. Modifications and adaptations (Hernandez *et al.*, 2012) to these exergames may be necessary to allow players with neurological or physical disabilities experience the full potential of each exergaming systems. Console hardware that support exergames based on traditional exercise equipment (GameCycle or GameBike) have been shown to sufficiently produce intensities adequate to improve cardiometabolic health (Warburton *et al.*, 2009; Widman *et al.*, 2006). Further work on identifying exergaming technologies on health improvements should focus on adapting exergames for targeted specific population. This can enhance the feasibility and efficacy of exergaming as an exercise training platform whilst providing robust, evidenced-based guidelines.

1.6 Terminology

Exercise: Exercise is a subset of leisure time physical activity that is planned, structured, and repetitive for the purpose of conditioning any part of the body (Caspersen *et al.*, 1985).

Exergaming: A combination of video gaming with active body movements for in-game control and user interactivity (Tanaka *et al.*, 2012). It uses various different types of game controllers as dynamic interfaces, including but not limited to motion tracking cameras, foot operated pads, arm crank/bicycle ergometers and musical instruments.

Fitness: Fitness is the ability to carry out daily tasks with vigour and alertness, without undue fatigue, and with ample energy to enjoy leisure time pursuits and respond to emergencies. Physical fitness includes a number of components consisting of cardiorespiratory endurance, skeletal muscle endurance, skeletal muscle strength, skeletal muscle power, flexibility, balance, speed of movement, reaction time and body composition (Caspersen *et al.*, 1985).

Leisure Time Physical Activity (LTPA): Physical activities performed during an individual's free time and may include sports or leisure activity participation, recreational activities or pre-planned moderate-vigorous aerobic exercises that are separate from ADL (Bouchard & Shephard, 1994). Free time can be defined as time spent away from both paid and unpaid work, education, training, domestic chores, as well as necessary activities such as eating or sleeping.

Metabolic Equivalent of Task: The term metabolic equivalent of task (MET) refers to a unit of measure used to estimate the metabolic cost of a physical activity. The traditional value of 1 MET is approximately equal to a person's resting energy expenditure (3.5ml O_2/kg/min=1 MET) (World Health Organization, 2010).

Physical Activity: Physical activity (PA) is defined as any bodily movement produced by skeletal muscles that requires more energy expenditure than resting. It is a complex behaviour that involves many aspects described by four parameters; type, frequency, duration and intensity (Caspersen *et al.*, 1985).

Physical Activity Level: Physical activity level (PAL) refers to a method of quantifying or characterising physical activity according to its type, frequency, duration and intensity (World Health Organization, 2010).

Rating of Perceived Exertion: The rating of perceived exertion (RPE) is a way of estimating PA intensity. It is based on the physical sensations a person experiences during PA, including increased heart rate, respiration or breathing rate, sweating, and muscle fatigue (Borg, 1982).

Sports: Sports implies competitive PA, played according to specific rules, which requires practice to attain a level of expertise. It also embraces general exercise and a specific occupation (Stewart, 1981).

CHAPTER 2: HEALTH AND LEISURE TIME PHYSICAL ACTIVITIES: A NARRATIVE REVIEW OF THE LITERATURE

2.1 The physiological and psychological impact of spinal cord injury

Spinal cord injury (SCI) can cause morbidity and mortality (Garshick *et al.*, 2005) with significant effects in health care expenditure (DeVivo *et al.*, 1999). Survivors of SCI may experience complications related to loss of mobility/total paralysis (Taccola *et al.*, 2018), pulmonary complications (Schilero *et al.*, 2009), urinary incontinence (Viaene *et al.*, 2017) or impaired sexual functions (Čehić *et al.*, 2016; Sramkova *et al.*, 2017). The inability to ambulate was described as one of the most devastating impairments individuals with SCI face (Anderson, 2004) and mobility is strongly associated with longer life expectancy (Shavelle *et al.*, 2015). These effects do not include co-morbidities such as chronic pain affecting functional mobility (Dijkers *et al.*, 2009), pressure sores (Levy *et al.*, 2013), urinary tract infections (Shekelle *et al.*, 1999), impending obesity (Chiodo *et al.*, 2007), bone loss (Dolbow *et al.*, 2011) and depression (Rosenberg *et al.*, 2013). Furthermore, the population with acute SCI reported lower evidence in improving health parameters as compared to a population with chronic SCI (moderate-high confidence) (van der Scheer *et al.*, 2017).

The epidemiology on SCI demonstrated a relatively young age of onset and skewed towards the male population (Chiu *et al.*, 2010; Ibrahim *et al.*, 2013; Ning *et al.*, 2012), where in most parts of the world, are the main bread winners of the family. This traumatic event could substantially impact quality of life for both the individual with SCI, as well as the dependent family members. Individuals with SCI most often present with cardiometabolic complications on top of restricted locomotor mobility and functional independence (Stillman *et al.*, 2017). Therefore, to achieve longer life expectancy, an active lifestyle is needed to maintain health, establish community-reintegration, improve productivity and reduce cardiometabolic complications related to SCI. In order to reduce these risks and achieve better quality of life, exercising is therefore an important component of activities of daily living (ADL) for a population with SCI.

2.2 Leisure time physical activities after spinal cord injury

2.2.1 Leisure time physical activities and dose potency

Physical activity (PA) is defined as any bodily movements produced by the skeletal muscles that result in quantifiable energy expenditure (Caspersen *et al.*, 1985). Leisure time physical activities (LTPA) (World Health Organization, 2010), in addition, are done during an individual's free time encompassing exercise, sports, recreational and leisure activities. However, exercise is a more structured approach to LTPA that is both planned and repetitive (Caspersen *et al.*, 1985), geared towards improving greater fitness. In the adult population with SCI, participation in both exercise and LTPA have been highly recommended by various available guidelines (Garber *et al.*, 2011; Martin Ginis *et al.*, 2011; Tweedy *et al.*, 2017; World Health Organization, 2010) for health benefits. Activities that are of adequate intensity (moderate-vigorous aerobic exercise) to improve cardiometabolic health or cardiovascular fitness according to prescribed guidelines (Haskell *et al.*, 2007; Martin Ginis *et al.*, 2011; Martin Ginis, van der Scheer, *et al.*, 2017; Tweedy *et al.*, 2017) are collectively understood as "dose-potent" LTPA. This term was coined to mean a moderate-vigorous aerobic exercise intensity, performed within bouts of 10 minutes (Garber *et al.*, 2011; Tweedy *et al.*, 2017) that is sufficient to enable improvements in fitness and reduce risk of cardiovascular diseases. However, this "dose-potency" omitted the amount of time and frequency spent on the PA over the course of duration to establish PA level. The term dose-potency and moderate-vigorous intensity aerobic exercise were used interchangeably within this thesis to reflect the differing opinions in identifying LTPA with health benefits. The types of exercises and PA were standardised as LTPA, however, the words "exercise", "sports" or "leisure activities" were maintained in parts deemed appropriate to describe the activity.

2.2.2 Recommendations for leisure time physical activities prescribed by health guidelines

Guidelines to promote cardiometabolic fitness and health for a population with SCI have recommended both aerobic exercises, resistance training of the muscles as well as flexibility and range of motion (Evans, Wingo, *et al.*, 2015; Martin Ginis *et al.*, 2011; Tweedy *et al.*, 2017). Exercise prescriptions from Exercise and Sports Science Australia (ESSA) for adults with SCI within the age of 18-65 years (Tweedy *et al.*, 2017), have recommended at least 150 minutes per week of moderate-intensity or 60 minutes per week of vigorous-intensity aerobic exercise type of LTPA. These recommendations can be achieved by a combination of 3-5 days of moderate or vigorous exercise on 3–5 days a week. Although these PA guidelines were originally developed for the able-bodied population (American College of Sports Medicine, 1998; Garber *et al.*, 2011), experts in the area of SCI have mixed opinions on which of the exercise regimes can also be applied to adults with SCI (150 versus 40-90 minutes per week) (Martin Ginis *et al.*, 2011; Martin Ginis, van der Scheer, *et al.*, 2017; Tweedy *et al.*, 2017). Exercise types should include rhythmic episodes of contraction and relaxation of the major muscles (Durán *et al.*, 2001). It is also encouraged to include both upper and lower limb exercises to increase metabolic demand and reduce shoulder joint strain. Exercise recommendations among adults with SCI and able-bodied do not vary dramatically in terms of intensity or duration but a key important note is how each exercise type should be determined. Current available parameters in determining the intensity of each type of exercise have several limitations. Determining intensity based on HRpeak or VO_2peak may be underestimated since upper limb maximal stress test elicits a considerably reduced cardiovascular response (Theisen, 2012; West *et al.*, 2016). Heart rate measurements may be blunted for those with absent or reduced cardiac sympathetic innervation (Jacobs & Nash, 2004; Theisen, 2012). Owing to the muscle paralysis and fatigability, metabolic equivalent of task (MET) has been reported to be lower (Simmons *et al.*, 2014). Lastly, perceived exertion can be overestimated in peripheral perceptions or training platforms with high enjoyment scales (Astorino & Thum, 2018; Au *et al.*, 2017). Nevertheless, weekly aerobic exercise within moderate-vigorous intensity is important for health benefits and preventing secondary disease complications (Martin Ginis *et al.*, 2011; Martin Ginis, van der Scheer, *et al.*, 2017; Tweedy *et al.*, 2017).

2.2.3 The health benefits of leisure time physical activities after spinal cord injury

Early intensive therapeutic exercise rehabilitation has been shown to promote formation of new intraspinal circuits in the spinal cord interneurons which enhances synaptic plasticity for functional recovery (Rank *et al.*, 2015). Therefore, to improve upon functional recovery and maintain quality of life among a population with SCI, physical training promoted during physical and locomotor rehabilitation plays an important role in supporting their efforts (Fakhoury, 2015). Rehabilitative therapies are warranted to prepare individuals with SCI for community reintegration: recovering motor skills, regaining functional independence and maintaining their health status. In addition, regular participation in LTPA maintains the mental and physical wellbeing whilst promoting improvements in cardiometabolic fitness in individuals living with SCI (Hicks *et al.*, 2003). Intensive and continuous exercise participation can circumvent obesity, by increasing oxidative stress as an adaptive mechanism against chronic inflammation causing increased adipose tissue deposition (da Silva Alves *et al.*, 2013). However, community-dwelling individuals with SCI discharged from intensive rehabilitation most often experience marked reductions in their PAL (de Groot *et al.*, 2016; Rimmer, 2012) and exercise adherence (Ditor *et al.*, 2003; Myers *et al.*, 2012), caused by the various reported barriers (Hwang *et al.*, 2016; Roberton *et al.*, 2011). This concomitantly leads to a sedentary lifestyle with an increased risk in inactivity-related illnesses (Garshick *et al.*, 2005; Warburton *et al.*, 2007).

2.3 Leisure time physical activity participation and the barriers

2.3.1 Participation in leisure time physical activities and physical activity levels among individuals with spinal cord injury

Adherence in exercise, sports or other forms of LTPA that are adequate for health benefits among the adult population with SCI has been documented to decrease as time since injury increases (de Groot *et al.*, 2016; van den Berg-Emons *et al.*, 2008). Participation rates in LTPA among the population with SCI have been relatively poor (Jörgensen *et al.*, 2017; Rauch *et al.*, 2016; Roberton *et al.*, 2011), with an even lower percentage of them reported engaging in LTPA that are intensity (moderate-vigorous) adequate for fitness improvements (Rauch *et al.*, 2017). A reported 29-53% (Anneken *et al.*, 2010; Buchholz *et al.*, 2009; Jörgensen *et al.*, 2017; Martin Ginis, Arbour-Nicitopoulos, *et al.*, 2010; Martin Ginis, Latimer, *et al.*, 2010; Papathomas *et al.*, 2015; Rauch *et al.*, 2016; Roberton *et al.*, 2011; Rocchi *et al.*, 2017; Zbogar *et al.*, 2016) of individuals with SCI globally partake in intensity adequate LTPA that can achieve improvements in health. Physical inactivity can be defined as a PAL ratio of ≤1.6 (Nightingale *et al.*, 2016) or if individuals did not engage in at least 150 min per week of moderate-vigorous intensity exercise over the last 3 months (Wong *et al.*, 2013). Based on the currently available literature on LTPA participation rates globally, the reported PAL in the population with chronic SCI were at the lower end of the spectrum compared to able-bodied (Buchholz *et al.*, 2003; de Groot *et al.*, 2016; Martin Ginis, Arbour-

Nicitopoulos, *et al.*, 2010). These studies mostly reported descriptions of LTPA involvement within the Western or developing countries' socio-environmental perspectives (Jaarsma *et al.*, 2014; Malone *et al.*, 2012; Martin Ginis, Latimer, *et al.*, 2010; Roberton *et al.*, 2011). Therefore, epidemiological studies describing barriers associated with LTPA participation within a country with a lower socio-economic gradient, such as Malaysia are warranted.

2.3.2 Determining leisure time physical activity participation and the associated barriers

The use of questionnaires in determining LTPA participation and PAL have been widely used for large epidemiological studies covering the population with SCI (de Groot *et al.*, 2010; Martin Ginis, Latimer, *et al.*, 2010; Rauch *et al.*, 2016). Questionnaires provide a more economically viable method of PAL assessments and energy expenditure quantification that is practical and less invasive than accelerometry-based systems or the doubly-labelled water. Review of the current literature identified several questionnaires available for the population with SCI:

(i) Physical Activity Scale for Individuals with Physical Disabilities (PASIPD) (Washburn *et al.*, 2002)

(ii) Physical Activity Recall Assessment for Spinal Cord Injury (PARA-SCI) (Ginis *et al.*, 2005)

(iii) Leisure Time Physical Activity Questionnaire for Spinal Cord Injury (LTPAQ-SCI) (Martin Ginis, Phang, *et al.*, 2012)

(iv) Physical Activity and Disability Survey (PADS) (Kayes *et al.*, 2009)

These questionnaires were developed to determine the different types of ADL in adults with SCI or population with physical disabilities. The PASIPD questionnaire covers a larger group of different types of population with physical disabilities, but has demonstrated weak criterion validity against other activity measures (de Groot *et al.*, 2010; van den Berg-Emons *et al.*, 2011; Washburn *et al.*, 2002). For the population with SCI, the PARA-SCI and the LTPAQ-SCI demonstrated better construct and criterion validity index (Ginis *et al.*, 2005; Martin Ginis, Phang, *et al.*, 2012) but require a trained interviewer during administration and can be costly to deploy.

Surveys related to the barriers involved in LTPA participation include several themes generated from personal, environmental and activity related barriers perceived by respondents with SCI (Hwang *et al.*, 2016; Malone *et al.*, 2012; Roberton *et al.*, 2011). Perceptions related to barriers to LTPA can be analysed quantitatively or qualitatively to form a conceptualised framework. Quantitative measures using Likert scales such as the Barriers to Exercise Scale (BTES) (Roberton *et al.*, 2011), Exercise Benefits and Barriers Scale (Sechrist *et al.*, 1987) or the Barriers to LTPA in individuals with SCI (Hwang *et al.*, 2016) can associate several significant factors and predictors within the demographic and clinical descriptions. Alternatively, qualitative analyses allow formation of a theoretical model or grounded theory to develop policies for improvements (Kehn & Kroll, 2009; Vissers *et al.*, 2008). Qualitative methods are conducted via in-depth interviews using semi-structured or open ended questions, relying heavily on the interviewer's experience to navigate the sessions. The facilitators to encourage LTPA participation were mostly reported to be the inverse of overcoming the barriers (Buffart *et al.*, 2009; Hundza *et al.*, 2016; Kehn & Kroll, 2009; Papathomas *et al.*, 2015; Vissers *et al.*, 2008; Williams *et al.*, 2014) in qualitative designs. However, these questionnaires and scales within the context of Malaysia or any Asian developing countries require content adaptation, translation and piloting to ensure its validity prior to use.

2.3.3 Models and frameworks related to barriers and facilitators

The prevalence of such barriers were dependent on the sociodemographic background of each area (Buffart *et al.*, 2009; Cowan *et al.*, 2012; Cowan *et al.*, 2013; Dolbow & Figoni, 2015; Hundza *et al.*, 2016; Hwang *et al.*, 2016; Jaarsma *et al.*, 2014; Kehn & Kroll, 2009; Kerstin *et al.*, 2006; Martin Ginis *et al.*, 2016; Martin Ginis, Papathomas, *et al.*, 2017; Roberton *et al.*, 2011; Scelza *et al.*, 2005; Stephens *et al.*, 2012; Vissers *et al.*, 2008; Wilson & Khoo, 2013) and developing or underdeveloped countries were not well reported. A qualitative description on the perceived barriers among paralympic athletes (Wilson & Khoo, 2013) were not representative of community-dwelling individuals with SCI in Malaysia. The International Classification of Functioning, Disability and Health (ICF) by Fekete and Rauch (Fekete & Rauch, 2012) have focused on environmental factors, personal characteristics and body functions/structures affecting LTPA participation among populations with physical disabilities. Additionally, Martin Ginis and her team have (Martin Ginis *et al.*, 2016; Martin Ginis, Papathomas, *et al.*, 2017) reported barriers associated with participation in LTPA within the intrapersonal, interpersonal, community and policy levels. In particular, personal characteristics (such as reporting "too lazy to exercise") can be a determining factor in the likelihood of exercise participation (Cowan *et al.*, 2012), seen in the high household income population with SCI. Factors associated with barriers and facilitators to LTPA participation can be classified into socio-environmental, personal characteristics, physical limitations and policies related to social support in this review (Figure 2.1).

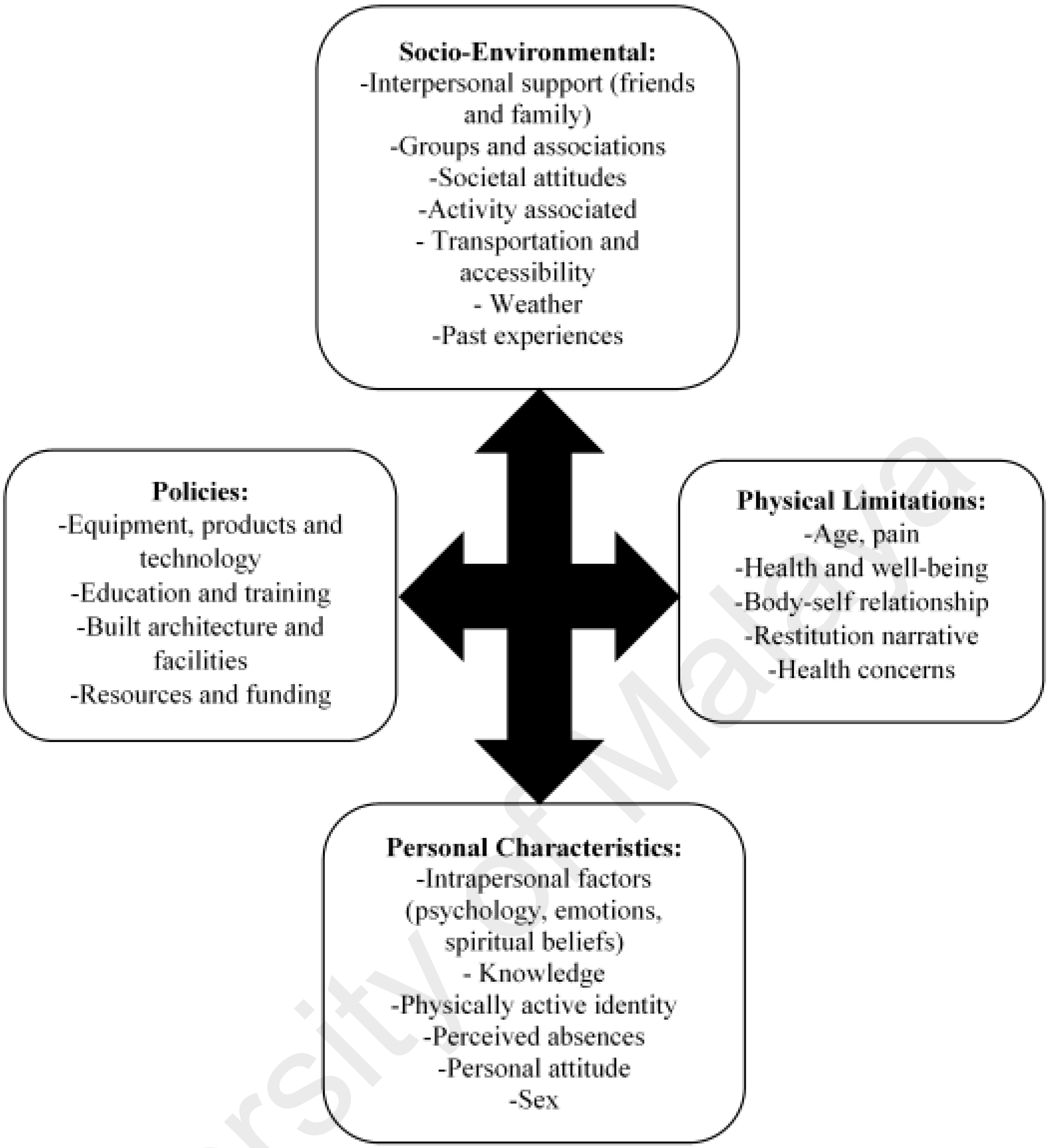

Figure 2.1: Four common themes associated with barriers to leisure time physical activity participation

2.4 Leisure time physical activity intervention programs

It is important for adults with SCI to partake in LTPA with adequate dose-potency since ADL alone may not be sufficient to maintain or improve physical fitness (Buchholz *et al.*, 2003; Janssen *et al.*, 1994; Tanhoffer *et al.*, 2015). Determining appropriate exercise interventions for the community with SCI has been a major hurdle among clinicians, physiotherapists and researchers alike. Evaluating the feasibility and measuring the effectiveness of any exercise intervention are key targets in training programs designed for the population with SCI. To address the gaps in approaches to increase intensity adequate LTPA participation in a population with SCI, this review compiled a synthesis of various evidence-based existing studies available for community-based exercise training programs.

2.4.1 Types of leisure time physical activities

Exercise types available for individuals with SCI can either be voluntarily activated upper limb muscles (arm cycling, exergaming or wheelchair training) or requiring assistive technologies such as functional electrical stimulation (FES) of the lower limbs and upper limb muscles for individuals with tetraplegia. Current trends in developing exercise intervention programs for individuals with SCI have delved into various assistive technologies, behavioural intervention therapies and improving social support to the facilities.

2.4.2 Voluntary activated muscle exercise

Conventional arm cranking, wheelchair training (van der Scheer *et al.*, 2015) and wheelchair sports (Barfield *et al.*, 2016; Sadowska-Krępa *et al.*, 2016) are some of the more traditional methods of upper body exercise available for individuals with SCI. These exercises have demonstrated efficacy in improving cardiorespiratory fitness (10-30%) (Valent *et al.*, 2007) but shown considerable differences in health outcomes depending on the level of injury (tetraplegia versus paraplegia) and time since injury (chronic versus acute) (Hoekstra *et al.*, 2017; Valent *et al.*, 2009). Although isolated upper body exercises can provide positive health outcomes, these did not improve lower limb musculature, function and strength. Prolonged excessive use of the upper limbs or shoulder joints can lead to overuse injuries and ligament tear, frequently seen in wheelchair users with SCI (Eriks-Hoogland *et al.*, 2016; Finley & Ebaugh, 2017). Additionally, conventional arm cranking was perceived to be boring and monotonous (Astorino & Thum, 2018), whilst providing little motivation for continued adherence.

2.4.3 Types of leisure time physical activities

Activity-based therapy (ABT) interventions are defined by a multitude of therapeutic training components that sought to improve muscle activation or sensory function below the level of the affected SCI. ABT are guided by the principles of neuroplasticity that encourage neural or functional improvements by repeated neuromuscular activation and augmented by sensory stimulation (Behrman *et al.*, 2017; Dolbow *et al.*, 2015). There are five key components comprising ABT, which includes locomotor and weight-bearing training, FES, task-specific and massed practices (Dolbow *et al.*, 2015). It was designed to incorporated aerobic exercise, flexibility in joint range of motion and muscle strength and endurance, in accordance to a comprehensive rehabilitation program. However, ABT have only reported evidence in improving upper limb independence and functional ability

(Quel de Oliveira *et al.*, 2017). There are no positive effects on quality of life and it is not superior to other conventional interventions when applied to the lower limbs (Quel de Oliveira *et al.*, 2017). Individuals with SCI, who sought ABT treatment, did not report higher level of rehabilitation engagement, although they expressed higher hopefulness (Felter *et al.*, 2017).

2.4.4 Assistive technologies for exercise

Assistive technologies refer to a wide range of equipment that include assistive, adaptive, and rehabilitative devices for individuals with disabilities. This category also covers the processes used in selecting, constructing, assessing the feasibility and efficacy of using such technologies for exercise. Some examples of exercise equipment that can be categorised under assistive technologies may include FES-cycling, FES-rowing (Gibbons *et al.*, 2016), FES-hybrid cycling (Hasnan *et al.*, 2013), overground bionic ambulation (OBA) devices such as exoskeleton suits (Evans, Hartigan, *et al.*, 2015; Hartigan *et al.*, 2015), virtual reality cybertherapies (Zimmerli *et al.*, 2013) or body weight supported treadmill training (BWSTT) (Wouda *et al.*, 2016). Treadmill-based locomotor training, under BWSTT, is usually performed with manual assistance by a physiotherapist, isolated transcutaneous electrical stimulation, a driven gait orthosis or locomotor training with FES-hybrid (Kressler *et al.*, 2013). Exercises such as neuromuscular electric stimulation (NES) or FES-hybrid are involuntarily stimulated muscle training that has shown to increase lean mass in the paralysed muscles, whilst reducing the total fat percentage (Shojaei *et al.*, 2017). However, FES-based exercises were recommended at low speed for optimal improvements in muscular training and conditioning (Fornusek *et al.*, 2013; Meyns *et al.*, 2014). Alternatively, exoskeleton powered suits are metal frameworks fitted with motorised “muscles” that can multiply the users’ lower limb strength to enhance mobility. These exoskeleton enhanced training sessions have been shown to improve mobility outcomes (Hartigan *et al.*, 2015), sensory measures (Sczesny-Kaiser *et al.*, 2015) and cardiometabolic responses (Evans, Hartigan, *et al.*, 2015).

2.4.5 Behavioural intervention programs

Behavioural intervention programs are usually targeted to harmonise coordinated integration between home-based interventions, community facilities and clinical institutions (Lai *et al.*, 2016; Nooijen *et al.*, 2017). It is an ideal form of deployment since it can be tailored according to specific level of injury, functional capacity, access to facilities and need for supervision. Some of these exercise programs can be remotely delivered via online, telephone or video monitoring for home-based training (Arbour-Nicitopoulos *et al.*, 2014; Lai *et al.*, 2016; Lai *et al.*, 2017). The activities in the programs can also be adapted according to the participant's choice in therapeutic goals, perceived enjoyment and ability to adhere. Participants attending such programs can benefit from the motivational or clinical advice that has shown increase in self-worth and self-esteem (Gernigon *et al.*, 2015).

2.4.6 Active video gaming and exergaming

Active body movements combined with video gaming is termed "exergaming" or "active video gaming", that provide various bodily movements in 3 dimensional rotation (Burns *et al.*, 2012; Fitzgerald *et al.*, 2004; Gaffurini *et al.*, 2013; O'Connor *et al.*, 2002; Warburton *et al.*, 2009). Video games integrated to an arm ergometer for propulsion and game control have demonstrated better enjoyment than the conventional counterpart, whilst also being intensity adequate (O'Connor *et al.*, 2002; Widman *et al.*, 2006). Exergaming with higher intensity correlated with higher perceived enjoyment (Malone *et al.*, 2016) and adherence (Widman *et al.*, 2006). This area of research is considered relatively new, with the potential to provide alternative forms of exercises as a physical training platform. Current available studies on exergaming for individuals with physical disabilities have focused on commercially-available video game consoles such as Nintendo Wii (Gaffurini *et al.*, 2013), Xbox Kinect (Malone *et al.*, 2016) and the XaviX (Burns *et al.*, 2012) systems. Further work would be needed to evaluate alternative console platforms such as the PlayStation Move that has different mechanical specifications.

2.5 Exercise and physical training programs after spinal cord injury

2.5.1 Effects of exercise training on health outcomes

Exercise and physical training provides multiple benefits for adults with acute and chronic SCI both within the cellular or biochemical levels (Sandrow-Feinberg & Houlé, 2015). Different exercise strategies can be applied at various stages of the post-injury response to provide neuroprotection, regeneration, rehabilitation and recovery. Health improvements were commonly based on cardiorespiratory fitness, cardiometabolic risk, power output, muscle strength, body composition, bone density and mental health. However these health parameters can be extended to include biological mechanisms integral for metabolic control: (1) haematological profile, (2) body composition, (3) PAL, (4) energy intake, (5) measures of health and wellbeing, (6) resting metabolic rate, heart rate and blood pressure, (7) aerobic capacity, (8) immune function, and (9) adipose tissue gene expression (Nightingale *et al.*, 2016).

2.5.2 Considerations for exercise training platforms

Assistive technologies face several major limitations that include large scale deployments, cost-efficiency, preventing side effects, technical challenges, expert monitoring during use and biological synergy adaptations for different types of SCI needing consideration (Chen *et al.*, 2013). To achieve the recommended intensity, duration and frequency, training programs can be mixed and matched with a variety of exercise modalities (Martin Ginis, Jörgensen, *et al.*, 2012). This is as long as each of them are aerobic exercises within moderate-vigorous intensity, to include muscle endurance training and range of motion or flexibility exercises. These can often include circuit resistance training, voluntarily muscle activated upper body exercises, video game integrated arm ergometry and OBA/BWST/FES-assisted exercises. Additionally, online monitoring and communication for home-based exercise programs were reported to be one of the most efficient format of delivery for improving participation and adherence (Lai *et al.*, 2016; Lai *et al.*, 2017; Munce *et al.*, 2014). This can be considered in future training exercise programs for the population with SCI.

2.5.3 Future of exercise training for individuals with spinal cord injury

The cost-effectiveness of some of these exercise modalities can be unrealistic and difficult to deploy in large-scale community centres as they require specialised trainers or are limited in number. Disability adjusted life year is a cost-effectiveness ratio scale that can be used for comparing exercise interventions against health parameters, and as a tool to measure the efficacy of exercise interventions in future research. Additionally, it can be potentially dangerous to deploy training programs using assistive technologies without monitoring by a trained therapist due to the reported side effects (i.e: autonomic dysreflexia, skin abrasion, lightheadedness) (Esquenazi *et al.*, 2012; Geigle *et al.*, 2013). This is an important aspect that should be taken into consideration, whereby proper training should be made for staff or users, so that they are aware of the potential side effects associated with the equipment.

2.6 Summary of exercise and health after spinal cord injury

Training programs designed for individuals with SCI must take into account the lack of access to fitness facilities, unaffordable or inappropriate equipment and inadequate supply of specialised trainers. Self-administered exercise programs at home or smaller community fitness centres can provide supplementary bouts of aerobic exercise and resistance training, but these can be limited to low-cost, low technology types of equipment. Assistive technologies such as FES, NES, OBA and BWSTT can be expensive to deploy to large communities and may only benefit a small group of population with SCI due to the various indicated restrictions (Tong *et al.*, 2017) and side effects reported (Benson *et al.*, 2016). Even though these therapies (Sandrow-Feinberg & Houlé, 2015) have been shown to promote motor recovery, adherence (Vissers *et al.*, 2008) is difficult to maintain within the same frequency or intensity after being discharged from intensive rehabilitation. This is partially due to the fact that most community-dwelling individuals with SCI do not have easy access to exercise equipment or trained therapists despite widespread awareness of the importance of exercise for recovery. These findings point toward the importance of integrating voluntary activated muscular exercises and assistive technologies in physical training. Various current available exercise training platforms and programs should be used in combination to deliver a multitude of adapted LTPA for the population with SCI.

CHAPTER 3: MALAYSIAN ADAPTATION OF THE PHYSICAL ACTIVITY SCALE FOR INDIVIDUALS WITH PHYSICAL DISABILITIES

3.1 Abstract

Purpose: The Physical Activity Scale for Individuals with Physical Disabilities (PASIPD) provides an assessment of physical activity after spinal cord injury (SCI). This study sought to adapt, with cultural competence, the English questionnaire and translate it into Bahasa Malaysia, including validation (content, face, internal consistency, factor analysis, variance and test-retest reliability) of its Malaysian version. **Materials and Methods:** A total of 250 individuals with SCI completed the PASIPD questionnaire that was distributed via email, postal mail, the internet, physically and by word of mouth. Sixty-eight individuals were re-contacted to complete the questionnaire again. **Results:** The adapted PASIPD demonstrated adequate internal consistency Cronbach's $\alpha = 0.68$ and good test-retest reliability, intraclass correlation coefficients (ICC=0.87, r = 0.05-0.94). Factor analysis extracted four main dimensions for physical activity; factor 1 (heavy housework, home repair, lawn work and gardening), factor 2 (sports and recreation), factor 3 (light housework and caring for another person) and factor 4 (leisure and occupational activities) that accounted for 64% of the physical activities' total variance. **Conclusion:** The Malaysian-adapted English and translated Bahasa Malaysia PASIPD questionnaires intended to measure physical activity levels in individuals with SCI, demonstrated good acceptable validity and reliability. However some individual items revealed weak reliability measures. Further work is needed to validate the questionnaire's criterion validity against other physical activity measures.

Keywords: disabled persons, translations, leisure activities, surveys and questionnaires, sports

3.2 Introduction and review of the literature

Assessment of physical activity level (PAL) among community-dwelling individuals with spinal cord injury (SCI) characterises their activities of daily living (ADL) and this can be used to promote a healthy lifestyle and promote research enquiry (Ainsworth *et al.*, 2012; Nightingale *et al.*, 2017). However, measuring PAL can be challenging as there is no "gold standard" for its quantification after SCI (Hills *et al.*, 2014). Direct and indirect calorimetry have practical restrictions (Reardon *et al.*, 2006) for individuals living in a community setting. Accelerometer-based approaches may have limitations in translating upper limb movements into energy expenditure and are relatively expensive and challenging to use in large populations (Berlin *et al.*, 2006; Ginis *et al.*, 2005). Heart rate measurements can be unreliable for individuals with cervical SCI, where there may be a blunted heart rate response during exercise due to sympathetic decentralization (Ginis *et al.*, 2005; Jacobs & Nash, 2004; Theisen, 2012). Doubly labelled water is costly, does not provide specific information regarding the type, intensity, duration and frequency of physical activities (Kriska & Caspersen, 1997; Schoeller & van Santen, 1982) and is usually only feasible to quantify energy expenditure over a period of 7-20 days (Ginis *et al.*, 2005; Schoeller & van Santen, 1982; Tanhoffer *et al.*, 2012). Finally, self-reported physical activity questionnaires may have the potential to introduce a retrospective recall bias, or may not be well-validated for classification of physical activities among wheelchair users (Ainsworth *et al.*, 2012; Ginis *et al.*, 2005; van den Berg-Emons *et al.*, 2011).

The Physical Activity Scale for Individuals with Physical Disabilities (PASIPD) (Washburn *et al.*, 2002) is a 13-item self-reported questionnaire intended to classify ADL covering the domains of leisure (items 1-6), household activities (items 7-12) and occupational tasks (item 13) during the previous 7 days. Originally intended by Washburn and colleagues (Washburn *et al.*, 2002) for PAL assessment, the PASIPD scores these activities by their intensity in Metabolic Equivalent of Task (MET), frequency and duration summed over each independent category (Washburn *et al.*, 2002). Each item is accompanied by several examples (Washburn *et al.*, 2002) to give participants an idea of the physical activities that it covers. The PASIPD was developed to assess recalled physical activities during the preceding 7 days for a range of physical disabilities, including cerebral palsy, stroke and chronic back pain (Washburn *et al.*, 2002). These activities were frequency-categorised as never, seldom (1-2days/week), sometimes (3-4days/week), or often (5-7days/week) and the average hours per day they participated (<1hour, 1 but <2hr, 2–4hr, >4hr for items 1-12, and <1hr, 1 but <4hr, 5 but <8hr, ≥8hr for item 13) (Washburn *et al.*, 2002). The PASIPD score is the summation of items 2 through 13, and each item score was created by multiplying the average hours per day with the MET value associated with the intensity of the activity (Washburn *et al.*, 2002). Possible mathematical scores may range from 0 MET (lowest) to 199.5 MET (highest) hours per day (Washburn *et al.*, 2002). The PASIPD questionnaire and its scoring instructions are available in the Appendix from Washburn and colleagues' original development and evaluation paper (Washburn *et al.*, 2002).

The PASIPD questionnaire was validated from study populations that were generally well-educated Caucasians and individuals with locomotor disabilities (de Groot *et al.*, 2010; Jimenez-Pardo *et al.*, 2015; Tanhoffer *et al.*, 2012; van den Berg-Emons *et al.*, 2011; van der Ploeg *et al.*, 2007; Warms & Belza, 2004; Washburn *et al.*, 2002). Prior work evaluating the PASIPD for individuals with SCI in a Dutch setting showed weak-to-moderate relationships with activity and fitness parameters, indicating limited association (de Groot *et al.*, 2010). However, the PASIPD can be used for various populations with physical disabilities in future work, can be easily self-administered within a short time (15 minutes) and is inexpensive to deploy. This study sought to adapt the English PASIPD questionnaire, with cultural competence, for use within a Malaysian context, and to also translate and validate it into Bahasa Malaysia (the Malaysian national language), for individuals with SCI. It was intended to provide preliminary support for the construct validity and reliability of both the PASIPD versions. The processes for the Malaysian PASIPD adaptation, included content validity (the extent of how much a test measure represents elements of the construct) and face validity (a superficial and subjective assessment of the test measure). Construct validity included internal consistency (Cronbach's alpha), factor analysis, item variance, divergent validity (tests that constructs that should have no relationship do, in fact, not have any relationship) and inter-rater reliability (assessment of stability measures). Intraclass correlation coefficient (ICC) and Spearman's test performs reliability testing to observe between-subject variability in the PASIPD scores. Since content and face validity are processes that do not infer any statistical means or measures, they are reported under the methods section. This study also provided information regarding the physical activity of individuals with SCI in a developing Asian country such as Malaysia.

3.3 Methods

3.3.1 Content validation: Malaysian adaptation of the English language PASIPD questionnaire

A consensus panel, comprising an English language expert, two clinicians who were highly familiar with SCI, a physiologist and a non-clinical university-educated person, reviewed the original questionnaire to adapt items that were not in a "cultural context" to Malaysian society. The activities "ballroom dancing", "softball" and "snow removal" were removed from items 4 and 10, respectively. The authors replaced "ballroom dancing" and "softball" with physical activity examples more in context to Malaysian culture, but with similar MET values extracted from the compendium of physical activities (Ainsworth *et al.*, 2011). These were "social badminton" and "volleyball", replacing the unfamiliar activities under item 4 "moderate sport and recreational activities". The activity "snow removal" from item 10 was not replaced as it was deemed the other examples provided in the PASIPD questionnaire were sufficient. This step produced the English language version of the PASIPD questionnaire that was adapted for Malaysian cultural context.

3.3.2 Content validation: Forward and backward translation of the questionnaire

The PASIPD questionnaire in English language was forward-translated into Bahasa Malaysia by two bilingual translators, working independently. The first translator came from a clinical healthcare background with extensive knowledge on medical terminology and the content area of the physical activity questionnaire (Sousa & Rojjanasrirat, 2011). The second translator, a certified translator, familiar with common colloquial phrases, layman's medical terms, health care slang, jargon, idiomatic expressions, and emotional terms in common use for both languages produced the second forward translation (Sousa

& Rojjanasrirat, 2011). The consensus panel, previously described, reviewed both translations, resolved any ambiguities or discrepancies of meanings and selected one coherent version of the Bahasa Malaysia PASIPD questionnaire.

The Bahasa Malaysia version of the PASIPD questionnaire was then back-translated into English by two other independent translators with the same qualifications and characteristics as described above (Sousa & Rojjanasrirat, 2011). Both the translators were blinded to the original version of the PASIPD. One additional independent university-educated person served as a third bilingual translator representing someone who was not an expert in, nor had detailed knowledge of, the physical activity field. The three English back-translated versions were compared to the original English version by a multidisciplinary team (Sousa & Rojjanasrirat, 2011), comprising three of the previous consensus panel members, two exercise physiology experts in the content area (one of whom was a native English speaker) and two of the translators involved in the translations. The committee also reviewed both the forward and backward translations, and decided on the most acceptable Bahasa Malaysia expression following feedback from all five translators. Any ambiguities and discrepancies regarding cultural meaning were resolved by consensus. Finally, the committee selected one coherent backward translated English version that was most similar to the original PASIPD questionnaire. Committee members were all Malaysians except one of the physiology expert who is an Australian and native English speaker. This step evaluated the content validity of the questionnaire.

3.3.3 Face validation of the translated and adapted questionnaires

The study was approved by the University of Malaya Medical Ethics Committee (MECID 201410-609). The translated Bahasa Malaysia and adapted English PASIPD questionnaires were pilot tested among 10 participants with SCI (the target population), as has been recommended (Beaton *et al.*, 2000; Sousa & Rojjanasrirat, 2011). They represented the various ethnicities common in Malaysia and were able to comprehend the two languages. They evaluated the clarity of the instructions, questions, response format and the examples in each of the PASIPD items with a dichotomous scale of either a "clear" or "unclear" rating. Participants who rated "unclear" for their evaluation were asked to provide feedback or suggestions on how to improve the text and meaning for better clarity.

Like some other Asian languages (for example, Japanese (Kay, 1995)), Bahasa Malaysia (Schneider, 2003) often adopts English words into the local vocabulary. Some Bahasa Malaysia words were rarely used and many Malaysians tended to be more familiar with the English-adopted words or phrases. Therefore, several words in English were retained in the questionnaire and added within inverted commas or brackets next to the Bahasa Malaysia version of the words. This is because, some of the translators and pre-test participants were unfamiliar with the Bahasa Malaysia version of the words, but recognized the English form immediately. These words were: darts (item 3), arm cranking and "off-road" pushing (item 5), push-ups, pull-ups, dips, wheelchair push-ups (item 6).

The numbering of the subdivision for each item responses were changed from Arabic numerals to alphabetic letters in order to minimise confusion by participants. For item 11 of the PASIPD questionnaire, examples of outdoor gardening were added, ranging from 3.5-4.5 MET that were extracted from the compendium (Ainsworth *et al.*, 2011). The examples gave participants an idea of what outdoor gardening activities might include. This was made as the original PASIPD did not provide any examples under "outdoor gardening" in item 11. The referred activities in the second part of each item questions were changed to "those activities" instead of repeating them again. Participants were initially confused and assumed the second part of each item question was a different set of questions unrelated to the first part. This step clarified the statement and avoided discrepancies. The author of the PASIPD questionnaire, Washburn (Washburn *et al.*, 2002), was contacted to review the original English and back-translated English versions of the questionnaires. His feedback on "washing dishes" in item 7 that must cover "plates, glasses, bowls and cups" was noted and adopted into the translated version. Another example, in item 1, the word "stationary" when translated to Bahasa Malaysia (pegun) means "immobile" and gave participants a confusing and conflicting impression (implying that one is not moving at all). For better clarity and understanding, the word "static" (statik) was employed in Bahasa Malaysia. This could not alter the outcome measure as item 1 was a practice question to familiarise the participants with the format and would not be used in any PAL calculation. These revisions were made back and forth until all the participants reached an inter-rater agreement of more than 80% per item. This step evaluated the face validity of the questionnaire.

3.3.4 Construct validation and reliability of the translated and adapted questionnaire

Malaysia's ethnic population comprises Malays and Bumiputra (67.4%), Chinese (24.6%), Indians (7.3%) and various other ethnic groups (0.7%) (Department of Statistics Malaysia, 2011). To avoid sample bias, an equal distribution of various ethnicities representing the Malaysian population was collected among individuals with SCI within the geopolitical states of Malaysia (drawn from the thirteen states and three federal territories). The survey was distributed via email, postal mail, internet media or physically among members of non-governmental organizations, outpatient rehabilitation attendees and during community events that catered for individuals with SCI. Distribution of the questionnaire was done physically or online as evidence supported that the two methods produced similar results (Anderson, 2004; Ritter *et al.*, 2004). Additionally, recruitment of participants was also conducted by word of mouth (passive "snowball recruitment" - refers to the non-probability sampling derived by recruiting future participants among acquaintances from existing participants) community-dwellers with SCI (Anderson, 2004). The first part of the questionnaire covered details of participants, which included their personal and demographic information. The second part consisted of the PASIPD questionnaire. Both the Malaysian adapted English and Bahasa Malaysia versions were made available to the participants. This was because the Malaysian education system in the post-British colonisation period and at university level (tertiary education) have used English as the medium of instruction (Molanorouzi *et al.*, 2014; Schneider, 2003). This made certain groups of participants more familiar with the English words rather than the Malaysian national language, Bahasa Malaysia words (Molanorouzi *et al.*, 2014). Informed consent was obtained from all participants. A copy of the Bahasa Malaysia PASIPD version is provided in the Appendix. The scoring instructions can be found from Washburn et al's development and evaluation paper (Washburn *et al.*, 2002).

In the construct validation of the adapted and translated PASIPD questionnaires, a recommended sample size of at least 10 individuals per item of the scale (Sousa & Rojjanasrirat, 2011) was used. The PASIPD questionnaire contains 13 items for both Bahasa Malaysia and English versions. However, only 12 of the items were analysed for validation since the first item was omitted because it was a practice question that did not have a scoring value. A minimum of 240 participants (120 for each versions) were therefore needed for the construct validation analyses. Two hundred and fifty participants with SCI were recruited to respond to the PASIPD questionnaires either in English (N=126) or Bahasa Malaysia (N=124) versions. They were given Arabic numeric codes according to the order they were recruited. A recall assessment to repeat the questionnaire within 7 days was collected to correlate test-retest reliability. The minimum sample size of 30 for the test-retest reliability assessment was derived from Cohen's formulation to achieve a power of 0.8, significance criterion, $\alpha = 0.05$, effect size of 0.25 (large) and within a large sample size population (population proportion = 0.5) (Cohen, 1992). Based on the formula for estimating sample size, 30 participants were needed to provide a power of 80%, large effect size of 0.25 and detect a significantly large relationship (ICC>0.5) between PASIPD scores at Day 1 and 7 days later. A large ICC was expected, given the significant associations shown from previous test-retest reliability assessments of questionnaires conducted within similar population with SCI (Ginis *et al.*, 2005; Martin Ginis *et al.*, 2012; van der Ploeg *et al.*, 2007). Sixty-eight participants (34 for each language versions respectively) recruited within the order range of 35 to 250 were recalled to repeat the questionnaires (Craig *et al.*, 2003; Ginis *et al.*, 2005). Some of these participants were unwilling to be involved in the questionnaire the second time or were uncontactable within the next 8 days. The inclusion criteria were individuals with SCI who understood either Bahasa Malaysia or English, with at least one year after their SCI and greater than 18 years of age. Individuals with impaired cognition affecting comprehension were excluded.

3.4 Data Analysis

All data were processed using Microsoft Excel and SPSS version 24.0 (SPSS Inc., Chicago, Illinois, USA). The original demographic groups presented in Table 3.1 were coded into binomial categories as follows: (a) age (18-35 years or 36 years and above - older/younger SCI age group); (b) time since injury (≤5 or ≥6 y - short/long standing SCI group); (c) sex (male or female) (d) ethnicity (Malay or non-Malays); (e) cause of SCI (traumatic or non-traumatic); (f) relationship status (in a relationship or not in a relationship) (g) state of residence (Selangor or outside Selangor); (h) area category (urban or rural); (i) type of housing (good accessibility or poor accessibility); (j) education level (non-graduate or graduate); (k) employment (paid employment or other); (l) total monthly household income (≤RM2499 or ≥RM2500) and (m) type of mobility aid (wheelchair or non-wheelchair). Since the PASIPD MET scores were not normally distributed (Kolmogorov-Smirnov test $p<0.05$), a two-sample Kolmogorov-Smirnov Z test assessed demographic data distribution differences between the two languages and to assess total PASIPD score differences (divergent validity) between the 2 language versions, different levels of SCI (paraplegia versus tetraplegia), time since injury, and age group.. The Kolmogorov-Smirnov Z test was used since it could be adapted for discrete variables and the MET scores extracted from this current study are semi-discrete variables extracted from objective measures (Arnold & Emerson, 2011; Washburn et al., 2002). The test statistics performed on the MET scores for the current study were similar to a continuous variable but the calculation of its significant values were more conservative (Arnold & Emerson, 2011). Responses from the two different language versions were analysed together and separately to increase the number of available cases and maximise the degrees of freedom in each analysis. This is also to determine if different languages may result in variations in factor extractions, demographic distribution and ICC. Factor analysis and determination was done by principal component extraction using a univariate descriptive with quartimax orthogonal rotations. The number of factors extracted were based on the criteria of an eigenvalue ≥1 and a factor loading ≥0.40 (de Groot *et al.*, 2010; Washburn *et al.*, 2002). The internal consistency used Cronbach's α as a measure to validate the inter-item reliability. Non-parametric Spearman two-tailed correlation coefficient was used to calculate the test-retest reliability between the first and second (recall within 7 days) PASIPD. ICC with 95% confidence interval, using a two-way mixed absolute agreement effect was also used to calculate the reliability of the test and retest assessments. The significance level was set at $p<0.05$. The strength of the correlations were rated poor if $0.1 < r < 0.3$, acceptable if $0.3 < r < 0.5$ and good if $0.5 < r < 1.0$ (Cohen, 2013).

3.5 Results

3.5.1 Description of study sample

Two hundred and fifty individuals with SCI were surveyed and the distribution of demographic variables are summarised in Table 3.1. Individuals were given the option of participating anonymously since some were reluctant or uncomfortable with disclosing their personal information. Both complete/incomplete and tetraplegia/paraplegia injuries were included since most participants were unaware of their neurological level or completeness of injury. American Spinal Injury Association (ASIA) classification was omitted since most participants did not know the true completeness of their injury, especially those diagnosed prior to the time when the ASIA classification scale was developed (Ditunno *et al.*, 1994), refined (Maynard *et al.*, 1997) and widely implemented.

3.5.2 Construct validity and reliability summary

Adaptation of the PASIPD questionnaire revealed acceptable inter-item correlation, Cronbach's alpha ($\alpha = 0.68$) and adequate overall test-retest reliability using Spearman's correlation ($r = 0.87$; $p<0.05$). The ICC were acceptable to good for all items (r = 0.32-0.94) except items 7 (light housework, Bahasa Malaysia, r = 0.29), 10 (lawn work, Bahasa Malaysia, r = 0.05) and 3 (vigorous sports, English, r = 0.20). Factor analysis revealed 4 dimensions with eigenvalues ≥ 1, factor loadings ≥ 0.40 and a cumulative variance between 61-69% (Table 3.2). The main physical activity dimensions extracted in the combined versions were; factor 1 (heavy housework, home repair, lawn work and gardening), factor 2 (sports and recreation), factor 3 (light housework and caring for another person) and factor 4 (leisure and occupational activities). Tables 3.2 and 3.3 summarised the construct validity and test-retest reliability findings. The mean total MET score (MET hours per day) was 18.92 with a standard deviation (SD) of 19.61.

Table 3.1: Demographic and clinical details (N=250)

Demographic and clinical details		Mean (SD)		
		Combined (N=250)	Bahasa Malaysia (N=124)	English (N=126)
Age (years) Missing *		42.6 (14.4) 1	39.6 (11.7) 1	45.6 (16.0) 0
Time since injury (years) Missing *		13.2 (11.4) 1	13.7 (10.2) 1	12.7 (12.4) 0
Demographic and clinical details		**Frequency scores**		
		Combined (N=250)	**Bahasa Malaysia (N=124)**	**English (N=126)**
Sex	Male Female	177 (70.8%) 73 (29.2%)	97 (78.2%) 27 (21.8%)	80 (63.5%) 46 (36.5%)
Ethnicity	Malay Chinese Indian Others Missing*	129 (51.8%) 81 (32.5%) 30 (12%) 9 (3.6%) 1	91 (74%) 19 (15.4%) 9 (7.3%) 4 (3.3%) 1	38 (30.2%) 62 (49.2%) 21 (16.7%) 5 (4%) 0
Type of distribution	Physical Online	220 (88%) 30 (12%)	119 (96%) 5 (4%)	101 (80%) 25 (20%)
State	Selangor Kuala Lumpur Others	121 (48.4%) 50 (20%) 79 (31.6%)	51 (41.1%) 17 (13.7%) 56 (45.2%)	70(55.6%) 33 (26.2%) 23 (18.2%)
Level of SCI	Paraplegia Tetraplegia Missing*	194 (78.2%) 54 (21.8%) 2	104 (85.2%) 18 (14.8%) 2	90 (71.4%) 36 (28.6%) 0
Cause of injury	Motor vehicle accident Medical/surgical complication Fall Gunshot Sports injury Unknown Missing*	117 (47.0%) 53 (21.3%) 37 (14.9%) 2 (0.8%) 11 (4.4%) 29 (11.6%) 1	66 (53.7%) 21 (17.1%) 18 (14.6%) 2 (1.6%) 2 (1.6%) 14 (11.4%) 1	51 (40.5%) 32 (25.4%) 19 (15.1%) 0 (0%) 9 (7.1%) 15 (11.9%) 0
Type of housing	Flat Apartment/condominium Terrace Semi-detached Bungalow Others Missing*	22 (8.9%) 41 (16.6%) 104 (42.1%) 12 (4.9%) 24 (9.7%) 44 (17.8%) 3	19 (15.6%) 12 (9.8%) 43 (35.2%) 4 (3.3%) 7 (5.7%) 37 (30.3%) 2	3 (2.4%) 29 (23.2%) 61 (48.8%) 8 (6.4%) 17 (13.6%) 7 (5.6%) 1
Area category	Rural Town City Missing*	42 (16.9%) 79 (31.7%) 128 (51.4%) 1	38 (30.9%) 36 (29.3%) 49 (39.8%) 1	4 (3.2%) 43 (34.1%) 79 (62.7%) 0

Table 3.1, continued: Demographic and clinical details (N=250)

Demographic and clinical details		Frequency scores		
		Combined (N=250)	Bahasa Malaysia (N=124)	English (N=126)
Marital status	Single	94 (37.8%)	51 (41.5%)	43 (34.1%)
	In a relationship	15 (6.0%)	4 (3.3%)	11 (8.7%)
	Married	123 (49.4%)	60 (48.8%)	63 (50%)
	Widowed	7 (2.8%)	4 (3.3%)	3 (2.4%)
	Divorced	10 (4.0%)	4 (3.3%)	6 (4.8%)
	Missing*	1	1	0
Education level	Primary school	25 (10%)	19 (15.5%)	6 (4.8%)
	Secondary school	132 (53%)	75 (61%)	57 (45.2%)
	University	92 (37%)	29 (23.5%)	63 (51.6%)
	Missing*	1	1	0
Occupational status	Working	120 (48.2%)	61 (49.6%)	59 (46.8%)
	Homemaker	9 (3.6%)	6 (4.9%)	3 (2.4%)
	Retired	51 (20.5%)	12 (9.8%)	39 (31%)
	Student	8 (3.2%)	3 (2.4%)	5 (4%)
	Unemployed	60 (24.1%)	40 (32.5%)	20 (15.9%)
	Missing*	2	2	0
Total monthly household income (RM) †	≤RM999	59 (24.0%)	44 (36.4%)	15 (12%)
	RM1000- RM2499	93 (37.8%)	44 (36.4%)	49 (39.2%)
	RM2500- RM3499	35 (14.2%)	15 (12.4%)	20 (16%)
	RM3500- RM4999	27 (11.0%)	7 (5.8%)	20 (16%)
	≥RM5000	32 (13%)	11 (9.1%)	21 (16.8%)
	Missing*	4	3	1
Type of mobility aid	Motorized wheelchair	13 (5.2%)	4 (3.3%)	9 (7.1%)
	Manual wheelchair	180 (72.3%)	101 (82.1%)	79 (62.7%)
	Uses canes/crutches	56 (22.5%)	18 (14.6%)	38 (30.2%)
	Missing*	1	1	0

SD: Standard deviation
Abbreviations: RM: Ringgit Malaysia, SCI: Spinal cord injury
* 1 participant declined to answer any part of the demographic section (except the state recruited and sex), 4 declined to answer the monthly household income section, 3 declined to answer type of house section and 2 did not wish to answer the level of SCI section
† RM conversion rates at time of study (as of 15th March 2016):
1 United States Dollar = RM4.1; 1 Euro = RM4.6; 1 Great Britain Pound = RM5.9

Table 3.2: Factor analysis of the Physical Activity Scale for Individuals with Physical Disabilities (Combined, N=250)

Item	Mean (SD) (MET hr•day^{-1})	α if item deleted	Factor 1	Factor 2	Factor 3	Factor 4
Combined (Bahasa Malaysia and English)						
2 (Leisure activities)	4.14 (4.04)	0.65				0.61
3 (Light sports)	1.80 (2.63)	0.65		0.74		
4 (Moderate sports)	1.68 (3.87)	0.62		0.81		
5 (Vigorous sports)	2.32 (6.21)	0.63		0.77		
6 (Resistance Training)	3.06 (5.03)	0.67		0.60		
7 (Light housework)	1.05 (1.70)	0.67			0.75	
8 (Heavy housework)	0.91 (2.51)	0.65	0.59			
9 (Home repair)	0.35 (1.68)	0.67	0.77			
10 (Lawn work)	0.24 (1.19)	0.68	0.90			
11 (Gardening)	0.33 (1.43)	0.68	0.85			
12 (Caring for another person)	1.04 (1.94)	0.68			0.73	
13 (Occupational)	1.91 (4.67)	0.69				0.87
Total score	18.92 (19.61)					
Cronbach's α	0.68 (total)		0.76	0.68	0.42	0.40
Intraclass correlation	0.87 (total)		0.44	0.34	0.26	0.22
Eigenvalue			2.68	2.39	1.47	1.21
Variance			22.32%	19.91%	12.24%	10.10%
Cumulative variance			22.32%	42.24%	54.48%	64.58%

Factor 1: Heavy housework, home repair, lawn work and gardening; Factor 2: Sports and recreation; Factor 3: Light housework and caring for another person; Factor 4: Leisure & occupational activities
Abbreviations: SD: Standard deviation; MET: Metabolic Equivalent of Task; hr•d^{-1}: Hours per day

Table 3.2, continued: Factor analysis of the Physical Activity Scale for Individuals with Physical Disabilities (Bahasa Malaysia, N=124)

Item	Mean (SD) (MET hr•day^{-1})	α if item deleted	Factor 1	Factor 2	Factor 3	Factor 4
Bahasa Malaysia						
2 (Leisure activities)	4.48 (4.22)	0.65				0.51
3 (Light sports)	2.00 (2.96)	0.64		0.73		
4 (Moderate sports)	2.16 (4.31)	0.60		0.84		
5 (Vigorous sports)	3.07 (7.41)	0.64		0.76		
6 (Resistance Training)	3.08 (5.47)	0.67		0.61		
7 (Light housework)	1.24 (1.81)	0.66			0.71	
8 (Heavy housework)	1.16 (2.57)	0.65	0.69			
9 (Home repair)	0.37 (1.63)	0.67	0.92			
10 (Lawn work)	0.37 (1.62)	0.67	0.94			
11 (Gardening)	0.44 (1.87)	0.67	0.88			
12 (Caring for another person)	1.02 (1.87)	0.69			0.76	
13 (Occupational)	1.82 (4.71)	0.66				0.73
Total score	21.29 (21.39)					
Cronbach's α	0.68 (total)		0.86	0.68	0.38	0.41
Intraclass correlation	0.88 (total)		0.59	0.34	0.24	0.22
Eigenvalue			3.20	2.57	1.42	1.13
% variance			26.67%	21.38%	11.87%	9.44%
Cumulative % variance			26.67%	48.04%	59.91%	69.35%

Factor 1: Heavy housework, home repair, lawn work and gardening; Factor 2: Sports and recreation; Factor 3: Light housework and caring for another person; Factor 4: Leisure & occupational activities
Abbreviations: SD: Standard deviation; MET: Metabolic Equivalent of Task; hr•d^{-1}: Hours per day

Table 3.2, continued: Factor analysis of the Physical Activity Scale for Individuals with Physical Disabilities (English, N=126)

Item	Mean (SD) (MET hr•day^{-1})	α if item deleted	Factor 1	Factor 2	Factor 3	Factor 4
English						
2 (Leisure activities)	3.81 (3.85)	0.64			0.62	
3 (Light sports)	1.58 (2.26)	0.65	0.80			
4 (Moderate sports)	1.21 (3.34)	0.63	0.78			
5 (Vigorous sports)	1.59 (4.66)	0.61	0.77			
6 (Resistance Training)	3.05 (4.58)	0.66	0.45			
7 (Light housework)	0.86 (1.56)	0.67		0.87		
8 (Heavy housework)	0.67 (2.43)	0.66		0.85		
9 (Home repair)	0.33 (1.72)	0.65		0.60		
10 (Lawn work)	0.12 (0.44)	0.69				0.75
11 (Gardening)	0.22 (0.76)	0.69				0.85
12 (Caring for another person)	1.06 (2.01)	0.66			0.54	
13 (Occupational)	1.99 (4.65)	0.72			0.75	
Total score	16.59 (17.47)					
Cronbach's α	0.68 (total)		0.68	0.76	0.39	0.45
Intraclass correlation	0.88		0.33	0.50	0.16	0.29
Eigenvalue			2.50	2.01	1.49	1.37
Variance			20.83%	16.75%	12.40%	11.44%
Cumulative variance			20.83%	37.58%	49.99%	61.42%

Factor 1: Sports and recreation; Factor 2: Housework and home repair; Factor 3: Caring for another person, leisure and occupational activities; Factor 4: Lawn work and gardening
Abbreviations: SD: Standard deviation; MET: Metabolic Equivalent of Task; hr•d^{-1}: Hours per day

Table 3.3: Test-retest reliability (Combined, N=250)

Item	Mean (SD) (MET hr•d^{-1})		r (p)	ICC [95% CI]
	Day 1	Recall		
	Combined			
2 (Leisure activities)	4.46 (4.07)	3.74 (3.79)	0.77 (<0.001)	0.71 [0.57, 0.81]
3 (Light sports)	2.27 (3.02)	1.95 (2.72)	0.37 (0.002)	0.67 [0.51, 0.78]
4 (Moderate sports)	1.67 (4.05)	1.49 (3.73)	0.60 (<0.001)	0.67 [0.52, 0.78]
5 (Vigorous sports)	2.12 (6.44)	2.73 (7.02)	0.51 (<0.001)	0.58 [0.39, 0.71]
6 (Resistance training)	3.67 (5.12)	3.61 (5.21)	0.73 (<0.001)	0.70 [0.56, 0.81]
7 (Light housework)	0.87 (1.39)	0.9 (1.37)	0.76 (<0.001)	0.64 [0.48, 0.76]
8 (Heavy housework)	0.75 (2.42)	0.85 (2.41)	0.55 (<0.001)	0.87 [0.80, 0.92]
9 (Home repair)	0.17 (0.49)	0.07 (0.24)	0.78 (<0.001)	0.62 [0.44, 0.75]
10 (Lawn work)	0.05 (0.19)	0.10 (0.31)	0.37 (0.002)	0.37 [0.15, 0.55]
11 (Gardening)	0.33 (1.39)	0.25 (0.74)	0.60 (<0.001)	0.33 [0.10, 0.52]
12 (Caring for another person)	0.77 (1.66)	0.88 (1.80)	0.69 (<0.001)	0.74 [0.61, 0.83]
13 (Occupational)	1.44 (3.87)	2.24 (4.69)	0.58 (<0.001)	0.52 [0.33, 0.68]
Total score	18.74 (12.04)	18.68 (17.92)	0.87 (<0.001)	0.87 [0.79, 0.92]

Abbreviations: SD: Standard deviation; MET: Metabolic Equivalent of Task; hr•d^{-1}: Hours per day; ICC: Intraclass correlation coefficient; CI: Confidence interval
^{NS} denotes non-significance, p>0.05

Table 3.3, continued: Test-retest reliability (Bahasa Malaysia, N=124)

Item	Mean (SD) (MET hr•d^{-1})		r (p)	ICC [95% CI]
	Day 1	Recall		
	Bahasa Malaysia			
2 (Leisure activities)	5.32 (4.20)	4.42 (4.07)	0.74 (<0.001)	0.67 [0.44, 0.82]
3 (Light sports)	2.37 (3.18)	2.21 (3.31)	0.42 (0.014)	0.81 [0.65, 0.90]
4 (Moderate sports)	1.78 (4.13)	2.04 (4.57)	0.55 (0.001)	0.86 [0.73, 0.93]
5 (Vigorous sports)	2.62 (6.88)	3.94 (9.09)	0.62 (<0.001)	0.71 [0.50, 0.85]
6 (Resistance training)	4.06 (6.24)	3.81 (5.65)	0.79 (<0.001)	0.79 [0.62, 0.89]
7 (Light housework)	0.58 (0.70)	0.66 (0.78)	0.69 (<0.001)	0.29 [-0.05, 0.57]
8 (Heavy housework)	0.71 (1.57)	0.70 (1.24)	0.40 (0.018)	0.50 [0.20, 0.72]
9 (Home repair)	0.20 (0.42)	0.08 (0.25)	0.65 (<0.001)	0.49 [0.20, 0.71]
10 (Lawn work)	0.50 (1.92)	0.32 (0.95)	***0.22^{ns} (0.218)***	***0.05 [-0.29, 0.38]***
11 (Gardening)	0.50 (1.92)	0.32 (0.95)	0.42 (0.013)	0.32 [-0.03, 0.59]
12 (Caring for another person)	0.88 (1.75)	0.73 (1.62)	0.69 (<0.001)	0.78 [0.61, 0.89]
13 (Occupational)	1.32 (3.55)	2.03 (4.40)	0.47 (0.005)	0.33 [-0.01, 0.60]
Total score	20.76 (18.90)	20.80 (20.28)	0.80 (<0.001)	0.88 [0.76, 0.94]

Abbreviations: SD: Standard deviation; MET: Metabolic Equivalent of Task; hr•d^{-1}: Hours per day; ICC: Intraclass correlation coefficient; CI: Confidence interval
^{NS} denotes non-significance, p>0.05

Table 3.3, continued: Test-retest reliability (English, N=126)

Item	Mean (SD) ($MET\ hr\bullet d^{-1}$)		r (p)	ICC [95% CI]
	Day 1	Recall		
	English			
2 (Leisure activities)	3.60 (3.80)	3.06 (3.41)	0.74 (<0.001)	0.74 [0.55, 0.86]
3 (Light sports)	2.17 (2.91)	1.68 (1.99)	***0.30^{ns}(0.088)***	***0.43 [0.12, 0.67]***
4 (Moderate sports)	1.56 (4.02)	0.95 (2.58)	0.66 (<0.001)	0.37 [0.05. 0.63]
5 (Vigorous sports)	1.62 (6.03)	1.52 (3.79)	0.35 (0.042)	0.20 [-0.15, 0.51]
6 (Resistance training)	3.29 (3.74)	3.42 (4.80)	0.69 (<0.001)	0.54 [0.24, 0.74]
7 (Light housework)	1.17 (1.80)	1.14 (1.75)	0.81 (<0.001)	0.69 [0.47, 0.83]
8 (Heavy housework)	0.78 (3.08)	1.00 (3.20)	0.71 (<0.001)	0.94 [0.89, 0.97]
9 (Home repair)	0.14 (0.56)	0.06 (0.24)	1.00 (<0.001)	0.71 [0.49, 0.84]
10 (Lawn work)	0.17 (0.44)	0.19 (0.45)	0.70 (<0.001)	0.66 [0.42, 0.81]
11 (Gardening)	0.17 (0.44)	0.19 (0.45)	0.75 (<0.001)	0.43 [0.10, 0.67]
12 (Caring for another person)	0.66 (1.58)	1.04 (1.98)	0.71 (<0.001)	0.71 [0.50, 0.84]
13 (Occupational)	1.57 (4.21)	2.44 (5.02)	0.68 (<0.001)	0.67 [0.44, 0.82]
Total score	16.73 (14.96)	16.57 (15.22)	0.89 (<0.001)	0.85 [0.72, 0.92]

Abbreviations: SD: Standard deviation; MET: Metabolic Equivalent of Task; $hr\bullet d^{-1}$: Hours per day; ICC: Intraclass correlation coefficient; CI: Confidence interval
^{NS} denotes non-significance, p>0.05

3.5.3 Group differentiation

The Kolmogorov-Smirnov Z analyses revealed significantly different (p<0.05) distribution of answers between the adapted English and Bahasa Malaysia versions, as seen in the demographic categories of neurological classification (p = 0.008), sex (p = 0.01), state (p = 0.022), ethnicity (p<0.001), type of housing (p<0.001), area category (p<0.001), education level (p<0.001), income (p = 0.001) and type of mobility aid used (p = 0.005). It was difficult to categorise participants according to their neurological classification (A-D) using the questionnaire, as most were not aware of their completeness of SCI. The distribution of MET scores between the two languages were only significantly different in three of the items within the PASIPD, item 4 (moderate sports, p = 0.003), item 7 (light housework, p = 0.029) and item 8 (heavy housework, p = 0.038).

Divergent validity revealed significantly lower PASIPD scores among the tetraplegia group (p=0.006) and this was observed in leisure activities (p=0.009), light (p<0.001) and heavy housework (p=0.039). Shorter injury years and individuals with tetraplegia had significantly lower PASIPD scores than those with longer injury years (p<0.001), and these differences were seen in leisure activities (p=0.005), moderate sports (p=0.023), light (p<0.001) and heavy housework (p=0.005). No differences in total PASIPD scores were noted in the younger age group as compared to the older age group, except for in resistance training (p=0.002).

3.6 Discussion

The main findings of this study were that both the Malaysian adaptation of the English PASIPD and Bahasa Malaysia translation had good internal consistency (Tavakol & Dennick, 2011), Cronbach's alpha, $\alpha = 0.68$ within the items tested, and that the values were comparable to the American ($\alpha = 0.37$-0.65) (Washburn *et al.*, 2002), Canadian ($\alpha = 0.49$-0.72) (Jimenez-Pardo *et al.*, 2015) and Dutch ($\alpha = 0.63$) versions (de Groot *et al.*, 2010). Stability measures, using ICC and Spearman's correlation ($r = 0.80$-0.89; $p<0.05$) revealed adequate total test-retest reliability for both versions of the questionnaire, demonstrating support for its use within the Malaysian context. The ICC for lawn work (item 10) in the Bahasa Malaysia version of the PASIPD was the only type of physical activity that changed considerably from test to retest (ICC = 0.05, $r = 0.22$). This may suggest that lawn work activities among individuals with SCI in Malaysia were often done spontaneously, making their assessment less reliable. However, the authors' do not recommend removing the lawn work questionnaire item, as this activity may significantly differ amongst community-dwelling individuals with SCI residing different types of houses or from urban/rural areas. The majority of the participants in this study sample lived in self-contained housing units or terrace homes where lawns were usually not available (Said, 2001). This suggested that they may have done lawn work sporadically in different places other than their primary residences.

Additionally, the Bahasa Malaysia and English versions of the Malaysian PASIPD adaptation revealed two different factors extracted. Gardening and lawn work were in a separate factor category for the English version, whilst the Bahasa Malaysia version revealed them under the heavy housework and home repair category. This was not unusual, as most (74%) of the Bahasa Malaysia participants were of Malay ethnicity, residing in rural or small town areas, and came from a lower income group. This reflected their normal activities of daily living doing household-related heavy chores. In contrast, English language participants were mostly in the higher income group and reflected their type of housing being more adapted for gardening or lawn work. It was possible that the English language participants did gardening and lawn work as more of a hobby than a chore. Another factor difference was that light housework and caring for another person were in a separate category in the Bahasa Malaysia version, as opposed to the English version. This may reflect the family function within the Malay ethnic setting, whereby domestic helpers are not readily available due to financial constraints. As a result, it was usual for the Bahasa Malaysia participants to take responsibility of light housework and caring for another person at home.

The statistical analyses conducted in the results, combined both the Malaysian adapted English and Bahasa Malaysia translated PASIPD versions based on collective responses within the same pool of population (Malaysians). There were significant differences in the response distribution between the two language versions in only three of the 12 items with some expected differences in the demographic categories. This reflects the different socio-demographic milieu of those who comprehend the adapted English or the Bahasa Malaysia versions of the PASIPD. Ethnic Malays were the majority of the respondents who answered the Bahasa Malaysia version of the PASIPD and they were found to be more actively involved in moderate sports, light and heavy housework activities. The construct validity and test-retest reliability were therefore an interpretation of results among Malaysians with SCI rather than assessment of the language differences. Wide-scale distribution of the questionnaire was done physically and digitally among individuals throughout Malaysia. The participants recruited, were national calibre athletes (Wilson & Khoo, 2013), members of non-governmental organizations (Ramakrishnan *et al.*, 2011) and sedentary common individuals with SCI recruited from various different parts of Malaysia (East and West of Malaysia). These PASIPD participants were community-dwelling individuals with SCI in Malaysia and the data therefore, represented the Malaysian context of PAL assessments. The overall reliability measures in the current study (r = 0.87) were slightly higher than de Groot's study sample with SCI (r = 0.77) (de Groot *et al.*, 2010).

The PASIPD questionnaire was validated from study samples that were generally well-educated Caucasians and individuals with locomotor disabilities (de Groot *et al.*, 2010; Jimenez-Pardo *et al.*, 2015 ; Tanhoffer *et al.*, 2012; van den Berg-Emons *et al.*, 2011; van der Ploeg *et al.*, 2007; Warms & Belza, 2004; Washburn *et al.*, 2002). Criterion validation of the PASIPD questionnaire revealed weak correlation (r = 0.22-0.60) compared to accelerometer-based measures of PAL assessments and some of the study sample were neither specific to SCI nor wheelchair-reliant (van den Berg-Emons *et al.*, 2011; van der Ploeg *et al.*, 2007; Warms & Belza, 2004). However, these low correlation coefficients were also found in questionnaires used among able bodied individuals, particularly the widely used International Physical Activity Questionnaire (r = 0.30-0.34) (Craig *et al.*, 2003; Ekelund *et al.*, 2006) and the Stanford 7-Day Recall Questionnaire (r = 0.36-0.60) (Richardson *et al.*, 2001). Additionally, a small study sample size can impact the precise measurement of a correlation and may have affected the relationships. Furthermore, accelerometer-based systems have been shown to underestimate PAL due to their poor upper limb movement detection (Berlin *et al.*, 2006). This is of special concern since, individuals in wheelchairs use upper limb movements for daily propulsion. Tanhoffer and co-workers' PASIPD criterion validation, comparing it to the doubly labelled water technique only revealed a non-significant underestimation of the physical activity energy expenditure by 3%, suggesting good criterion validity for energy expenditure estimation (Tanhoffer *et al.*, 2012). Other studies, compared the PASIPD to self-reported physical activity lists (de Groot *et al.*, 2010; Jimenez-Pardo *et al.*, 2015) that showed weak but significant correlations (r = 0.36-0.51) for PAL quantification.

The PASIPD questionnaire measured the average intensity of different types of activities using a standard MET based on able bodied samples and disregarded the participant's disability (mobility/motor/sensory), level of spinal injury (tetraplegia or paraplegia) or injury severity (complete vs incomplete) (Ainsworth *et al.*, 2011; Ginis *et al.*, 2005). The approach can be problematic as MET values tend to differ among various types of SCI, as well as being often much lower than for able bodied individuals (Collins *et al.*, 2010; Ginis *et al.*, 2005). Furthermore, the MET values, derived from the compendium of physical activities constantly changes as research progresses and is frequently updated (Ainsworth *et al.*, 2011). Thus, the criterion validity of PAL measures, using the PASIPD scores produced unsurprising weak (r = 0.36-0.51) correlations, even among a homogenous study sample with SCI (de Groot *et al.*, 2010). Further work would be warranted to assess the criterion validity of using the PASIPD questionnaire in a Malaysian setting, when compared against accelerometer-based systems for PAL quantification or doubly labelled water approaches for energy expenditure estimation.

3.7 Limitations

Several limitations to the study constrain our findings. The participants recruited comprised individuals who comprehended either English or Bahasa Malaysia. There are Malaysians with SCI who do not comprehend either language, communicating exclusively in Cantonese, Hokkien or Tamil, and they were not recruited. The sample size of 250 participants represent minimal requirements for the statistical analyses. Further work should include larger sample sizes that can also recruit individuals with different types of physical disabilities, such as stroke, cerebral palsy and traumatic brain injury.

This study represents only the first part of adaptation, translation, preliminary validation and test-retest reliability, where it has to be replicated with a larger sample size for more robust statistical analyses. Finally, criterion validity (assessment of the measurement against other physical activity measures) were not assessed for this study, and should be evaluated prior to wide scale use.

3.8 Conclusion

The Malaysian adapted English and translated Bahasa Malaysia PASIPD questionnaires intended to measure PAL in individuals with SCI, demonstrated acceptable construct validity and reliability measures. However, individual item reliability measures were weak in light housework and lawn work for the Bahasa Malaysia version and vigorous sports for the English version. The PASIPD has the potential to provide data and characterise activities of daily living in community-dwelling SCI population within the context of large-scale epidemiological studies. Further work is needed to validate the PASIPD questionnaire for its criterion validity (i.e; energy expenditure, PAL assessments) against other activity measures in a Malaysian setting.

CHAPTER 4: PUBLISHED PAPER 1

4.1 LEISURE TIME PHYSICAL ACTIVITY PARTICIPATION IN INDIVIDUALS WITH SPINAL CORD INJURY IN MALAYSIA: BARRIERS TO EXERCISE

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Mat Rosly, M participated in all the research design and coordination, collection of data, conducted the data analysis and remains as the primary author of the manuscript. Halaki, M, Mat Rosly, H and Husain, R assisted in the translation, gave conceptual advice on the design of the study and helped in data analysis and interpretation. Halaki, M, Hasnan, N, Davis, GM and Husain, R supervised the development of work and edited the manuscript.

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ARTICLE

Leisure time physical activity participation in individuals with spinal cord injury in Malaysia: barriers to exercise

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Abstract

Study design Cross-sectional.

Objectives An epidemiological study describing leisure time physical activities (LTPA) and the associations of barriers, sociodemographic and injury characteristics to moderate-vigorous aerobic exercise participation among individuals with spinal cord injury (SCI) in a developing Southeast Asian country.

Setting SCI community in Malaysia.

Methods The study sample consisted of 70 participants with SCI. Questionnaires were distributed containing an abbreviated Physical Activity Scale for Individuals with Physical Disabilities (items 2–6) and the Barriers to Exercise Scale using a 5-tier Likert format. Statistical analyses were χ^2 tests, odds ratios, and binary forward stepwise logistic regression to assess the association and to predict factors related to participation in moderate-vigorous intensity aerobic exercise (items 4 and 5).

Results Seventy-three percent of the study sample did not participate in any form of moderate or vigorous LTPA. The top three barriers to undertaking LTPA (strongly agree and agree descriptors) were expensive exercise equipment (54%), pain (37%) and inaccessible facilities (36%). Participants over the age of 35 years, ethnicity, health concerns, perceiving exercise as difficult and indicating lack of transport were significantly different ($p < 0.05$) between participation and non-participation in moderate-vigorous aerobic exercise type of LTPA. Age, ethnicity, indicated health concerns and lack of transport were the significant predictors in likelihood of participating in moderate-vigorous LTPA ($p < 0.1$).

Conclusion The issues raised depicted barriers within the intrapersonal (health concerns, exercising is too difficult, pain while exercising, age more than 35), interpersonal (different ethnicity), community (expensive exercise equipment), and policy levels (lack of or poor access to transportation, inaccessible facilities) that prevent LTPA participation.

Introduction

Aerobic and muscle strength fitness levels among community-dwelling individuals with chronic SCI have been reported to be low [1]. Activities that are of adequate intensity (moderate-vigorous) to improve health or fitness levels according to prescribed guidelines [2, 3], are important for lowering the risk of cardiometabolic diseases. Guidelines for improving health, fitness, and functional outcomes among the population with SCI have recommended moderate-vigorous aerobic exercises and resistance training [2, 3], both of which are within the domain of leisure time physical activities (LTPA). LTPA are performed during an individual's free time and may include sports or exercise participation, recreational activities or pre-planned moderate-vigorous upper body exercises that are separate from activities of daily living [4]. Participation in LTPA among the population with SCI globally consistently has shown that no more than 52% [5–9] undertake such activities on a regular basis. Although LTPA is an important component for improving positive psychological well-being and quality of life among a population with chronic SCI [10], performing LTPA alone may not

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necessarily be sufficient to provide health benefits or raise cardiometabolic fitness [11]. In addition, activities of daily living among individuals with SCI who use wheelchairs, as opposed to the able-bodied, may not be adequate for producing intensities that are health beneficial [12, 13], though some studies have reported otherwise [14, 15]. Therefore, in a population with SCI, the need for moderate-vigorous intensity LTPA performed over an adequate amount of time and frequency is crucial in maintaining or improving cardiometabolic fitness and muscle strength.

For individuals with SCI, maintaining an active physical lifestyle can be challenging, especially once they are reintegrated into the community [16] following completion of intensive rehabilitation therapies. Efforts to increase LTPA participation in a population with SCI are often impeded by their deconditioned capacity [17], physical impairments [7], poor motivation [18], rudimentary wheelchair skills [19], and a variety of highly interrelated barriers within the institutional, community and policy levels [7, 20–22]. Barriers to LTPA participation could be categorized into personal characteristics or environmental factors in accordance to the International Classification of Functioning, Disability and Health [23, 24]. Wheelchair users with SCI often have cited lack of adequate facilities, transportation and poor accessibility as reasons for their reduced LTPA participation [20, 25]. In addition, lack of motivation, lack of energy and physical limitations were reported as personal barriers among this group [7, 26]. Misconceptions toward individuals with SCI who ambulate often exist, since their disability is frequently perceived as less serious than for those who use wheelchairs. This led to poorer LTPA support and guidance resulting in reduced motivation to undertake LTPA [19].

Studies focusing on the barriers to LTPA participation in general largely have been reported in developed countries [25, 26] and within a western sociocultural perspective [19, 21]. In addition, studies reporting on barriers specifically associated with moderate-vigorous intensity aerobic exercise participation have reported domains in body functions and structures, activities and participation, personal or environmental factors as significant predictors [27, 28]. Epidemiological studies on LTPA participation rates and barriers to LTPA among the population with SCI from developing or underdeveloped regions are warranted, since this population often experiences significant socioeconomic limitations and poorer health support [29, 30]. The main objective of this study was to characterize self-reported LTPA participation rates that are moderate-vigorous in intensity for health benefits. The study also sought to identify the barriers to moderate-vigorous intensity aerobic exercise type of LTPA reported by individuals with SCI in the context of a developing country (Malaysia), and to investigate associations based on clinical details, socioeconomic demographics and injury characteristics. These findings may assist in future research and policy development that support a more versatile and innovative approach in improving LTPA participation among individuals with SCI within the sociodemographic milieu of a developing country.

Methods

Methodology

The study design was a retrospective statistical analysis of cross-sectional data extracted from a questionnaire. Ethical approval was obtained from the University of Malaya Medical Research Ethics Committee (protocol number: MECID 201410-609), from which members registered under their rehabilitation programs were recruited. Following written informed consent, participants responded to a series of questionnaires broken down into three components. The first part requested socioeconomic and other demographic information from each participant with SCI. The second part covered questions pertaining to their current LTPA levels using an abbreviated version of the Physical Activity Scale for Individuals with Physical Disabilities (PASIPD) questionnaire [31]. The last part surveyed the barriers involved in maintaining LTPA among individuals with SCI using the Barriers to Exercise Scale (BTES) [7] that was adapted (as described below) for a Malaysian sociocultural setting. For the purpose of this current study, LTPA was defined as leisure activities, light, and moderate-vigorous intensity exercise participation.

Participants

The questionnaires were physically distributed to individuals with SCI attending outpatient rehabilitation programs at the University of Malaya Medical Center. This study sample represented community-dwelling individuals with SCI, where attendees were not explicitly involved in competitive sports. This was specifically to avoid biased recruitment of those for whom exercise was primarily for sport performance. Seventy participants from a total of 173 individuals in the databases were surveyed. Based on four inclusion criteria; (i) SCI, (ii) competent with either Bahasa Malaysia or English languages, (iii) time since SCI of at least 1 year, and, (iv) age between 18 and 65 years, individuals from the database were filtered for participation. An exclusion criterion of neurological lesions affecting cognitive functions was applied. Figure 1 shows the number of participants recruited for the study sample.

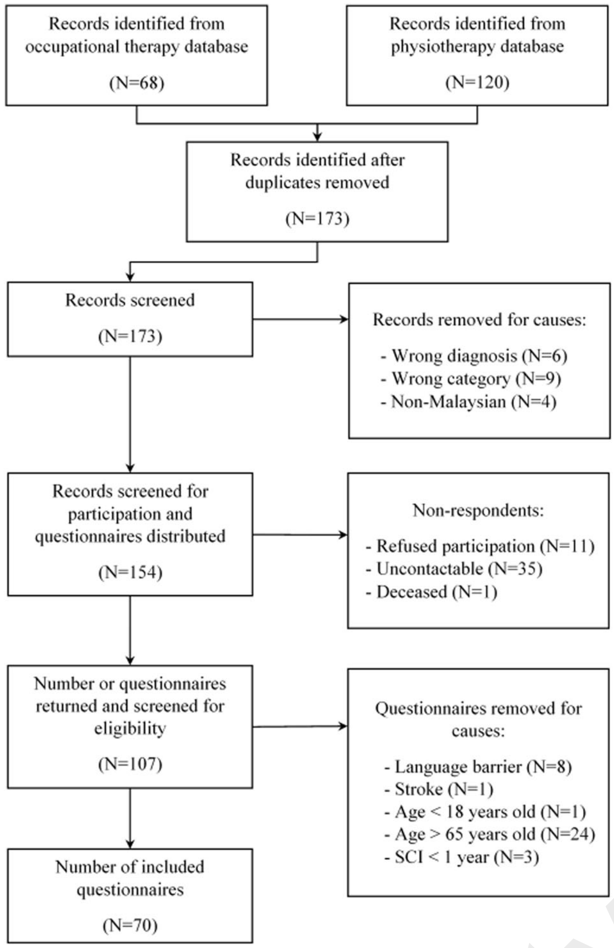

Fig. 1 Registration list and participation extraction

Instruments

The PASIPD [31], designed for individuals with physical disabilities, consists of a 2-part, 13-item questionnaire covering the domains of LTPA (items 1–6), household activities (items 7–12) and occupation (item 13) objectively recalled over the preceding 7 days. The PASIPD has been used in several economically-developed countries (Netherlands, Canada, Australia and United States of America) [7, 31, 32], as an instrument to measure physical activity levels in average metabolic equivalents of task (MET) in hours per day. For this current study, the use of the adapted PASIPD questionnaire in Bahasa Malaysia was piloted for its content and face validity. However, criterion validity of the questionnaire to "estimate" accurate energy expenditure and physical activity levels currently is untested within the Malaysian context. Hence, this study only sought to characterize "descriptive" content—describing LTPA participation information within a community-dwelling SCI sample. For this purpose, the PASIPD was amended to consist of only five of the original questions (items 2–6), covering leisure activities, light, moderate and vigorous sports and resistance exercises. The responses in each item were further abbreviated to consist of only the first part (response options: never, seldom, sometimes, and often) where answers to the average hours spent in each activity were omitted.

The third part of the questionnaire covered the perceived barriers to LTPA among individuals with SCI. For this purpose, the BTES was used to evaluate the degree of agreement for each of the barriers listed. The 23-items included originally were extracted from the Barriers to Physical Activity and Disability Survey [33] with two added items adapted from Roberton and colleagues' study [7]. Following pilot one-to-one sample interviews conducted among 32 Malaysian individuals with SCI using the BTES, the addition of two more items (costly exercise equipment and bad weather) into the questionnaire were deemed necessary, bringing it to 27 items. The questionnaire served to assess the barriers to LTPA among community-dwelling individuals with SCI within the Malaysian demographic environment. The Malaysian version of the PASIPD and the modified BTES were translated (forward and backward), adapted and validated (face, content and construct validated) to ensure that the meaning remained intact. Pilot test data showed good inter-item correlation between the BTES items, with Cronbach's $\alpha = 0.83$. Participants indicated their agreement on each item relating to the barriers of LTPA using a 5-tier Likert scale ranging from strongly agree, agree, neutral, disagree to strongly disagree. An open-ended comments section was added at the end of the section. Both the adapted English and Bahasa Malaysia versions were made available to participants.

Data analysis

Data were processed using SPSS version 22.0 (SPSS Inc., Chicago, Illinois, USA) and Excel 2013 (Microsoft Corp., Redmond, Washington, USA). Items 2 and 3 query leisure and light sports activities, categorized as MET 2.5-3.0, on average. These are not of sufficient intensity to be categorized as "moderate-vigorous" based on this internationally-standardized PASIPD questionnaire [31]. Item 6, although reporting an average MET score of 5.5 [31], categorizes resistance training and therefore is not aerobic exercise requiring moderate-vigorous intensity [2, 3]. Hence, only moderate-vigorous intensity aerobic exercises (items 4 and 5) were used to assess the association and predict factors using χ^2 tests, odds ratios and binary forward stepwise logistic regression. The groups (demographic, LTPA and perceived barriers) were then coded into binomial categories as follows: (i) non-participation (never) and participation (seldom, sometimes or often) in moderate-vigorous aerobic exercise type of LTPA (items 4 and 5); (ii) agreement to barriers to LTPA (yes: strongly agree or agree) vs. non-agreement (no: neutral, disagree or strongly disagree); (iii) education level (non-graduate or graduate); (iv) ethnicity (Malay or Non-Malay); (v) total monthly household income (≤RM2499 or ≥RM2500); (vi) employment (paid employment or other); (vii) type of mobility aid (wheelchair or non-wheelchair); (viii) state of residence (Selangor or outside Selangor); (ix) cause of injury (traumatic or non-traumatic); (x) area (urban or rural); (xi) type of housing (good accessibility or poor accessibility)—based on availability of lifts or ramps for wheelchair access; (xii) relationship status (in a relationship or not in a relationship); (xiii) American Spinal Injury Association (ASIA) Impairment Scale (AIS) (A or B/C/D); (xiv) age (18–35 years or 36–65 years); (xv) sex (male or female); (xvi) time since injury (≤5 or ≥6 years)—grouped based on moderate-vigorous LTPA percentage of participation; and (xvii) neurological level (paraplegia or tetraplegia). χ^2 tests and odds ratios were used to assess the association between the demographic categories or a given barrier to the participation in moderate-vigorous LTPA.

A binary forward stepwise logistic regression was performed to predict non-participation in LTPA at moderate-vigorous intensity using the binary predictors which exhibited a χ^2 p-value <0.20 (Tables 1 and 2). χ^2 analysis was used to assess the differences in data distribution between the English and Bahasa Malaysia versions. However, distribution of answers was only different ($p < 0.05$) in two of the barriers ("I don't have the energy to exercise" and "I am not motivated enough to exercise") and four of the demographic categories (ethnicity, sex, type of house and area category). Therefore, language was also included as a predictor in the logistic regression. Significance levels of $p < 0.05$ for χ^2 and $p < 0.1$ for the logistic regression were used.

Results

Participants' demographic summary

Aggregated data from the participants demonstrated one third were female, and the majority were individuals with paraplegia (82.9%). A large portion of the participants (85.7%) resided in the state of Selangor (65.7%) or Kuala Lumpur (20%), the capital city of Malaysia. The majority were in a lower income bracket, (70% with a monthly household income of less than RM2500, including 27% of individuals earning less than RM1000). The mean age was 39 ± 12.6 years and time since injury 9.6 ± 9.2 years. The demographic details of the participants are presented in Table 3.

Leisure time physical activity participation

Using the modified PASIPD questionnaire, the overall frequency distribution for each type of LTPA within this study sample revealed that more adults with SCI partake in leisure activities, light or resistance-training exercises compared to aerobic moderate-vigorous exercise (Fig. 2). Seventy-three (73%) percent did not participate in any form of moderate or vigorous LTPA. When categorized separately, 80 or 85% of participants did not participate in moderate or vigorous LTPA, respectively.

Barriers to leisure time physical activity participation

The barriers to LTPA reported by participants, as shown in Fig. 3 were presented in three categories; agree (agree and strongly agree), neutral and disagree (disagree and strongly disagree). The top three barriers endorsed (strongly agree and agree), were costly exercise equipment (54%), pain while exercising (37%), and no access to facilities (36%). Open ended comments or answers were sometimes provided by the survey participants and one particular comment seemed to stand out. 18 of the 70 (26%) participants added "laziness" as a factor for their lack of LTPA.

No significant differences were observed between moderate-vigorous LTPA participation and non-participation in the type of neurological classification (AIS or neurological level) or time since injury. Malays were three times more likely to participate in moderate-vigorous LTPA compared to non-Malays and those aged between 18 and 35 years were three times more likely to participate in moderate-vigorous LTPA compared to those older than 35 years (Table 1). The lower income group (with total monthly household income of less than RM2500 per month) were not different in reporting issues related to costly programs, expensive equipment, lack of transport or no personal attendant (but did so for health concerns $p = 0.014$ and wetting or soiling issues $p = 0.030$) compared to the upper income group ($p > 0.05$).

χ^2 analysis and odds ratios indicated that age greater than 35 years, ethnicity, health concerns, having transportation difficulties and perceiving exercise to be difficult were significantly ($p < 0.05$) different between moderate-vigorous LTPA participation and non-participation (Tables 1 and 2). Participants who indicated transportation difficulties as a barrier were nine times less likely to participate in moderate-vigorous LTPA, whilst those who reported health concerns were five times less likely to participate in moderate-vigorous LTPA. However, those who agreed to exercise difficulty being a barrier were no less likely to participate and those who did not agree were 32% more likely to participate. The barriers identified were

Table 1 χ^2 analysis of participation in moderate-vigorous leisure time physical activities with participants' demographic and clinical factors

Variable	Groups	Participation in moderate-vigorous LTPA (%)			χ^2	p	Odds ratio (95% CI)
		Yes ($N = 19$)	No ($N = 51$)	All ($N = 70$)			
Age	18–35 years[a]	13 (39%)	20 (61%)	33 (47%)	4.74	0.029*	3.36 (1.10, 10.28)
	36–65 years	6 (16%)	31 (84%)	37 (53%)			
Time since injury	≤5 years[a]	9 (26%)	25 (74%)	34 (49%)	0.02	0.90	0.94 (0.33, 2.69)
	≥6 years	10 (28%)	26 (72%)	36 (51%)			
Sex	Male[a]	13 (27%)	36 (73%)	49 (70%)	0.03	0.86	0.90 (0.29, 2.82)
	Female	6 (29%)	15 (71%)	21 (30%)			
Ethnicity	Malays[a]	13 (39%)	20 (61%)	33 (47%)	4.74	0.029*	3.36 (1.10, 10.28)
	Non-Malays	6 (16%)	31 (84%)	37 (53%)			
Cause of injury	Traumatic[a]	12 (32%)	26 (68%)	38 (54%)	0.83	0.36	1.65 (0.56, 4.86)
	Non-traumatic	7 (22%)	25 (78%)	32 (46%)			
AIS classification	A[a]	7 (25%)	21 (75%)	28 (40%)	0.44	0.51	0.70 (0.24, 2.03)
	B/C/D	12 (29%)	30 (71%)	42 (60%)			
Neurological level	Paraplegia[a]	18 (31%)	40 (69%)	58 (83%)	0.11	0.74	0.83 (0.28, 2.47)
	Tetraplegia	1 (8%)	11 (92%)	12 (17%)			
State	Selangor[a]	12 (26%)	34 (74%)	46 (66%)	0.08	0.78	0.86 (0.29, 2.57)
	Outside Selangor	7 (29%)	17 (71%)	24 (34%)			
Area type	Urban[a]	10 (23%)	33 (77%)	43 (61%)	0.85	0.36	0.61 (0.21, 1.76)
	Rural	9 (33%)	18 (67%)	27 (39%)			
Type of housing	Good accessibility[a]	12 (23%)	40 (77%)	52 (74%)	1.69	0.19	0.47 (0.15, 1.48)
	Poor accessibility	7 (39%)	11 (61%)	18 (26%)			
Relationship status	In a relationship[a]	9 (24%)	28 (76%)	37 (53%)	0.32	0.57	0.74 (0.26, 2.13)
	Not in a relationship	10 (30%)	23 (70%)	33 (47%)			
Education level	Non-graduate[a]	10 (23%)	34 (77%)	44 (63%)	1.17	0.28	0.56 (0.19, 1.62)
	Graduate	9 (35%)	17 (65%)	26 (37%)			
Employment	Paid employment[a]	10 (37%)	17 (63%)	27 (39%)	2.18	0.14	2.22 (0.76, 6.49)
	Other	9 (21%)	34 (79%)	43 (61%)			
Total monthly household income[b]	≤RM2499[a]	13 (27%)	36 (73%)	49 (70%)	0.03	0.86	0.90 (0.29, 2.82)
	≥RM2500	6 (29%)	15 (71%)	21 (30%)			
Type of mobility aid	Wheelchair[a]	13 (25%)	38 (75%)	51 (73%)	0.26	0.61	0.74 (0.23, 2.35)
	Non-wheelchair	6 (32%)	13 (68%)	19 (27%)			

1 United States Dollar = RM4.2, 1 Euro = RM4.5, 1 Great Britain Pound = RM6.4; Odds ratio represents the odds of Group a participating in moderate-vigorous leisure time physical activities

LTPA leisure time physical activity, *AIS* American Spinal Injury Association (ASIA) Impairment Scale, χ^2 chi-square, *CI* confidence intervals, *18–35 years* young adults, *36–65 years* middle and older adults, *RM* ringgit Malaysia, *OR* odds ratio

*Significant ($p < 0.05$) difference between those who participated and did not participate in moderate-vigorous LTPA

[a] Reference category

[b] RM conversion rates at time of study (25th November 2015)

categorized into themes according to the levels within the social ecological model [22]. These barriers existed within the intrapersonal (health concerns, exercise is too difficult, pain while exercising, age more than 35), interpersonal (different ethnicity), community (expensive exercise equipment), and policy levels (lack of or poor access to transportation, inaccessible facilities).

Predictors of moderate-vigorous leisure time physical activity participation

The binary forward stepwise logistic regression model was statistically significant, $\chi^2 = 20.55$, $p < 0.001$, explained 36.9% (Nagelkerke R^2) of the variance in participation and correctly classified 75.7% of cases. The only significant predictors ($p < 0.1$) of a higher likelihood of not

Table 2 χ^2 analysis of participation in moderate-vigorous leisure time physical activities with barriers reported

Variable	Groups	Participation in moderate-vigorous LTPA (%)			χ^2	p	Odds ratio (95% CI)
		Yes ($N = 19$)	No ($N = 51$)	All ($N = 70$)			
Exercise equipment too costly	Non-agreement[a]	12 (38%)	20 (62%)	32 (46%)	3.20	0.07	2.66 (0.90, 7.89)
	Agreement	7 (18%)	31 (82%)	38 (54%)			
Pain prevents me from exercising	Non-agreement[a]	15 (34%)	29 (66%)	44 (63%)	2.89	0.09	2.85 (0.83, 9.78)
	Agreement	4 (15%)	22 (85%)	26 (37%)			
I don't have access to an appropriate facility	Non-agreement[a]	14 (31%)	31 (69%)	45 (64%)	1.00	0.32	1.81 (0.56, 5.80)
	Agreement	5 (20%)	20 (80%)	25 (36%)			
I don't have a personal care attendant who will help me exercise	Non-agreement[a]	15 (31%)	34 (69%)	49 (70%)	0.99	0.32	1.88 (0.54, 6.53)
	Agreement	4 (19%)	17 (81%)	21 (30%)			
Health concerns prevent me from exercising as much as I would like	Non-agreement[a]	17 (35%)	32 (65%)	49 (70%)	4.71	0.030*	5.05 (1.05, 24.29)
	Agreement	2 (10%)	19 (90%)	21 (30%)			
It costs too much to attend an exercise program	Non-agreement[a]	13 (26%)	37 (74%)	50 (71%)	0.12	0.73	0.82 (0.26, 2.58)
	Agreement	6 (30%)	14 (70%)	20 (29%)			
I don't have the energy to exercise	Non-agreement[a]	16 (32%)	34 (68%)	50 (72%)	2.09	0.15	2.67 (0.68, 10.43)
	Agreement	3 (15%)	17 (85%)	20 (28%)			
I am worried about wetting or soiling myself whilst exercising	Non-agreement[a]	16 (31%)	35 (69%)	51 (73%)	1.70	0.19	2.44 (0.62, 9.57)
	Agreement	3 (16%)	16 (84%)	19 (27%)			
I don't have the transportation to get me to a fitness center	Non-agreement[a]	18 (35%)	34 (65%)	52 (74%)	5.71	0.017*	9.00 (1.11, 73.21)
	Agreement	1 (6%)	17 (94%)	18 (26%)			
Bad weather (e.g., rainy days/hot days)	Non-agreement[a]	15 (27%)	40 (73%)	55 (78%)	0.00	0.96	1.03 (0.28, 3.74)
	Agreement	4 (27%)	11 (73%)	15 (22%)			
I am not motivated enough to exercise	Non-agreement[a]	16 (28%)	41 (72%)	57 (82%)	0.13	0.72	1.30 (0.32, 5.35)
	Agreement	3 (23%)	10 (77%)	13 (18%)			
I don't know how to exercise	Non-agreement[a]	17 (29%)	41 (71%)	58 (83%)	0.80	0.37	2.07 (0.41, 10.48)
	Agreement	2 (17%)	10 (83%)	12 (17%)			
My work prevents me from exercising as much as I would like	Non-agreement[a]	16 (27%)	43 (73%)	59 (84%)	0.00	0.99	0.99 (0.23, 4.21)
	Agreement	3 (27%)	8 (73%)	11 (16%)			
I don't know where to exercise	Non-agreement[a]	18 (31%)	41 (69%)	59 (84%)	2.15	0.14	4.39 (0.52, 36.91)
	Agreement	1 (9%)	10 (91%)	11 (16%)			
Exercising is too difficult	Non-agreement[a]	19 (32%)	40 (68%)	59 (84%)	4.86	0.027*	Could not be computed
	Agreement	0 (0%)	11 (100%)	11 (16%)			
I feel uncomfortable or self-conscious in a fitness center	Non-agreement[a]	16 (27%)	43 (73%)	59 (84%)	0.00	0.99	0.99 (0.23, 4.21)
	Agreement	3 (27%)	8 (73%)	11 (16%)			
I don't have the time to exercise	Non-agreement[a]	18 (30%)	43 (70%)	61 (87%)	1.34	0.25	3.35 (0.39, 28.76)
	Agreement	1 (11%)	8 (89%)	9 (13%)			
Exercise is boring and monotonous	Non-agreement[a]	18 (29%)	44 (71%)	62 (89%)	0.98	0.32	2.86 (0.33, 24.98)
	Agreement	1 (12%)	7 (88%)	8 (11%)			
I don't have support from friends or family to exercise	Non-agreement[a]	18 (29%)	45 (71%)	63 (90%)	0.65	0.42	2.40 (0.27, 21.37)
	Agreement	1 (14%)	6 (86%)	7 (10%)			
Exercise will not improve my condition	Non-agreement[a]	19 (30%)	44 (70%)	63 (90%)	2.90	0.09	Could not be computed
	Agreement	0 (0%)	7 (100%)	7 (10%)			
Family responsibilities prevent me from exercising	Non-agreement[a]	17 (27%)	47 (73%)	64 (91%)	0.13	0.72	0.72 (0.12, 4.31)
	Agreement	2 (33%)	4 (67%)	6 (9%)			

Table 2 (continued)

Variable	Groups	Participation in moderate-vigorous LTPA (%)			χ^2	p	Odds ratio (95% CI)
		Yes ($N = 19$)	No ($N = 51$)	All ($N = 70$)			
I have no interest in exercising	Non-agreement[a]	19 (30%)	45 (70%)	64 (91%)	2.45	0.12	Could not be computed
	Agreement	0 (0%)	6 (100%)	6 (9%)			
I am too old to exercise	Non-agreement[a]	18 (28%)	47 (72%)	65 (93%)	0.14	0.71	1.53 (0.16, 14.65)
	Agreement	1 (20%)	4 (80%)	5 (7%)			
I am afraid to leave my home to exercise	Non-agreement[a]	19 (29%)	47 (71%)	66 (94%)	1.58	0.21	Could not be computed
	Agreement	0 (0%)	4 (100%)	4 (6%)			
I am satisfied with my physical appearance, so I don't need to exercise	Non-agreement[a]	19 (28%)	49 (72%)	68 (97%)	0.77	0.38	Could not be computed
	Agreement	0 (0%)	2 (100%)	2 (3%)			
It is just not worth the time it takes to exercise	Non-agreement[a]	19 (28%)	49 (72%)	68 (97%)	0.77	0.38	Could not be computed
	Agreement	0 (0%)	2 (100%)	2 (3%)			
Exercise will make my condition worse	Non-agreement[a]	19 (28%)	49 (72%)	68 (97%)	0.77	0.38	Could not be computed
	Agreement	0 (0%)	2 (100%)	2 (3%)			

Odds ratio represents the odds of Group a participating in moderate-vigorous leisure time physical activities; "Could not be computed" denotes an odds ratio could not be calculated because there were no participants in one of the groups

LTPA leisure time physical activity, χ^2 chi-square, *CI* confidence intervals, *agreement* strongly agree or agree, *non-agreement* neutral, disagree or strongly disagree

*Significant ($p < 0.05$) difference between those who participated and did not participate in moderate-vigorous LTPA

[a] Reference category

participating in moderate-vigorous LTPA were age, ethnicity, indicating that transportation was a problem and indicating that health concerns were an issue (Table 4; Fig. 4).

Discussion

Findings from this study indicated that the majority (73%) of this at-risk sample of individuals with SCI did not participate in moderate-vigorous intensity LTPA as recommended by the American College of Sports Medicine [34], World Health Organization [4], the SCI Action Canada® [35] and Exercise and Sports Science Australia [3] guidelines. Non-Malays with SCI were less likely to participate in moderate-vigorous LTPA compared to Malays, which may indicate difficulties in community reintegration after their disability, limited resources or different cultural expectations [16, 36]. The reported rates of moderate-vigorous LTPA participation in the current study were comparable to a Western Australian study by Roberton and colleagues [7], wherein the majority of their study participants reported "never" engaging in moderate (73%) or vigorous (86%) LTPA. Additionally, a study in Canada [9] observed similar participation rates (36%) in aerobic exercise type of LTPA that are intensity-adequate, whilst a report from Switzerland revealed a higher (48.9%) proportion in their study sample that met World Health Organization recommendations [6]. The consequences of SCI were known to have brought about a more than 50% reduction in sports participation [37]. This trend has been reported to be associated with increased cardiometabolic risk resulting in premature mortality [38].

Given minimal moderate-vigorous LTPA participation rates (27%) observed within this study sample, more versatile LTPA promotion efforts clearly need to be implemented. The common recurrent themes identified that were perceived as barriers to moderate-vigorous LTPA participation existed within the intrapersonal, interpersonal, policy, and community levels [22]. Interestingly, in the current study sample, barriers at the intrapersonal level [22] or personal characteristics [24] such as laziness, lack of motivation, perceived boring and monotonous exercises or no interest in exercising were less pronounced than had been reported in an Australian SCI study [7]. Laziness has been reported to reduce the odds of exercising among high

Table 3 Demographic details of participants

Demographic factor	Mean ± standard deviation	
Age (years)	39 ± 12.6	
Time since injury (years)	9.6 ± 9.2	
Demographic factor	Frequency (%)	
Language used	Bahasa Malaysia: 49 (70%)	English: 21 (30%)
Sex	Male: 49 (70%)	Female: 21 (30%)
Ethnicity	Malay: 33 (47.1%)	Indian: 10 (14.3%)
	Chinese: 21 (30%)	Others: 6 (8.6%)
Cause of injury	Motor vehicle accident: 24 (34.3%)	Fall: 13 (18.6%)
	Medical/surgical complication: 24 (34.3%)	Gunshot: 1 (1.4%)
		Others: 8 (11.4%)
Neurological level	Paraplegia: 58 (82.9%)	Tetraplegia: 12 (17.1%)
AIS classification	A: 28 (40%)	C: 13 (18.6%)
	B: 6 (8.6%)	D: 23 (32.8%)
Relationship status	Single: 30 (42.9%)	Married: 33 (47.1%)
	In a relationship: 4 (5.7%)	Divorced: 3 (4.3%)
State	Selangor: 46 (65.7%)	Other states: 10 (14.3%)
	Kuala Lumpur: 14 (20%)	
Area category	Rural: 9 (12.9%)	City: 43 (61.4%)
	Small town: 18 (25.7%)	
Education level	No formal education: 1 (1.4%)	Diploma: 13 (18.6%)
	Primary school: 8 (11.4%)	Tertiary—Bachelor's degree: 10 (14.3%)
	Secondary school—PMR: 7 (10%)	Postgraduate—Master's degree: 1 (1.4%)
	Secondary school—SPM: 28 (40%)	Postgraduate—PhD: 2 (2.9%)
Type of housing	Flat: 7 (10%)	Semi-detached: 4 (5.7%)
	Apartment/condominium: 10 (14.3%)	Bungalow: 2 (2.9%)
	Terrace: 36 (51.4%)	Others: 11 (15.7%)
Employment status	Working: 27 (38.6%)	Student: 6 (8.6%)
	Homemaker: 5 (7.1%)	Unemployed: 23 (32.8%)
	Retired: 9 (12.9%)	
Total monthly household income (in RM[a])	≤RM999: 19 (27.1%)	RM2500–RM3499: 10 (14.3%)
	RM1000- RM2499: 30 (42.9%)	RM3500–RM4999: 3 (4.3%) ≥ RM5000: 8 (11.4%)
Type of mobility aid	Motorized wheelchair: 5 (7.2%)	Canes, crutches or walking frames: 19 (27.1%)
	Manual wheelchair: 46 (65.7%)	

1 United States Dollar = RM4.2; 1 Euro = RM4.5; 1 Great Britain Pound = RM6.4

SPM equivalent to Malaysian certificate of education, *PMR* equivalent to Malaysian certificate of lower secondary assessment, *AIS* American Spinal Injury Association (ASIA) Impairment Scale, *RM* ringgit Malaysia

[a] RM conversion rates at time of study (25th November 2015)

income individuals with SCI [39], as seen in the current study. Policies to improve services with regard to transport, accessibility and costly exercise equipment need to be addressed to increase LTPA participation. Home training programs may assist in overcoming issues with transportation or difficulties in accessing exercise facilities. The significant χ^2 association of moderate-vigorous LTPA with age ($p < 0.05$) predicts that individuals with SCI are less likely

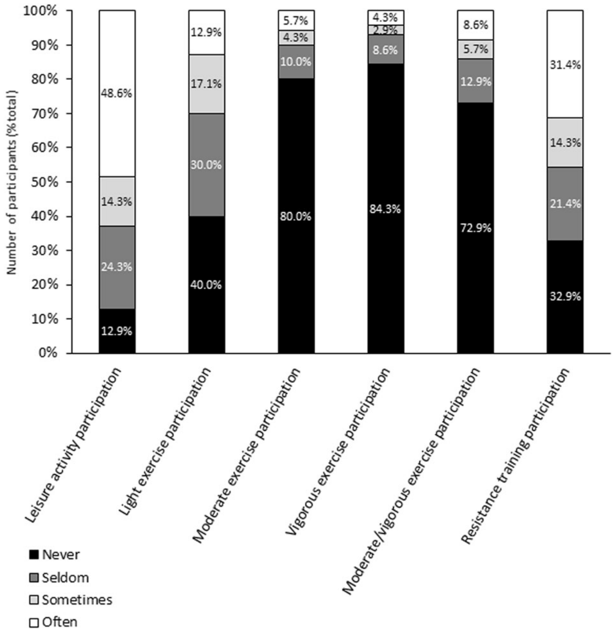

Fig. 2 Percentage of participants engaging in leisure time physical activities

Demographic data from this study revealed a finding that the majority of the study sample were within the lower income bracket (70% earning less than RM2500; ~600USD per month), with about a third of them unemployed (32.9%). Interestingly, there were no significant differences observed across the income gradient for indicating expensive exercise equipment, costly programs or the lack of a personal attendant as barriers to moderate-vigorous LTPA participation. However, the study sample may still be considered more privileged financially since the participants recruited were from a semi-subsidized rehabilitation program. The reported income from a fully government-funded SCI study sample from a similar region had 76% earning less than RM1000 per month (~USD 320 per month) [30] compared to 27% from the current study. Consequently, these findings can be important in ideating LTPA or equipment that are relatively cheaper and more "affordable" for the lower income bracket. The application of interactive technology or behavior change therapy [41–44] may improve compliance to health-beneficial LTPA that are more enjoyable and wheelchair-user friendly.

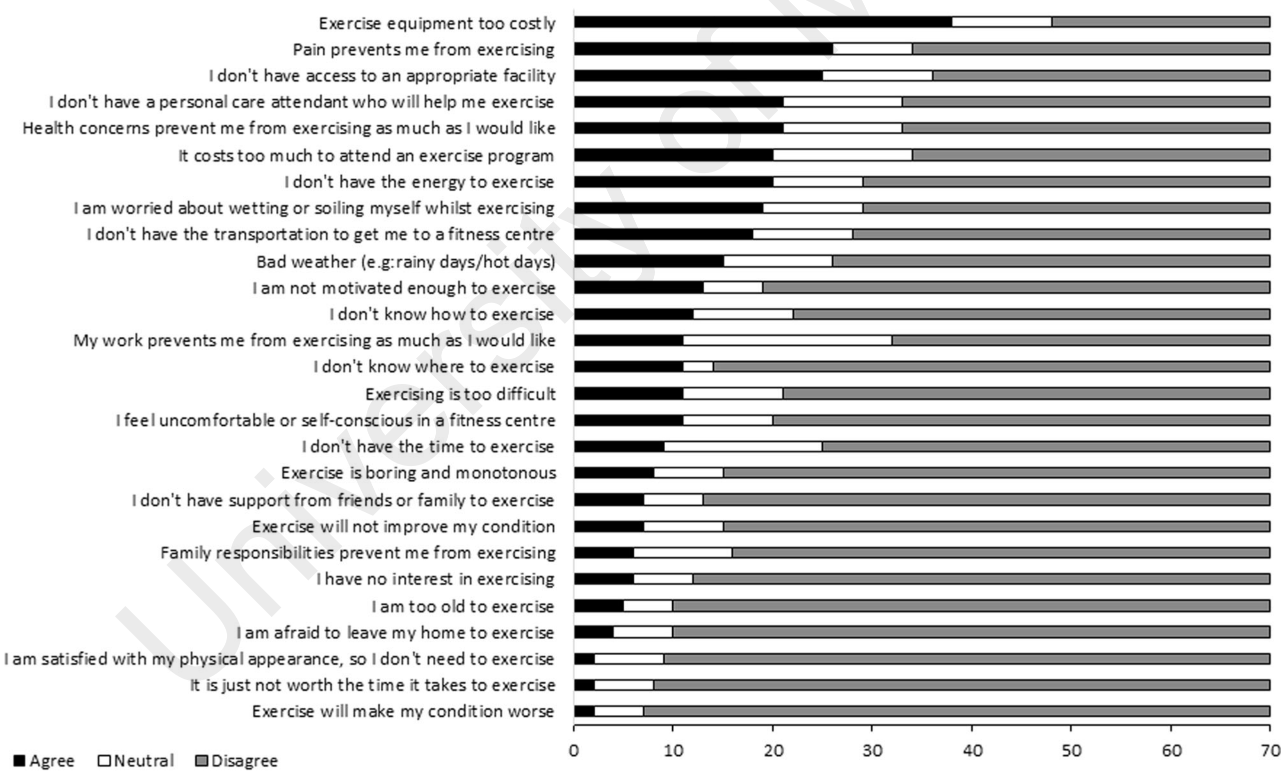

Fig. 3 Barriers to leisure time physical activities

to participate after the age of 35. A similar study by Jörgensen et al. also [8] reported lower LTPA levels among older individuals with SCI and is unsurprising as it is also commonly seen among the able-bodied population [40].

The current study reported that participation in moderate-vigorous LTPA was not associated with either type of neurological classification or time since injury. Of notable importance was that those who indicated that exercising was

Table 4 Factors related to participation in moderate-vigorous intensity leisure time physical activities

Variable	Regression coefficient, b	SE	Wald statistic	*p*	Exp(B)	95% CI	
						Lower	Upper
Age	1.36	0.65	4.36	0.037[a]	3.88	1.09	13.86
Ethnicity	1.34	0.65	4.22	0.040[a]	3.81	1.06	13.68
I don't have the transportation to get me to a fitness center	2.38	1.15	4.31	0.038[a]	10.84	1.14	102.90
Health concerns prevent me from exercising as much as I would like	1.50	0.89	2.83	0.092[a]	4.50	0.78	25.88
Constant	−5.63	1.55	13.28	0.000	0.004		

Model summary

−2 Log likelihood	Cox and Snell R^2	Nagelkerke R^2
61.301	0.254	0.369

Classification table

Observed	Predicted			
	Participation in moderate-vigorous LTPA			
		Yes	No	Percentage correct
Participation in moderate-vigorous aerobic exercise LTPA	Yes	6	13	31.6
	No	4	47	92.2
Overall percentage (%)				75.7

Analysis by binomial forward stepwise logistic regression

SE standard error, *CI* confidence intervals, *LTPA* leisure time physical activity, *Exp(B)* exponentiation of the B coefficient

[a]Significant ($p < 0.1$) factor related to participation in moderate-vigorous LTPA

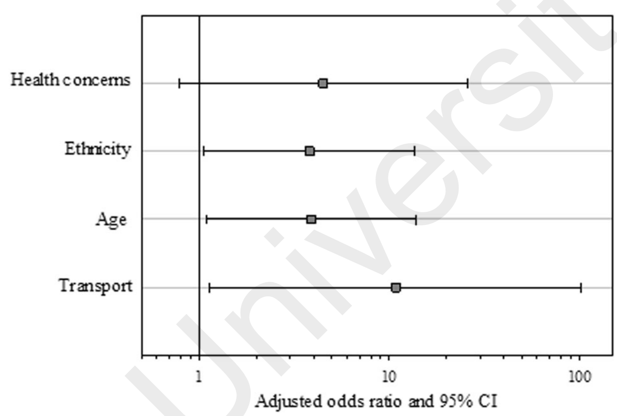

Fig. 4 Adjusted odds ratio for factors related to participation in moderate-vigorous intensity leisure time physical activities

difficult and posed as a barrier were not likely to participate. This may be due, in part, to their actual experience in exercising at moderate or vigorous intensities that may have influenced their tendency to participate. Although individuals with different levels of SCI may perceive more or different barriers to LTPA, it was difficult to categorize the different degrees of limitation in SCI via the questionnaire. However, previous studies [8, 45] have reported no associations or differences in the barriers reported by individuals with SCI with different degrees of limitation. Another study [46] reported no significant differences in the level of concerns in exercising between non-ambulatory individuals with tetraplegia or paraplegia. Health concerns were similarly [46] reported to be associated with LTPA participation, where they have expressed concerns on the lack of experienced staff in fitness facilities. There was also evidence that even healthcare professionals were unable to identify suitable LTPA opportunities for an individual with SCI [18]. These reasons may explain why individuals with SCI were more hesitant to participate in moderate-vigorous LTPA and efforts must be made to educate both healthcare professionals and those with SCI in proper, safe and moderate-vigorous LTPA practices. In view of these findings, advocacy in promoting the importance of moderate-vigorous LTPA participation, regardless of their AIS classifications, neurological limitations or level of injury, can be recommended.

Limitations

The study sample was recruited from a registration list that represented community-dwelling individuals with SCI either involved or not involved in sports participation. There may be possible selection bias since the registration may not have had participants who were actively involved in continuous sports competition (e.g., athletes). The study samples collected from previous studies [29, 36] within similar regions were primarily national calibre athletes or members of non-governmental sports groups, as they were recruited from organizations involved in continuous sports participation. However, the current study also was limited by the smaller study sample size ($N = 70$) and constrained within two major urban areas (Kuala Lumpur and Selangor). Further research will be needed to cover other major urban and rural areas within Malaysia. Another limitation to the current study was the omission of the reported amount of time spent on LTPA. This was because the PASIPD questionnaire has not been criterion validated to assess physical activity levels and the current study specifically focused only on the intensity of aerobic exercise type of LTPA recommended by health guidelines. The structure of the PASIPD questionnaire allows determination of average hours spent on moderate-vigorous aerobic exercise type of LTPA per week [31], but has been reported to have poor reliability [32, 47]. This is unlike the Physical Activity Recall Assessment and the Leisure Time Physical Activity questionnaires that reported in minutes, are designed specifically for samples of individuals with SCI, and with good reliability [35, 48]. Additionally, it would be interesting to determine whether the time spent per week fulfilled different durations (150 vs. 40–90 min) recommended by guidelines [2, 3, 35], for future consideration. However, the PASIPD was designed for various types of physical disabilities and can be self-administered by participants [31, 32], as opposed to requiring a trained interviewer in other available questionnaires for individuals with SCI [35, 48]. Conversely, such self-reported recall measures are also susceptible to recall bias [49], but for large epidemiological studies, this approach was more feasible from a financial perspective.

Although both languages were combined for analysis in this study, distribution of data between the two showed some significant differences. The differences in the demographic variables were expected, since Bahasa Malaysia is the native language for Malays instead of non-Malays with the differences in the barriers reflecting exercising habits apparent between Malays and non-Malays [36]. However, the language of the questionnaire used was not a significant predictor in the regression analysis. As a result, it was deemed appropriate to combine the results of both languages to reflect the responses of the Malaysian sample more precisely. Another strength to this study was that the study population was classified into their respective AIS classifications and neurological level. This allowed determination of whether moderate-vigorous LTPA participation was somewhat affected by the level (paraplegia or tetraplegia) or completeness of injury (AIS A or B/C/D), to which this study has reported non-significance ($p > 0.05$). However, since this was a cross-sectional study, determination of any causal relationship between moderate-vigorous LTPA participation and the reported barriers or relations to socioeconomic demographic factors could not be ascertained. Further work would be needed to assess possible causal relationships of the barriers with moderate-vigorous LTPA participation. The current study may assist in future research that would support a more versatile and innovative approach to improve LTPA promotion, narrowing the gap between academic research and clinical practice.

Conclusion

The majority of individuals with SCI within this community-dwelling study sample of urban Malaysians reported low LTPA participation that is intensity appropriate (moderate-vigorous) to achieve health benefits. The issues raised depicted barriers within the intrapersonal (health concerns, exercising is too difficult, pain while exercising, age more than 35), interpersonal (different ethnicity), community (expensive exercise equipment), and policy levels (lack of or poor access to transportation, inaccessible facilities). Efforts to promote moderate-vigorous intensity LTPA participation within the Malaysian setting should encourage more affordable exercise equipment, improvements in access to facilities, home training programs and identifying suitable moderate-vigorous LTPA for individuals with SCI.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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CHAPTER 4: PUBLISHED PAPER 2

4.1 EXERGAMING FOR INDIVIDUALS WITH NEUROLOGICAL DISABILITY: A SYSTEMATIC REVIEW

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Mat Rosly, M conducted and participated in all the systematic search, data extraction, analysis, interpretation and remains as the primary author of the manuscript. Mat Rosly, H gave conceptual advice on the design of the study, assisted in the systematic search and helped in data interpretation. Hasnan, N, Davis, GM and Husain, R supervised the development of work and edited the manuscript.

An updated content has been added following the publication. Additional brief search was conducted in December 2017 to identify any new studies found that met the inclusion and exclusion criteria. The PubMed search engine used the same terms indicated in the methodology section of the published work. Three new papers were identified at this stage. An additional paper was also found through hand search and the grey literature. The included papers have been added in Table 4.1.

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REVIEW

Exergaming for individuals with neurological disability: a systematic review

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ABSTRACT

Introduction: Exergames have the potential to enable persons with disabilities to take part in physical activities that are of appropriate "dose-potency" and enjoyable within a relatively safe home environment. It overcomes some of the challenges regarding transportation difficulties in getting to commercial gymnasium facilities, reducing physical activities perceived as "boring" or getting access into the built environment that may be "wheelchair unfriendly".
Objective: This systematic review assessed available evidence whether "exergaming" could be a feasible modality for contributing to a recommended exercise prescription according to current ACSM™ or WHO guidelines for physical activity.
Methods: Strategies used to search for published articles were conducted using separate search engines (Google Scholar™, PubMed™ and Web of Science™) on cardiometabolic responses and perceived exertion during exergaming among neurologically-disabled populations possessing similar physical disabilities. Each study was categorized using the SCIRE-Pedro evidence scale.
Results: Ten of the 144 articles assessed were identified and met specific inclusion criteria. Key outcome measures included responses, such as energy expenditure, heart rate and perceived exertion. Twelve out of the 17 types of exergaming interventions met the ACSM™ or WHO recommendations of "moderate intensity" physical activity. Exergames such as Wii Jogging, Bicycling, Boxing, DDR and GameCycle reported moderate physical activity intensities. While Wii Snowboarding, Skiing and Bowling only produced light intensities.
Conclusion: Preliminary cross-sectional evidence in this review suggested that exergames have the potential to provide moderate intensity physical activity as recommended by ACSM™ or WHO in populations with neurological disabilities. However, more research is needed to document exergaming's efficacy from longitudinal observations before definitive conclusions can be drawn.

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➤ IMPLICATIONS FOR REHABILITATION

- Exergaming can be deployed as physical activity or exercise using commercially available game consoles for neurologically disabled individuals in the convenience of their home environment and at a relatively inexpensive cost
- Moderate-to-vigorous intensity exercises can be achieved during exergaming in this population of persons with neurological disabilities. Exergaming can also be engaging and enjoyable, yet achieve the recommended physical activity guidelines proposed by ACSM™ or WHO for health and fitness benefits.
- Exergaming as physical activity in this population is feasible for individuals with profound disabilities, since it can be used even in sitting position for wheelchair-dependent users, thus providing variability in terms of exercise options.
- In the context of comprehensive rehabilitation, exergaming should be viewed by the clinician as "at least as good as" (and likely more enjoyable) than traditional arm-exercise modalities, with equivalent aerobic dose-potency as "traditional" exercise in clinic or home environments.

Introduction

Physical activity levels (PALs) amongst the global population of individuals with neurological disabilities lie within the lower end of the spectrum of children and adults. Buchholz and colleagues [1] have reported that among free-living SCI populations with chronic paraplegia, their PAL was lower (mean 1.56 ± 0.34) compared to an able-bodied general population (1.64–1.85). Children with cerebral palsy (CP) were found to be more inactive compared to their peers without disabilities, with an average upright time of 5.1, 2.5 and 0.5 h for children with spastic hemiplegia, spastic diplegia and spastic quadriplegia, respectively, versus 5.6 h for children without disabilities.[2] Field and colleagues' review on physical activity after stroke estimated only 4355.2 steps per day, a much lower value than the recommended 6500–8500 steps per day.[3] Participation in exercise to improve PAL is important even

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among neurologically disabled populations. It has been shown to improve:

i. physical capacity and muscle strength,[4–6]
ii. subjective well-being, self-perception and depressive symptoms,[7,8] and
iii. reduce risk of diabetes, obesity, androgen deficiency.[9,10]

However, amongst paraplegics and tetraplegics, normal activities of daily living alone are inadequate to produce sufficient physical activity intensity or duration to promote health benefits.[11–13] Globally, published studies have noted a significant drop in exercise adherence and low PAL following discharge from rehabilitation centres [14,15] or even during rehabilitation itself.[16] Lifestyles with increasing levels of physical inactivity may have accelerated trends to reduced fitness, increase cardiovascular complications and lead to poorer health outcomes in this at-risk population. Factors identified as barriers to post-rehabilitation moderate–vigorous physical activity have included:

i. Barriers to facilities, accessibility and other ergonomic problems associated with the built environment;[17–19]
ii. Socio-environmental issues, motivational and mental health problems;[17,18,20–22]
iii. High costs of equipment for exercise/sports participation [18–20] and
iv. Boredom associated with conventional arm exercise equipment, such as arm cranking or wheelchair roller systems.[23–25]

Since the availability of the Nintendo Wii® (Nintendo Inc., Kyoto, Japan) game system in 2006, researchers have explored the feasibility of using commercial home video game consoles as a means to integrate more physical activities into peoples' daily lifestyles through "exergaming". "Exergaming" involves integrating physical activity into a video game environment that requires active core and/or body movements to control the in-game experience. It has various types of game controllers used as interfaces, ranging from foot operated pads like Dance Dance Revolution® (DDR) (Konami Digital Entertainment Inc., Tokyo, Japan), motion sensor video cameras, Sony EyeToy® (Sony Computer Entertainment Inc., Tokyo, Japan) and exercise equipment such as bikes/wheelchair rollers/arm crank cycle such as GameCycle (Three Rivers Holdings, Mesa, AZ). These human-activated response devices trace gestures or movements of their user and simulate it into a video portrayal that can be viewed on a television, computer screen or image projector. Commercially available exergame producers, have released their own versions of movement-controlled game consoles. These include the EyeToy® for Playstation 2® and 3 or the Move® for PlayStation 3® add 4 (Sony Computer Entertainment Inc., Tokyo, Japan), Kinect™ for Microsoft's Xbox 360™ (Microsoft Inc., Redmond, WA), Nintendo's Wii® or Gamecube® (Nintendo Inc., Kyoto, Japan) and other consoles available in the market such as XaviX® (SSD Company Ltd., Shiga, Japan) and are relatively affordable.

Exergames have the potential to enable persons with disabilities to take part in exercises that are of appropriate "dose-potency" to achieve moderate–vigorous intensity physical activity, but are fun to play and deploy within a relatively safe home environment. It overcomes some of the previously mentioned barriers associated with exercise participation in this population. This particularly addresses some of the challenges regarding transportation difficulties in getting to commercial gymnasium facilities, reducing "boring" physical activities or getting access into the built environment that may be "wheelchair unfriendly". Furthermore, participation in exergames can be used to introduce an alternative option of leisure-time physical activity (LTPA), or to accumulate incidental physical activity into activities of daily living in neurologically disabled population.

This new area of research utilizes game entertainment technologies to achieve health benefits. Some studies have shown that exergaming achieves sufficient exercise intensity to meet American College of Sports Medicine (ACSM™) guidelines for the aerobic component of an exercise program.[26,27] However, prior work has concentrated on able-bodied populations such as children, adolescents and college students.[28–32] This review sought to investigate innovative approaches to exercise by evaluating the feasibility of commercially-available technologies for non-ambulatory populations that could be integrated into community or home-based environments, specifically through virtual technology and exergaming.

Methods

Data sources

Strategies used to search for published articles were conducted using available online bibliographic databases from three search engines within Google Scholar™, PubMed™ and Web of Science™ from September 2014 to March 2015. Search terms used were "All fields" headings for PubMed, "Keywords" in Web of Science and "with at least one of the words" for Google Scholar:

- Energy expenditure, heart rate, perceived exertion, metabolic equivalents, MET.
- exergam*, active video gam*, sports exergam*, Nintendo Wii, Xbox Kinect, Playstation Move. In these search engines, the "*" was employed to find derivative words from base words.

The literature collected was limited to publications written in English and published from 1 January 2006 until March 2015. The year 2006 was selected as it was in this year Nintendo debuted the Nintendo Wii, which popularized exergames as part of its Wii Fitness program. All study design methodologies and abstracts were screened by two reviewers, hand searched and filtered for reference articles within the collected data sets which focused on exergaming. Cardiometabolic and perceived exertion (*PE*) during exergaming such as oxygen consumption (VO_2), energy expenditure (*EE*), heart rate (*HR*) and rating of perceived exertion (*RPE*) were included in the criteria. Studies included, employed an indirect calorimetry for calculating *EE* and Borg's scale for *PE*. Instruments employed to estimate *EE* such as the Intelligent Device for Energy Expenditure and Activity (IDEEA), accelerometry based systems or the SenseWear Armband (SWA) were excluded. The inclusion and exclusion criteria were summarized as below;

Inclusion criteria

i. Chronic muscular or neurological impairments;
ii. focus on cardiometabolic and psychoperceptual outcomes of sports exergames;
iii. usage of commercially available home-based video game consoles,
iv. publications limited in English language;
v. published from year 2006 to 2015 and
vi. instruments using indirect calorimetry for *EE*, heart rate monitors for *HR* and BORG scale for *RPE*.

Exclusion criteria

i. Disabilities directly or indirectly related to obesity or cognitive impairment;
ii. psychological motivation, balance or postural stability, neurocognitive training, sensorimotor functioning and skill training outcomes and

Table 1. SCIRE-pedro level of evidence.

Level of evidence	Criteria
Level 1	Randomized Control Trial, pedro score > 6
Level 2	Randomized Control Trial, pedro score < 6
	Prospective Control Trial (not randomized)
	Cohort
Level 3	Case-control studies
Level 4	Pre–post-test
	Post-test
	Case series
Level 5	Observational
	Clinical Consensus
	Case report

iii. studies on technological aspect of the video game such as software development and hardware specifications.

The evidence level of each study was coded using the Spinal Cord Injury Rehabilitation Evidence (SCIRE) [33] system and the Physiotherapy Evidence Database (PEDro) [34] score. The SCIRE system utilizes a 5-tier category that distinguishes the various research designs and differing quality of each study. Table 1 provides description of each SCIRE-PEDro level of evidence, respectively.

Given the wide variety of possible physical, intellectual or psychological impairments that may be classified as "disability", widespread inclusion of all disabled populations was considered unwarranted. For this review, only physical disabilities associated with chronic muscular or neurological impairments were considered. Possible study populations selected were sampled from the demographic data of participants involved in Washburn's Physical Activity Scale for Individuals with Physical Disabilities (PASIPD) evaluation questionnaire.[35]

Repetition of articles located in the multiple databases were identified and eliminated. Figure 1 shows the data extraction process and synthesis. The final papers selected for this review were study designs that comprised quasi-experimental studies, cross-sectional investigations and case studies. Any relevant disclosure of published works was not retrieved from the authors.

Results

A total of 10 published works from the 144 articles assessed, which met our inclusion criteria, and were not omitted by the exclusion criteria were considered within this systematic review. The current review included a wide range of age distributions, ranging from 7 to 75 years old. Neurological disabling conditions within this review included individuals with spina bifida ($n = 9$), CP ($n = 37$), SCI ($n = 11$) and stroke ($n = 31$). Table 2 summarizes the key outcome measures from which intensity was determined and the level of evidence of the research according to SCIRE. The intensity of exergames in this review was determined using absolute intensity (metabolic equivalents) guided by World Health Organization (WHO) [36] or relative intensity (percentage of maximum oxygen uptake reserve, *HR* reserve or maximum *HR*) using ACSM's recommendation.[37]

All 10 studies assessed intensities within a laboratory setting, but only one added a second phase of deploying the intervention for a home training program. The results of the search were divided into their respective console types (XaviX, Nintendo, Playstation or Xbox), type of gameplay used (Tennis, Boxing, Jogging, GameCycle etc.) and position (sitting/standing) of the exergame played. Twelve of the 17 types (with exception to Wii Tennis in sitting position, Bowling, Penguin, Snowboarding and Skiing) of exergaming interventions met the recommended moderate intensity exercise as guided by ACSM or WHO guidelines. It is worth noting that Wii Tennis, when played in sitting position was only able to achieve light intensity but when played standing produced moderate intensity. Eight of the 10 cross-sectional interventions focused on the Nintendo Wii video game console. Two studies involved integrating a Nintendo Gamecube system with an arm crank ergometer and increasing the resistance settings slowly until volitional exhaustion using the Gamecycle.[24,38]

No significant differences of *HR* elevation were found between an able-bodied group and a physically disabled group of cerebral palsied children while using the Wii Jogging or Bicycling in an investigation by Robert and colleagues.[39] However, Kafri et al. [40] and Neil et al. [41] noted that *EE* or *PE* was lower for post-stroke than able-bodied individuals, yet still enough for the former to achieve a "moderate" intensity of exercise. Widman et al. [24] included emotional and psychological aspects of exergaming in his study. Most of the participants felt exergaming was fun, motivating, easily learned and could be physically challenging. The available studies are small in number and heterogeneous in terms of patient disabilities and outcome measures. This hinders comparisons across the studies, which cannot be meta-analysed.

Discussion

Nine of the 10 studies' outcome measures that were noted in this review revealed that exergame modalities produced "moderate" absolute or relative exercise intensities according to WHO [36] and ACSM [37] guidelines. Exergames such as Wii Jogging, Bicycling, Boxing, DDR and GameCycle reported moderate physical activity intensities. While Wii Snowboarding, Skiing and Bowling only produced light intensities. Kafri et al. [40] reported that exergames performed in a standing posture were of much higher intensity compared to sitting activities. This suggested that a certain amount of upper or lower body movements were needed to achieve higher intensities of exercise. This can be difficult to achieve, since populations with neurological disabilities are often wheelchair dependent, with limited upper or lower limb movement flexibility and strength. However, it is important to note that Wii Boxing and GameCycle, in particular, can be played in sitting position, yet still achieve moderate intensities and were amongst the highest *EE*s compared to the other "classical" games included in this review.[24,38,40,42–44]

Exergames performed in sitting position among cerebral palsied and spina bifidic participants in Rowland and colleague's [45] Wii Tennis, Bowling and a modified upper limb version of DDR study were only of light intensity. However, exergames undertaken in sitting posture amongst SCI using Wii Boxing, Nintendo GameCycle or XaviX Tennis were able to produce moderate intensities of physical activity. This suggested that exergames requiring bilateral upper limb movements were able to produce higher intensities than unilateral upper limb modalities and would be more likely to produce moderate to vigorous intensity exercises. It also pointed out that upper limb capacity in individuals with SCI was higher than for individuals with spina bifida or CP. Therefore, development of exergames for wheelchair-dependent individuals could focus on variations in bilateral upper limb movements, in three axes. This form of exergaming exercise might be engaging, enjoyable and would tend to alleviate the feeling that patients are actually "exercising" in a mundane way.[25] In this regard, in the context of comprehensive neurorehabilitation, exergaming can provide arm-exercises with equivalent aerobic dose-potency as "traditional" exercise in clinic or home environments.

The limited capacity of neurologically disabled populations like Rowland and colleagues [45] exergame intervention in non-ambulatory participants produced light intensity exercise with inadequate *HR* acceleration (29–36% of *HR* reserve). Yet, introduction

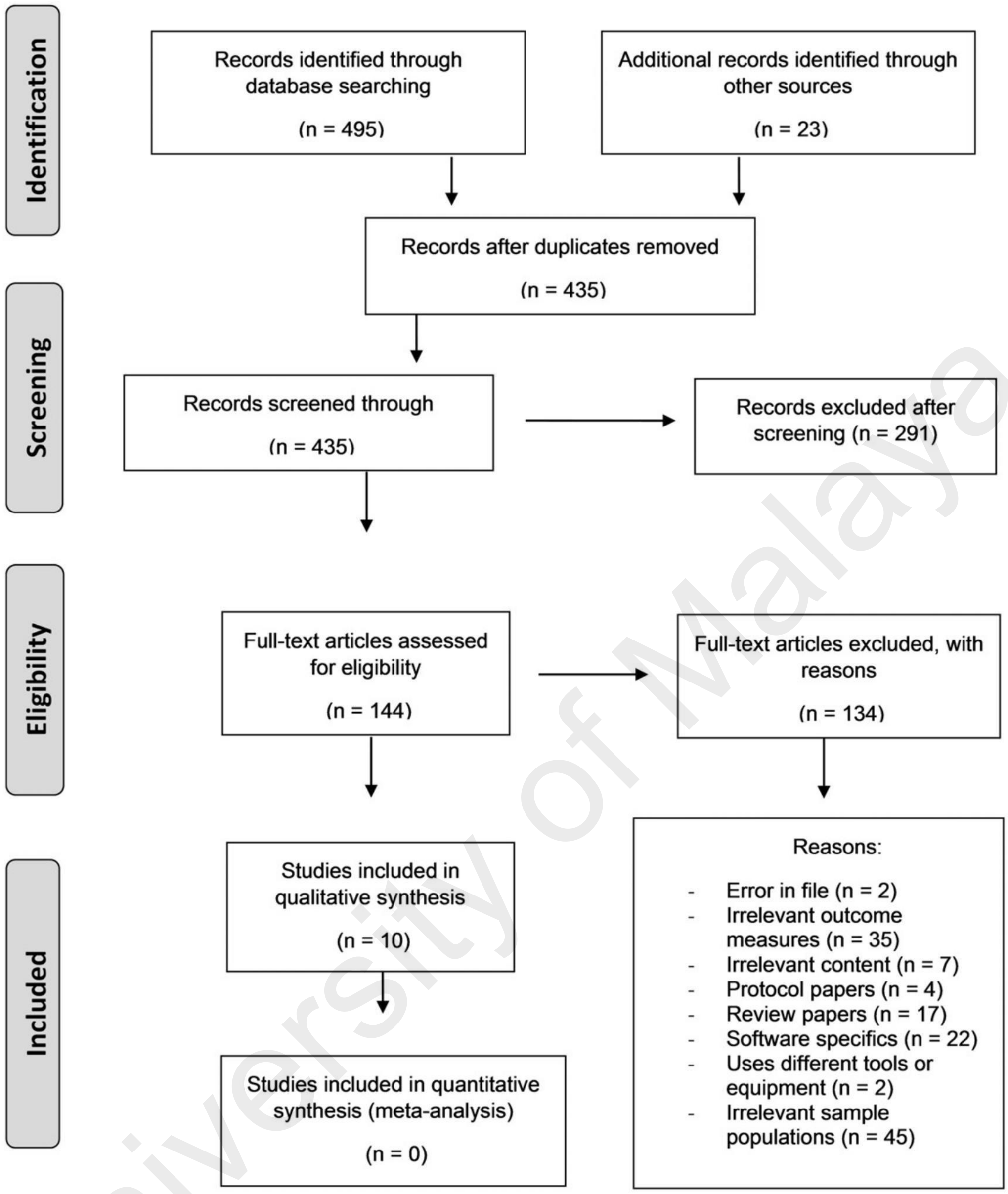

Figure 1. Data extraction and synthesis.

of lower-intensity activities producing greater than resting *EE* amongst sedentary populations, may also be beneficial for limited health improvements.[47] Clinically meaningful increases in *EE* or *HR*, can contribute substantially to total daily *EE* among those who are physically disabled, particularly if they are non-ambulatory and/or use motorized wheelchairs.[45] An increment in the amount of incidental physical activity provides cumulative effects which can improve cardiorespiratory fitness among sedentary populations.[48]

According to current physical activity guidelines for adults aged 18–65 years,[37] people should be encouraged to achieve at least 150 min per week of moderate-intensity or 75 min per week of vigorous-intensity aerobic-type physical activities. These recommendations can be achieved by completing either 30–60 min of moderate intensity exercise on five days a week, or 20–60 min of vigorous intensity exercise on three days a week. Though these recommendations were developed for the able-bodied population, the exercise regimes can also be applied to adults with disabilities as exercise recommendations among disabled persons and able-bodied populations do not vary dramatically in terms of intensity or duration. However, individuals, who are deemed rather unfit or just recently initiated their training can start at lower intensity workouts ranging from 40 to 49% of reserve oxygen uptake (VO_2R) or *HR* reserve (*HRR*) or 55–64% of maximum *HR* (*HRmax*).[37] Nevertheless, moderate-to-vigorous intensity exercises on a weekly basis are important for health benefits and preventing secondary disease complications.[37,49]

The use of exergames among children and adolescents has been well documented and provides a feasible tool to combat the growing youth obesity pandemic.[29] Exergaming tends to be more favourable and enjoyable as exercise among participants.[24,25] For able-bodied adults, deploying exergames in long-

Table 2. Exergaming studies.

Author/year/country/level of evidence	Study design/population/mean age (in years)	Intervention/position	Instrument/tools	Key outcome measures	Intensity	Conclusion
Widman et al.,[24] 2006, USA Level 4	Cross-sectional study $n = 8$ Spina bifida adolescents ♂: 4 age, μ: 17.5 ± 0.9 ♀: 4 age, μ: 15.5 ± 0.6	Nintendo Gamecube GameCycle Position: sitting	Metabolic Cart (Medgraphics) Polar heart rate monitor Borg Scale of Perceived Exertion	*EE/HRR/RPE* ($N = 6$) achieved ≥50% VO_2R ($N = 7$) achieved ≥50% of *HRR* All achieved $RPE \geq 12$	Moderate	GameCycle was able to produce moderate intensity arm cranking work out
	Prospective study $n = 8$ Spina bifida adolescents ♂: 4 age, μ: 17.5 ± 0.9 ♀: 4 age, μ: 15.5 ± 0.6	Nintendo Gamecube GameCycle 16 weeks home training (three days/week, 20 min per session	Polar heart rate monitor	Work output (W) ($N = 6$) Mean arm crank work output increased by 12% ($p < 0.015$).		Subjects were able to reach training zone intensity when program deployed at home. Mean arm crank work output improved.
Hurkmans et al.,[42] 2010, Netherlands Level 5	Cross-sectional study $n = 8$ Cerebral palsy adults ♂: 5 ♀: 3 Age, μ: 36 ± 7	Nintendo Wii Wii Tennis Wii Boxing Position: standing	Cosmed K4b^2 (portable indirect calorimeter) Modified Borg Scale of Perceived Exertion	*METS* Tennis: 4.5 ± 1.1 Boxing: 5.0 ± 1.1 *RPE* (modified Borg) Tennis: 3.5 ± 1.2 Boxing: 5.4 ± 1.9	Moderate	Wii Tennis and Boxing produced moderate intensity exercise according to WHO guidelines
Hurkmans et al.,[43] 2011, Netherlands Level 5	Experimental study Chronic stroke $n = 10$ ≥6 month Tennis: (age: 33–68) μ: 48 ♂-3 ♀-4 Boxing: (age: 33–74) μ: 56 ♂-5 ♀-3	Nintendo Wii Wii Tennis Wii Boxing Position: standing	Cosmed K4b^2 (portable indirect calorimeter) Polar T61 Modified Borg Scale of Perceived Exertion	*METS* Tennis: 3.7 ± 0.8 Boxing: 4.1 ± 0.7 *RPE* (modified Borg) Tennis: 4.1 ± 1.2 Boxing: 5.3 ± 2.7	Moderate	Wii Tennis and Boxing produced moderate intensity exercise according to WHO guidelines
Howcroft et al.,[44] 2012, Canada Level 5	Experimental study Cerebral Palsy children $n = 17$ ♂: 10 ♀: 7 Age, μ: 9.43 ± 1.51	Nintendo Wii Wii Bowling Wii Tennis Wii Boxing DDR (Dance Dance Revolution) Position: standing	Cosmed K4b^2 (portable indirect calorimeter) Polar heart rate monitor	*METS* Wii Bowling: 2.14 ± 0.68 Wii Tennis: 2.60 ± 0.78 DDR: 3.20 ± 1.04 Wii Boxing: 3.36 ± 1.50	Light for Wii Bowling and Tennis Moderate for DDR and Wii Boxing	DDR and Wii Boxing were able to achieve moderate intensity exercise
Burns et al.,[38] 2012, USA Level 5	Cross-sectional study Spinal cord injury adults, Chronic paraplegia $n = 9$ Age: 18–69, μ: 34 ± 8	Nintendo GameCube GameCycle (level resistance increased every 3 min till volitional exhaustion) Position: sitting	Oxycon Mobile (portable spirometric system) Polar heart rate monitor	*EE/HRR* GCE: all achieved ≥50% VO_2R and ≥50% of *HRR*	Moderate	GCE as a potential tool for exercising in moderate intensities that satisfy ACSM guidelines among individuals with paraplegia
		XaviX XaviX Tennis (15 min of gameplay, level of resistance increased by adding 1 lbs every 3 min, up to 4 lbs) Position: sitting	Oxycon Mobile (portable spirometric system) Polar heart rate monitor	*EE*/HRR XTSE: 33% ($N = 3$) participants achieved ≥50% of VO_2R and ≥50% of *HRR*	Moderate	About one third of participants achieved moderate intensity exercise with the XaviX Tennis
Rowland et al.,[45] 2012, USA Level 5	Case study $n = 3$ (2 Cerebral palsy	Nintendo Wii Wii Tennis Wii Bowling	Polar heart rate monitor VMax Encore 29C	*METS* DDR: 1.2–2.1	Light	*EE* were of light intensity ($METS < 3$) and *HR* values did not meet the ACSM guidelines of achieving at

(*continued*)

Table 2. Continued

Author/year/country/ level of evidence	Study design/population/mean age (in years)	Intervention/position	Instrument/tools	Key outcome measures	Intensity	Conclusion
	and 1 spina bifida) ♂: 2 ♀: 1 Age: 19–21	DDR (Dance Dance Revolution) *all three done in sitting position	(Portable metabolic unit)	Wii: 1.4–1.9 %*HRR* DDR:29–36% of *HRR* Wii: 29–36% of *HRR*		least 40% of *HRR* (light intensity)
Robert et al.,[39] 2013, Canada Level 5	Cross-sectional study Cerebral palsy children *n* = 10 ♂: 4, ♀: 6 *n* = 10 able-bodied, ♂: 5, ♀: 5 Age: 7–12	Nintendo Wii Wii Jogging Wii Bicycling Wii Snowboarding Wii Skiing Position: standing	Polar heart rate monitor (RS400)	*HRR* Wii Jogging: >40% *HRR* at >50% of total gameplay Wii Bicycling: >40% *HRR* at >30% of total gameplay	Moderate	No significant difference between groups in % of time spent with *HRR* > 40%. Exercise intensity for Wii Jogging and Bicycling are of moderate level which met ACSM standards
Neil et al.,[41] 2013, Israel Level 5	Cross-sectional study Stroke and able-bodied *n* = 10; stroke (μ age: 61 ± 7.3) *n* = 10; able-bodied (μ age: 54.4 ± 12.6) Age:19–75	Nintendo Wii Sony Playstation 2 EyeToy Wii Canoeing Wii Sword Fighting EyeToy Wishy Washy EyeToy Kung Foo Position: standing	Borg Scale of Perceived Exertion	*RPE* All games on both respective consoles achieved *RPE* rating score between 11 and 13	Light to moderate	Light to moderate level intensity, recommended for self-paced or startup exercise for sedentary individuals
Kafri et al.,[40] 2014, USA Level 5	Cross-sectional study *n* = 11; post-stroke *n* = 8; able-bodied Age: 25–75	Nintendo Wii Wii Boxing (standing) Wii Boxing (sitting) Wii Run (standing) Wii Penguin (standing)	Cosmed K4b^2 (portable indirect calorimeter) Polar heart rate monitor	*METS*/*HRmax*% Wii Boxing (sitting) stroke: 2.73/60% Wii Boxing (standing) stroke: 3.08/63% Wii Run stroke: 3.23/65%	Moderate	*EE* was lower for post-stroke than able-bodied but still enough to meet moderate intensity and *HRmax*% met ACSM standards
		Xbox 360 Kinect Boxing Position: standing	Cosmed K4b^2 (portable indirect calorimeter) Polar heart rate monitor	*METS*/*HRmax*% KBoxing stroke: 3.46/65%	Moderate	
Roopchand-Martin et al.,[46] 2014, Jamaica Level 5	Case study Spinal Cord Injury adults *N* = 2, ♂: 2 Age: 19, 23	Nintendo Wii Wii Boxing Position: sitting	Polar heart rate monitor	*HR* Wii Boxing *HR* > 50% of *HRR*	Moderate	Achieved training *HR*, moderate intensity training

Abbreviations: AVG: active video game; *HR*: heart rate; *HRR*: heart rate reserve; *HRmax*: maximum heart rate; *RPE*: rating of perceived exertion; *EE*: energy expenditure; *METS*: metabolic equivalents; VO_2R: reserve oxygen uptake; ♂: male; ♀: female; μ: mean; *n*: sample size; GCE: GameCycle Ergometer; XTSE: XaviX Tennis System Exergaming; DDR: Dance Dance Revolution; ACSM: American College of Sports Medicine; WHO: World Health Organization.

term training programmes have demonstrated positive outcomes in various domains of physical and mental health. Such exergame physical activity has been shown to:

i. alleviate depression,[50]
ii. reduce fat and BMI,[51,52]
iii. increase physical capacity and [24]
iv. provide longer and more intense workout sessions [25]

Accordingly, identifying options for increasing physical activity and the need to undertake exercise in this population becomes an important global health priority.[53] The barriers encountered by individuals with physical impairments that inhibit their exercise participation or limit certain physical activities can be a pivotal stepping stone to provide alternative technological modalities that are low cost and affordable, as well as motivating and enjoyable. Increased physical activity is not only essential in the long term for improved quality of life, it also helps reduce the risks of developing secondary complications of a sedentary lifestyle, especially among those confined to wheelchairs.

Limitations

This review included mostly cross-sectional and case studies with low level of evidence quality. It has been impacted by the lack of well-designed studies according to either the SCIRE criteria or the PEDro scale. Nine of the articles were of evidence level 5 and only one had a pre–post-test design that achieved PEDro level 4. Sample populations in published studies have been small in number and heterogeneous in terms of patient disabilities. As such, the outcome measures hinder comparisons across the studies and make meta-analyses statistical approaches difficult.

Variation in the terms to refer exergame exist, however, the keyword ''game'' was included during the search by inputting the option "All fields" or "with at least one of the words" into the search engines to ensure the selection was as comprehensive as possible. Despite these limitations, bias was reduced by careful selection and screening of each individual study report by two separate reviewers. As such, the total number of participants involved in the studies that we reviewed was 88. This comparatively small sample size may have been because participants with physical disabilities who met the inclusion criteria were not in large supply. Furthermore, this review included populations ranging from 7 to 75 years old, which could have been critical in terms of motivation.

Exercise prescription is usually determined through intensities guided by percentages of maximum *HR* elevation. However, current physical activity and exercise guidelines (inter alia ACSM [37] position stands) have been developed primarily from able bodied populations. In spinal cord injury, *HR* response may be irregular or blunted due to their imbalanced sympathetic control.[54] Notably, Jacobs and colleagues [55] observed that spinal cord injuries occurring at the level of T4 and above resulted in diminished cardiac acceleration, with their maximal *HR*s reaching only up to 130 b min^{-1}. Despite that, exercise intensities can still be determined through oxygen uptake, *EE*s and *RPE*.

Eight of 10 reviewed exergame intervention literatures have focused on the Nintendo Wii console. More research is warranted to compare other available video game consoles such as the Xbox Kinect and Playstation Move that offer better hardware specifics to augment the quality of the movements within the virtual exergaming environment. Furthermore, use of different video game consoles such as the Xbox have been shown to produce higher *EE* as compared to older generation consoles such as the Nintendo Wii.[40]

Conclusion

Cross-sectional studies of sports exergaming within this systematic review revealed that exergames have the potential to provide moderate intensity exercises (>3–5.9 *METS*), BORG RPE scale 12–13, 40–59% of VO_2R or *HRR* of 55–69% *HRmax* as guided by ACSM or WHO in populations with neurological disabilities.[36,37] Viewed in the context of comprehensive neurorehabilitation, exergaming should be viewed by the clinician as ''at least as good as'' (and likely more enjoyable) than traditional arm-exercise modalities, with equivalent aerobic dose-potency as "traditional" exercise in clinic or home environments. Non-ambulatory populations with neuromuscular disabilities now have the option of supplementing their PALs with LTPA or incidental activity promoted by the movements encouraged by exergames. This system is not only a low cost technology, it is also commercially available, easy to set up and an efficient tool for home based exercise. In an age where applications dominate the world, associating video games with physical exercise becomes an important alternative means for exercise. Exergaming may hold the potential to overcome barriers of physical activity promotion that neurologically disabled people face in their daily lives. Thus, allow them to adhere to physical activity guidelines, at the comfort of their homes within a safer environment, realize meaningful health improvements and lower their disease risk. However, more work will be needed to prove its efficacy within a longitudinal observation before transparent conclusions can be made.

Disclosure statement

The authors declare no conflict of interest for this review.

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Table 4.1: Exergaming studies (Updated extension of the published format)

Author/ Year/ Country/ Level of Evidence	Study Design/ Population/ Mean Age (in years)	Intervention	Instrument	Key Outcome Measures	Intensity	Conclusion
Gaffurini et al. [1], 2013, Italy Level 5	Cross-sectional study N=10 Spinal Cord Injury adults ♂:10 Age, µ: 40±8.5	Nintendo Wii Wii Tennis Wii Bowling Wii Boxing Position: sitting	Metabolic Cart (Cosmed K4b^2)	**MET** Tennis: 2.2±0.6 Bowling: 1.7±0.3 Boxing: 3.3±0.9	Light to moderate	Wii Boxing achieved the highest intensity (moderate) and is doable in a sitting position. Wii exergames significantly increase metabolic rate above resting levels.
Malone et al. [2], 2016, USA Level 5	Cross-sectional study N=16 ♂:11 ♀:5 Age, µ: 13.8±2.7 n=8 cerebral palsy n=5, spina bifida n=1, spinal cord injury n=1, muscular dystrophy n=1, skeletal dysplasia	Nintendo Wii Just Dance 4: Let the Party Begin Outdoor Challenge: Endurance Exercises Punch-Out!!: Exhibition Position: sitting	Polar heart rate monitor (Polar S610)	**HR** Nintendo Wii Just Dance: 113± 25 Outdoor Challenge: 114±23 Punch-Out: 114±27 (~57% of HRmax)	Very light to light	Higher HR was associated with higher quality of gameplay and higher PACES scores.
		Xbox Kinect Just Dance 2014: Just sweat custom routine Fitness: Mossa Fight Sports Rivals: Preseason Zumba Fitness World Party: Custom dance routine Position: sitting		**HR** Xbox Kinect Just Dance: 99 ±16 Mossa Fight: 100±15 Sports Rivals: 97±8 Zumba Fitness: 101±15 (~49-51% of HRmax)		
		PlayStation Move UFC Personal Trainer: Custom workout Sports Champions: Beach Volleyball Start the Party!: Bug Bashing Game Zumba Fitness Join the Party: Single routine Position: sitting		**HR†** PlayStation Move UFC Personal Trainer: 104±26 Sports Champions: 102 ±23 Start the Party: 105 ±22 Zumba Fitness: 102 ±21 (~51-53% of HRmax)		

Table 4.1, continued: Exergaming studies (Updated extension of the published format)

Author/ Year/ Country/ Level of Evidence	Study Design/ Population/ Mean Age (in years)	Intervention/ Position	Instrument/ Tools	Key Outcome Measures	Intensity	Conclusion
Trinh et al. [3] 2016 Australia Level 3	Pre-post case-control study (WMT vs CiMT) N=29 for WMT, N=17 for CiMT Stroke adults Age: 62.2±11.9 (WMT) Age: 55.5±17.4 (CiMT)	Nintendo Wii Wii Golf Wii Bowling Wii Baseball Wii Tennis Wii Boxing Position: standing	Two-electrode electrocardiograph array with wireless telemetry (Myomonitor IV, Delsys, USA)	**HR** HR: 72-76bpm Average HR achieved 21-28% HRpeak Wii boxing achieved the highest intensity of 27% above HRrest	Very light	Wii exergaming improves cardiovascular fitness in significantly deconditioned chronic stroke population.
MacIntosh et al [4], 2017 Canada Level 3	Prospective randomized trial N=8 Cerebral palsy ♂:6 ♀:2 Age: 10.2±2.2	Liberi pedalling station + Xbox 360 Race Dyads	Polar heart rate monitor H1 (Polar Electro, Oulu, Finland)	**HR†** Race Dyads: 120±8 **(~56-64% of HRmax)**	Light to moderate	The Liberi exergame station allows cerebral palsy youths with different levels of physical ability to play cycling-based Exergames to improve gross-motor function.

HRmax predicted using Tanaka et al's formula [208-(0.7xage)][5]; Intensity classification was based on ACSM 2011 by Garber et al[6]
†Intensity calculated by % of mean age predicted HR max
Level of evidence is based on SCIRE-pedro scale
Abbreviations: HR: Heart rate; HRmax: Maximum heart rate; MET: Metabolic equivalent of task; WMT: Wii-based movement therapy; CiMT: constraint-induced movement therapy

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CHAPTER 4: PUBLISHED PAPER 3

4.1 EXERGAMING FOR INDIVIDUALS WITH SPINAL CORD INJURY: A PILOT STUDY

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Mat Rosly, M conducted and participated in all the research experiments, coordinated the data analysis and remains as the primary author of the manuscript. Halaki, M, Mat Rosly, H and Cuesta, V gave technical support, conceptual advice on the design of the study and helped in data interpretation. Halaki, M, Hasnan, N, Davis, GM and Husain, R supervised the development of work and edited the manuscript.

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Exergaming for Individuals with Spinal Cord Injury: A Pilot Study

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Abstract

Objective: Commercially available exergames that are for wheelchair-bound individuals with spinal cord injury (SCI) are scarce. This study sought to identify exergames for individuals with SCI that are ''dose-potent'' for health benefits.

Materials and Methods: Six participants with SCI were recruited for a pilot study to investigate the exercise intensity of selected exergames (Move Tennis, Move Boxing, and Move Gladiator Duel) for the potential to improve health. Issues relating to exergaming for individuals with SCI were identified, and a Move Kayaking exergame was conceived using relevant design processes in an iterative manner. These processes included the following: participant needs and requirements, system requirements (hardware), system architecture (physical and operational views), and integration and verification of the finished system. Emphasis was given to operational and physical designs of the Move Kayaking exergame.

Results: Move Boxing, Move Gladiator Duel, and Move Kayaking achieved moderate intensity exercise, while Move Tennis only achieved exercise of low intensity based on participants' metabolic equivalent. However, all four exergames achieved at least moderate intensity based on individuals' ratings of perceived exertion (RPE).

Conclusion: The intensity classification while playing Move Boxing, Move Tennis, Move Gladiator Duel, and Move Kayaking, using RPE, reported adequate exercise intensities prescribed by exercise guidelines.

Keywords: Physical activity, Exercise, Health, Videogames, Metabolic intensity

Introduction

Spinal cord injury (SCI) may lead to a profound disability, with negative physiological,[1,2] physical, or psychological[3,4] sequelae and restricted employment opportunities,[5,6] even after the individual has reintegrated into community living. The global incidence of SCI has been estimated to range between 8 and 246 cases per million persons, with prevalence being dependent on factors such as epidemiological diversity, acute medical care, and degree of post-traumatic rehabilitation in different countries.[7–9] This population most often occupies the lower end of the physical activity spectrum, described as possessing a ''sedentary lifestyle''.[10,11] Structured exercise or participation in leisure time physical activities has only been observed in about 20%–50% of community-dwelling individuals with SCI.[12–14] In addition, among SCI wheelchair users, the intensity of activities of daily living alone, are insufficient to provide health and fitness benefits.[11,15,16] A wheelchair-bound lifestyle, with increasing levels of physical inactivity and sedentary lifestyle has accelerated trends to reduced fitness and increased secondary complications in this at-risk population.[17–19] ''Dose-potent'' physical activities, defined herein as exercises that are of adequate intensity for increasing cardiorespiratory fitness or lowering the risk of cardiovascular disease,[20–23] are important for improvements in health, fitness, and functional outcomes.[21,24] However, despite exercise being positively associated with health benefits,[25,26] SCI individuals' fitness[27] and exercise adherence are often reduced over time.[28] Furthermore, individuals with SCI are often constrained to wheelchair-bound exercises, perceived to be less enjoyable

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than the range and option available for able bodied individuals.[29,30] Approaches to increase participation in exercises that are ‘‘dose-potent’’ can be challenging as upper body exercises are often perceived as boring, and facilities are often inaccessible to wheelchair users such as individuals with SCI.[31]

The Nintendo Company (Nintendo Co., Kyoto, Japan) was the pioneer in producing movement-controlled interfaces for the seventh generation game console that enabled various sports-like physical activities to be produced in-game, which has been termed ‘‘exergaming.’’ Other commercially available game console producers, Move® for PlayStation® 3 or 4 (Sony Interactive Entertainment, Inc., Tokyo, Japan), Kinect™ for Microsoft's Xbox™ (Microsoft Co., Redmond, Washington), and XaviX® (SSD Company Ltd, Shiga, Japan) have released their own versions of movement-controlled interactive exergaming. These commercially available exergaming systems provided alternative means to improve health parameters as well as participation in leisure time physical activities in various populations.[32–34] In the context of rehabilitation, exergaming has reported evidence of ‘‘dose-potency’’[35] and the ability to simulate real-life sports within a relatively safe environment.[36] Exergaming has been deemed ‘‘dose-equipotent’’ to their ‘‘real’’ sports counterpart,[37] while adding perceptual enjoyment by making the system more engaging or fun to play,[29,37,38] as well as accessible within a home environment.[29] However, research is warranted to investigate commercially available and ‘‘affordable’’ exergaming modality for exercise among SCI wheelchair users, at an intensity to provide health benefits.

This study sought to determine the physiological and perceived exertional responses of several types of exergaming activities that might achieve the requisite ‘‘dose-potency’’ for health benefits as recommended by the American Heart Association (AHA) - American College of Sports Medicine (ACSM),[21] World Health Organization (WHO),[23] or SCI Action Canada©[20] guidelines while being suitable for exercise in a sitting position. Three types of exergaming (Move Tennis, Move Boxing, and Move Gladiator Duel) were identified and compared, while a fourth was adapted (Move Kayaking) specifically for SCI users.

Materials and Methods

Participants

The University of Malaya Medical Ethics Committee (MECID 201410-609) approved the study protocol and written informed consent was obtained from all participants who volunteered for the study. Six individuals with SCI were recruited and received physician's clearance before study participation. The participants were classified into their respective American Spinal Injury Association Impairment Scale (AIS).[39] Participants were included if they were between the ages 18–65 and had either a traumatic or nontraumatic SCI for more than 2 years. They were also required to have no cognitive deficits and could follow verbal instructions.

Equipment and materials

The PlayStation 3® console, along with its Move controllers were selected as the most appropriate hardware platform based on the criteria required. Table 1 depicts some of the conditions essential in the selection process with brief descriptions of the hardware's main features and limitations.

Three different types of exergaming activities were investigated for this pilot study–Move Tennis, Move Boxing, and Move Gladiator Duel. The exergaming utilized the PlayStation 3 console with two PlayStation Move controllers, a Sony Eye Camera®, displayed on a 65-inch (1.65 m) high-definition light emitting diode television (all components by Sony Interactive Entertainment, Inc.). Sports Champion 2® software (Sony Interactive Entertainment, Inc.) was used to run the Move Boxing and Move Tennis, while Move Gladiator Duel used Sports Champion 1® software (Sony Interactive Entertainment, Inc.). Both Move Boxing and Move Gladiator Duel required bilateral upper limb movements, while Move Tennis only required unilateral upper limb movements.

Experiment and physiologic measurements

All three exergaming activities were performed on separate days. The order of exergaming sessions was randomized, and the time between sessions was set at a minimum of 1 day and maximum of 14 days. Each participant was given between 10–20 minutes of practice and briefing before the exercise sessions to familiarize themselves with the equipment and exergames. Before the start of each gaming activity, resting heart rate (HR) and metabolic equivalent (MET) were collected over 15 minutes. A 1–2 minute ‘‘on-transient’’ period was allowed during the warm-up session to achieve a physiological steady state[46] and was excluded beforehand. This was followed by 10 minutes of continuous exercise duration wherein representative cardiorespiratory data were averaged and met the shorter bouts of accumulative exercise recommended by ACSM.[22] No form of verbal encouragement (i.e., cheering) was given during the exercise sessions.

Physiological assessments were recorded using a metabolic cart and a HR monitor (Cosmed Quark PFT, Cosmed Co., Rome, Italy). The Cosmed gas sensors were calibrated before and after each session with a certified mixed gas content of 5% carbon dioxide, 16% oxygen, and balance of nitrogen. Rating of perceived exertion (RPE) was collected at the end of each session using the modified Borg scale of 1 to 10, with 0 being ‘‘nothing at all’’ and 10 being ‘‘very, very strong’’.[47] A postsession semistructured survey, designed by the authors, requested participants to provide written feedback. The questions asked were given as below:

(i) Which exergaming was the most and least enjoyable?
(ii) Which exergaming was the hardest and the easiest?
(iii) Would you like to add any comments on the exergaming?

In addition, the authors also captured spontaneous comments remarked by participants while exergaming.

Data analysis

Data were processed using SPSS version 22.0. Friedman's test was used to contrast the physiological and perceived exertional responses among the three modalities of the exergaming. All data are presented herein, as mean ± standard deviation (SD). Wilcoxon signed-rank test was used to further compare each exergaming modalities in pairs, for data with significant differences detected from the Friedman's test. The significance level was set at $P < 0.05$. Predicted maximum heart rate (HRpredmax) for each participant was

TABLE 1. CONCEPT SELECTION IN CHOOSING THE APPROPRIATE HARDWARE

	Hardware		
Criteria	*PlayStation Move®*	*Nintendo Wii®*	*Xbox Kinect®*
Controllers	Dual	Single	None
Sensor interface	3D acceleration, position, and angular rotation, 3D gyro sensor, 3D geomagnetic sensor[40]	3D acceleration and angular rotation, 3D gyro sensor, limited 3D position[40]	3D position information and orientation[40]
Latency period	115 milliseconds (fastest response)[40]	143 milliseconds (moderate response)[40]	218 milliseconds (slow response)[40]
Exercise intensity reported	Moderate to vigorous[37]	Light to moderate[41–43]	Moderate[43]
Advantages	Inverse kinematics allow upper body motion estimation	Largest documented game console used in exergaming studies[32,35]	SCI users do not need to hold any controllers
Limitations	SCI users will have to hold controllers, which can be difficult for those with upper limb involvement (tetraplegia)	SCI users will have to hold controllers, which can be difficult for those with upper limb involvement (tetraplegia)	Motion capture uses a static standing position model as a general template to map user's bodily movements. This makes recognition and calibration difficult and inaccurate in a sitting position
		Controller has limited motion interaction and hand-motion positioning information, rendering minimal exercise benefit[40,43–45]	Arm axial rotation motion poorly recognized due to limited depth information
		Games are region locked	Low temporal resolution, prolonged latency period, and low image processing[40]

determined using the formula 208–(0.7 × age) by Tanaka et al.[48] Exercise intensity levels were classified as light intensity (MET: <3.0, RPE: 0.5–2.5, %HRpredmax: 35%–54%), moderate intensity (MET:3.0–6.0, RPE: 3–4.5, %HRpredmax: 55%–69%), or vigorous intensity (MET: >6.0, RPE: ≥5.0, %HRpredmax: ≥70%).[21,22,47]

Study Results

Physiological and perceived exertional analysis

Table 2 summarizes the physical characteristics of SCI participants along with their cardiorespiratory and RPE responses at rest and during exercise collected. Mean total energy expenditure and oxygen consumption during the 10 minutes of exercise were highest for Move Boxing and lowest for Move Tennis, as shown in Table 2. Friedman's test revealed significant differences ($P < 0.05$) among the oxygen consumption and MET responses among the three modalities of exergaming. Further analysis using Wilcoxon signed-rank test found that oxygen consumption and MET responses in two pairs of exergaming, Move Boxing versus Move Tennis and Move Gladiator Duel versus Move Tennis were significantly different ($P < 0.05$).

Postsession user feedbacks and observations

Following trial of each modality of the three exergaming used, observations from authors and participants' user feedbacks were gathered. It was interesting to note that all the participants felt Move Gladiator Duel was the hardest of the three modalities and five of them did not enjoy the gameplay. Move Boxing was perceived most enjoyable for four of the participants, while the remaining two enjoyed Move Tennis the most. From the study, the authors collected a few important guidelines that included the following:

(i) Provide less user input in the form of button pressing: Exergaming requiring too many button pressing from the user (e.g., Move Gladiator Duel) was challenging for participants with tetraplegia, due to the poor fine motor control of their fingers. Simpler control mechanics that do not require too many simultaneous button input were preferred. Comments from participants included ''I can't press this button'' for Move Gladiator Duel.

(ii) Preference for fast-paced exergaming: The participants noted that Move Boxing was very engaging due to the nature of it being fast-paced and highly responsive in terms of movement control. One participant denoted ''Best!'' for Move Boxing, which is a slang term used commonly among Malaysians to indicate enjoyment. Another participant lamented ''This is too slow for me'' for Move Tennis.

(iii) Elements of competition and adjusting difficulty levels: Exergaming can be more engaging and appealing if elements of competition and the need for improvement were included. Feedback from participants included personal best performance records, where

Table 2. Participants' Physical Characteristics and Physiological Measures While Exergaming

	Participants						
	#1	*#2*	*#3*	*#4*	*#5*	*#6*	*Mean ± SD*
Gender (M/F)	M	M	M	M	F	M	
Age (y)	29	26	52	37	26	21	32 ± 11
Stature (m)	1.71	1.85	1.63	1.66	1.66	1.50	1.67 ± 0.11
Body mass (kg)	67.0	73.9	71.0	64.1	46.9	66.1	64.8 ± 9.5
BMI (kg/m^2)	22.9	21.6	26.7	23.3	17.0	29.4	23.5 ± 4.3
Hand dominance	Right	Left	Right	Right	Right	Right	
Neurological level of injury	C7	T4	C6	T10	T4	L3	
Neurological classification	Tetraplegia	Paraplegia	Tetraplegia	Paraplegia	Paraplegia	Paraplegia	
AIS	B	A	C	A	A	C	
Time since injury (y)	15	8	26	16	19	17	17 ± 6
VO_2 at rest (mL/[kg·min])	2.8	3.8	3.6	3.2	4.5	4.4	3.7 ± 0.7
MET at rest	0.8	1.1	1.0	0.9	1.3	1.3	1.1 ± 0.2
Heart rate at rest (b/min)	55	62	71	68	55	75	64 ± 8
VO_2 (mL/min)							
Tennis	514	635	836	700	457	565	618 ± 137
Boxing	797	949	858	1131	495	919	858 ± 211
Gladiator duel	626	856	814	943	581	931	792 ± 154
VO_2 (mL[kg·min])							
Tennis	7.7	8.6	11.8	10.9	9.7	8.6	9.5 ± 1.6
Boxing	11.9	12.8	12.1	17.6	10.6	13.9	13.2 ± 2.5
Gladiator duel	9.3	11.6	11.5	14.7	12.4	14.1	12.3 ± 1.9
EE (kJ/min)							
Tennis	10.4	12.9	16.9	14.4	9.1	11.3	12.5 ± 2.8
Boxing	16.7	19.6	14.7	24.0	10.0	18.9	17.3 ± 4.8
Gladiator duel	13.0	17.5	16.3	20.4	11.7	18.6	16.3 ± 3.3
$\Sigma EE_{10\text{-min}}$ (kJ)							
Tennis	106	131	166	147	92	124	128 ± 27
Boxing	203	203	147	211	102	197	177 ± 43
Gladiator duel	134	180	152	208	118	189	164 ± 35
VE (L/min)							
Tennis	14.6	21.5	25.6	20.9	17.2	16.4	19.4 ± 4.1
Boxing	25.9	29.9	21.4	55.8	19.6	30.3	30.5 ± 13.1
Gladiator duel	21.1	28.6	23.4	42.4	24.8	25.7	27.7 ± 7.6

(*continued*)

Table 2. (Continued)

	Participants						
	#1	*#2*	*#3*	*#4*	*#5*	*#6*	*Mean ± SD*
MET							
Tennis	2.2	2.5	3.4	3.1	2.8	2.5	2.8 ± 0.4
Exercise intensity	Light	Light	Moderate	Moderate	Light	Light	
Boxing	3.4	3.7	3.5	5.9	3.0	4.0	3.9 ± 1.0
Exercise intensity	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	
Gladiator duel	2.7	3.3	3.3	4.2	3.5	4.0	3.5 ± 0.5
Exercise intensity	Light	Moderate	Moderate	Moderate	Moderate	Moderate	
HR (b/min)							
Tennis	74 ± 8	115 ± 8	103 ± 3	107 ± 6	NA[a]	104 ± 6	101 ± 16
% of HRpredmax	35%–44%	56%–65%	58%–62%	55%–62%	NA	51%–57%	
Exercise intensity	Light	Moderate	Moderate	Moderate	NA	Light to moderate	
Boxing	118 ± 19	116 ± 5	100 ± 5	151 ± 11	NA[a]	115 ± 5	120 ± 19
% of HRpredmax	53%–73%	58%–64%	55%–61%	77%–89%	NA	57%–62%	
Exercise intensity	Light to vigorous	Moderate	Moderate	Vigorous	NA	Moderate	
Gladiator duel	82 ± 13	113 ± 10	102 ± 6	158 ± 9	140 ± 7	111 ± 5	118 ± 27
% of HRpredmax	37%–51%	54%–65%	56%–63%	82%–92%	70%–77%	55%–60%	
Exercise intensity	Light	Light to moderate	Moderate	Vigorous	Vigorous	Moderate	
RPE							
Tennis	5	4	9	6	4	3	5.2 ± 2.1
Exercise intensity	Vigorous	Moderate	Vigorous	Vigorous	Moderate	Moderate	
Boxing	7	8	6	10	4	5	6.7 ± 2.2
Exercise intensity	Vigorous	Vigorous	Vigorous	Vigorous	Moderate	Vigorous	
Gladiator duel	5	7	7	9	7	7	7.3 ± 1.3
Exercise intensity	Vigorous	Vigorous	Vigorous	Vigorous	Vigorous	Vigorous	

Values are Mean ± SD or otherwise indicated.

M, male; F, female; BMI, body mass index; AIS, American Spinal Injury Association (ASIA) Impairment Scale; MET, metabolic equivalent; SD, standard deviation; VO_2, oxygen consumption; EE, energy expenditure; $\Sigma EE_{10\text{-min}}$, total energy expenditure during 10 minutes of exercise; MET, metabolic equivalent; HR, heart rate; % HRpredmax, percentage of predicted maximum heart rate; VE, minute volume; RPE, rating of perceived exertion; NA, not available.

[a]Heart rate data could not be reliably determined.

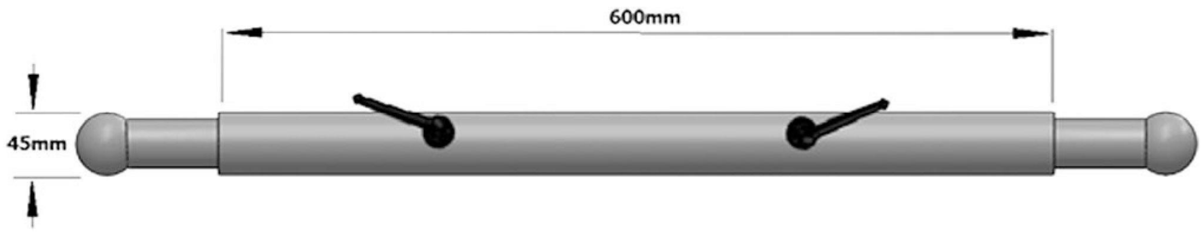

FIG. 1. Physical view of kayak paddle case (Prototype A).

they can slowly appreciate improvements in their level of playing skill.

(iv) Limit certain bodily movements: In contrast to exergaming designed for able bodied, movements that require users with SCI to stand, do trunk twisting or sudden/abrupt turning should not be included. These include jumping, spinning, or swerving (e.g., Move Gladiator Duel). SCI individuals with higher level of spinal injury have difficulty controlling their trunk and cannot perform these movements.

(v) Interactive gameplay: Exergaming has the potential to be more interactive, within a video game environment despite the opponent/partner being physically absent. Participants reported that engaging in exergaming can be more motivating, whether it be with a friend via online or against a game's artificial intelligence.

Designing and adapting an exergame for individuals with SCI

Exergaming requirements. Based on the results and participants' feedback from the pilot study, the authors then adapted a kayak video game from London 2012 (Sega Games Co., Tokyo, Japan), allowing it to be played using bilateral upper limb involving muscles similarly used for arm cranking[49] or boxing[50] in a sitting position. A kayak paddle case fitted to hold two Move controllers was designed by the authors to be detachable, allowing recharging of the controllers and weighed less than 150 grams. Figure 1 shows the diagram for one of the prototypes used as the kayak exergaming paddle case. The gameplay interface was adjusted into a dual-linked control mechanism, and no button input was required by the SCI user during gameplay.

The paddle case for the Move controllers was 3D printed using polylactide filament. The 3D-printed cases were integrated with the Move controllers to verify that the physical dimensions of the cases were appropriate and provided a tight fit around the shape of the Move controllers. Initial prototypes, which allowed access to the controller buttons, were complicated by its curved edges and indentations. The latest model provides easy access to all the buttons.

The game system was then recalibrated to provide user input that can be received through the control sensors embedded in the kayak paddle case. Figure 2 shows the operational flow diagram of the Move Kayaking system. The control scheme linked the Move controller, which was embedded into the kayak paddle case and a DualShock® controller together during gameplay. Button input from the DualShock controller allowed an independent observer to provide system selection in between gameplay. This control mechanism was needed to avoid interrupting user input from players and ensure a continuous, rapid succession of kayaking movements during gameplay.

Validation of Move Kayaking for individuals with SCI. This adapted Move Kayaking was then pilot tested among four of the SCI participants who were recruited in the previous pilot study. Beta test on prototype D used the same

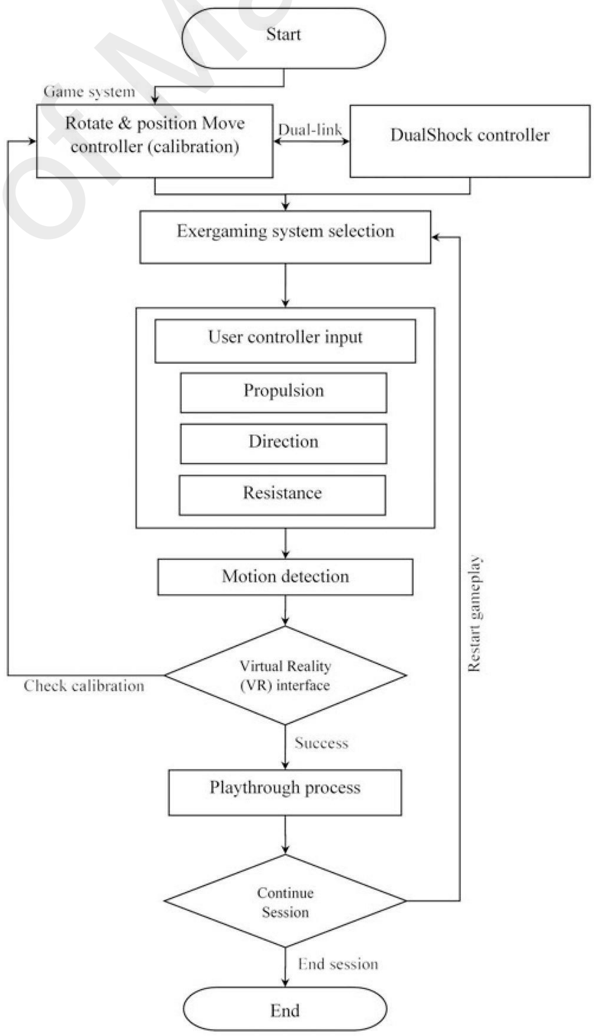

FIG. 2. Operational flow diagram of Move Kayaking.

TABLE 3. OUTCOME MEASURES DURING MOVE KAYAKING

Values	Participants					
	#2[b]	#3	#4	#5	#6	
Type of paddle case	*Prototype D*	*Prototype C*	*Prototype D*	*Prototype D*	*Prototype D*	*Mean ± SD*
VO_2 (mL/min)	797	NA[c]	907	578	859	785 ± 145
VO_2 (mL/[kg·min])	13.6	NA[c]	14.1	12.3	13.0	13.3 ± 0.8
EE (kJ/min)	15.9	NA[c]	19.3	11.6	17.2	16.0 ± 3.2
$\Sigma EE_{10\text{-min}}$ kJ	144	NA[c]	212	91	175	155 ± 51
VE (L/min)	19.9	NA[c]	44.0	22.8	27.5	28.6 ± 10.8
MET						
Kayaking	3.9	NA[c]	4.0	3.5	3.7	3.8 ± 0.2
Exercise intensity	Moderate	NA[c]	Moderate	Moderate	Moderate	
HR (b/min)						
Kayaking	NA[a]	119 ± 11	152 ± 11	138 ± 6	113 ± 3	131 ± 18
% of HRpredmax	NA	63%–76%	77%–90%	69%–76%	57%–60%	
Exercise intensity	NA	Moderate to vigorous	Vigorous	Moderate to vigorous	Moderate	
RPE						
Kayaking	6	7	9	7	7	7.3 ± 1.3
Exercise intensity	Vigorous	Vigorous	Vigorous	Vigorous	Vigorous	

Values are Mean ± SD or otherwise indicated.
[a]Heart rate data could not be reliably determined.
[b]Participant had one of his lower limb amputated, thus his body weight reduced to 58.6 kg.
[c]No data acquisition due to technical issues.
NA, not available.

methodology in this pilot study to collect physiological and perceived exertional responses from four SCI participants following end of gameplay. Prototype C was tested on participant #3 by only collecting HR and RPE due to technical issues. The Move Kayaking achieved moderate exercise intensities based on MET and RPE. Table 3 summarizes the physiological response outcome while using Move Kayaking, the paddle case prototypes. Figures 3 and 4 present MET and RPE outcomes for all four types of exergaming modalities for each participant.

Discussion

This study reported that, from the small sample of convenience, 3 of the 4 exergames investigated (Move Boxing, Move Gladiator Duel, and Move Kayaking) achieved

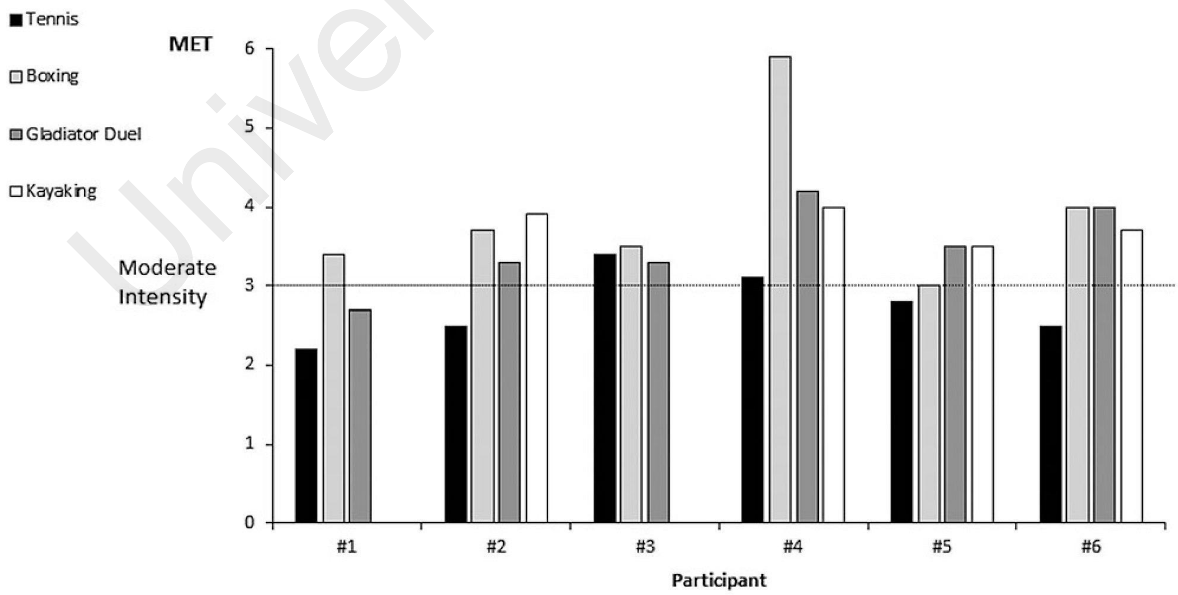

FIG. 3. Participant MET values for all four types of exergaming modalities. MET, metabolic equivalent.

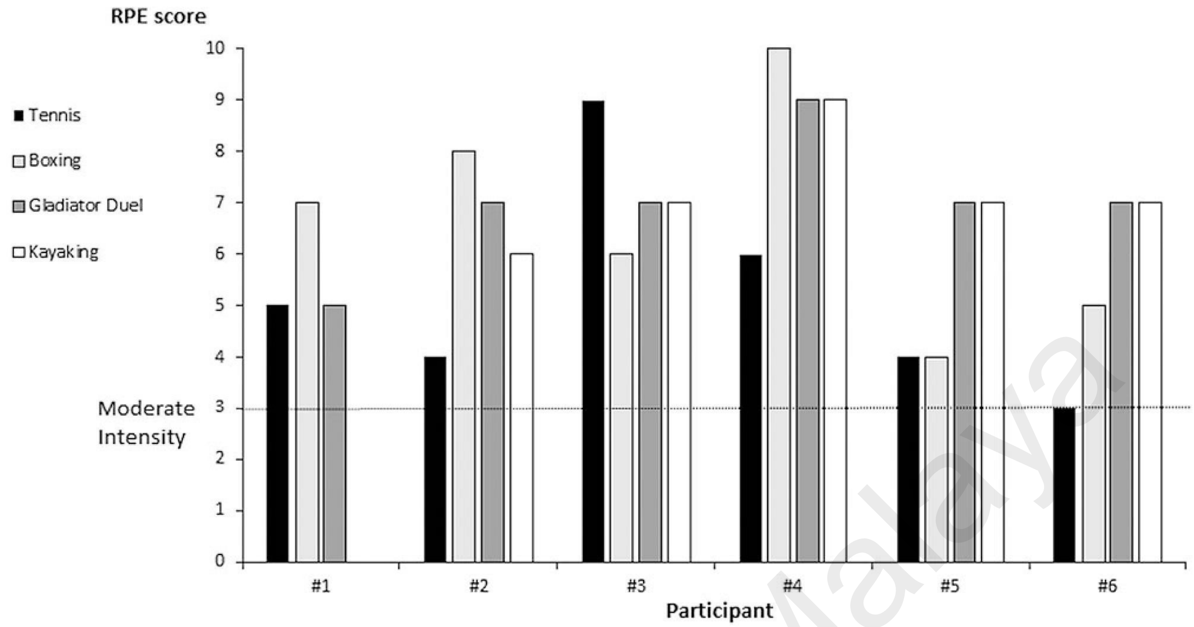

FIG. 4. Participant RPE scores for all four types of exergaming modalities. RPE, ratings of perceived exertion.

moderate-to-vigorous exercise intensities, measured by MET and %HRpredmax according to current guidelines from the AHA-ACSM,[21,47] WHO,[23] and SCI Action Canada[20] consensus statements. However, Move Tennis did not meet the classification of ''moderate'' exercise according to the MET values among four of the participants and %HRpredmax in two of the participants, but achieved that classification based on participants' RPE. At least one of the three methods of estimating the exergaming intensities showed viability in achieving moderate intensity and met exercise prescription guidelines.[21] Since the relationship among MET, %HRpredmax, and RPE can be influenced by a multitude of factors (fitness level, test protocol, type of exercise, body composition, and whether the participants enjoy the exergame),[51] it is expected that each method of estimating exercise intensity would provide different classification of the same exercise and should not be considered equivalent. Therefore, the findings from our pilot study only provided initial insight that all four types of exergaming activities were feasible for individuals with SCI, whether tetraplegia or paraplegia to achieve physiological ''dose-potency'' for health benefits based on MET, %HRpredmax, or RPE.[21,22,47]

The study reported that the MET or HR elevation values consistently underestimated the intensity of the exergaming activities compared with the RPE scores. As guidelines to determining intensity using MET were prescribed for able bodied,[22,51] it may be more appropriate to use RPE for a population with SCI. Since the use of their muscles is more limited in view of paralysis, it is unsurprising that the exergaming activities produced lesser oxygen consumption and may not depict their actual effort. RPE have been reported to depict a more accurate picture of exercise intensity among SCI population.[52] However, RPE values were designed to titrate exercise intensities that disregarded factors associated with ''concentration'' or ''engagement''[47] which is inherent in exergaming and may have impacted the intensity classification perceived by SCI participants.[53]

In individuals with SCI, exergaming in a sitting position using bilateral upper limb movements (Move Boxing, Move Gladiator Duel, and Move Kayaking) provided higher intensity exercises as opposed to unilateral (Move Tennis) and are important to achieve sufficient ''dose-potent'' exercise intensity for fitness and health benefits. Similar results were also seen in another SCI study comparing XaviX Tennis against a GameCycle exergame.[54] Future exergaming designs should focus more on bilateral upper limb movements. MET value for Move Boxing was highest compared with other exergames in our pilot study, and this was also similarly reported in another study conducted using the Wii Boxing in a population with SCI.[41] Wii Boxing in a stroke population done in standing position has been shown to produce higher energy expenditure compared with the same exercise performed in a sitting position.[43] In our study, Move Gladiator Duel produced higher oxygen consumption (12.3 ± 1.9 mL/(kg·min), MET ~ 3.5 = moderate intensity) compared with that when done in standing among able bodied sample (9.8 ± 0.7 mL/(kg·min), MET ~ 2.8 = light intensity).[55] The former study also reported consistent intensity classification based on MET and RPE in the able bodied sample, but not in the stroke sample.[43] This comparison may suggest that SCI participants in this study may have indeed been exercising at an intensity much higher than that reported by their MET.

Although all four exergaming activities produced at least moderate intensity exercises in terms of RPE, but for individuals with tetraplegia, Move Boxing, Move Tennis, and Move Kayaking appeared to be an appropriate recommendation since they reported difficulties with button input and trunk stabilization in Move Gladiator Duel. All four exergames were observed to be feasible in terms of intensity and practicality, for injuries occurring at the level of T4 and below (paraplegia) as they have better control of their fingers and lower trunk movements. However, Move Gladiator Duel was considered ''difficult'' and unpopular due to some of the impractical movements (jumping and side evasion) required during gameplay. Although MET values for Move Tennis reported the lowest across the four exergaming activities, low intensity exercise can still be important for SCI individuals who are commencing a structured training program, for those who have been highly sedentary or when their aerobic fitness is poor. In the context of rehabilitation, Move Tennis could be deployed as ''warm-up'' sessions for those initiating regular exercise from a sedentary lifestyle. After several weeks of Move Tennis, the program should evolve from unilateral arm movements to more vigorous bilateral movements, inherent in Move Gladiator Duel, Move Kayaking, or Move Boxing.

Younger male participants (participants #1, #2, #4 and #6) in our study preferred Move Boxing as it was perceived to be fast-paced and highly responsive in terms of movement control. However, Move Tennis was considered ''too slow'' as the tempo was predictable, and participant #6 felt it was rather frustrating that he had to play it in a stationary position throughout the match. In addition, our only female participant (participant #5) has expressed a liking for Move Tennis and Move Kayaking compared with the other two exergames. This revelation, although based on only one participant, indicated that a female player may prefer a nonpugilistic/nonfighting type of exergaming and should be considered when tailoring a structured program for them. Move Kayaking was not immediately intuitive to participants as it is not a common sport in Malaysia. Briefing for this exergame usually took longer compared with the other exergames and participants were not specifically asked for their level of enjoyment following Move Kayaking. The least popular exergaming was Move Gladiator Duel as participants felt that the game was too difficult and their characters hardly won the matches. The authors were unable to determine which of the four exergames was the most superior, and larger sample sizes with a more varied or focused group of SCI classification may provide a better conclusion.

A potential limitation to the study was that the intensity of the four types of exergaming analyzed in this study was guided by absolute intensity measurements as the participants' peak HR or peak oxygen consumption was not measured before deploying the exergaming modalities. As such, relative intensities of effort from percentage of peak HR or peak oxygen consumption could not be determined more precisely to titrate exercise intensity. Other studies have determined exergaming ''dose-potency'' by relative intensities derived from peak performance parameters.[29,54] However, measuring exercise intensities based on peak performance may not be appropriate for the SCI population, since neurological lesions occurring above T4 face consequent blunting of cardioacceleration,[15] and those individuals' capacity is heavily influenced by the level of lesion and sensorimotor limitation.[56,57] This results in a much lower peak performance compared with able bodied parameters, and intensity titration will sometimes only encroach just above resting values. Experts familiar with SCI have also recommended a more ''empirical'' approach, by way of using self-reported intensity measurements, to determine exercise intensity in SCI population.[53] Another limitation to this study was the small ($n = 5$–6) convenience sample size, and the results of this study should not be generalized among SCI population. However, the SCI population represents a special and small cohort of individuals, whereby, feasible candidates were limited in number, and this study only serves as pilot ''proof of concept'' for further research in the area of exergaming after SCI.

Conclusion

The intensity classification while playing Move Boxing, Move Tennis, Move Gladiator Duel, and Move Kayaking, using RPE, reported adequate exercise intensities prescribed by exercise guidelines. Bilateral upper limb exergaming activities produced higher energy expenditure compared with unilateral. The results of this pilot study represent preliminary findings from a small sample of convenience and may not reflect future studies. Further work to establish the potential of these exergaming activities in increasing cardiovascular fitness in individuals with SCI is warranted.

Acknowledgment

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Author Disclosure Statement

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CHAPTER 4: PUBLISHED PAPER 4

4.1 EXERGAMING BOXING VERSUS HEAVY-BAG BOXING: ARE THESE EQUIPOTENT FOR INDIVIDUALS WITH SPINAL CORD INJURY?

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Mat Rosly, M conducted and participated in all the research experiments, coordinated the data analysis and remains as the primary author of the manuscript. Mat Rosly, H gave technical support, conceptual advice on the design of the study and helped in data interpretation. Hasnan, N, Davis, GM and Husain, R supervised the development of work and edited the manuscript.

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ORIGINAL ARTICLE

Exergaming boxing *versus* heavy-bag boxing: are these equipotent for individuals with spinal cord injury?

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ABSTRACT

BACKGROUND: Current strategies for increased physical activity and exercise in individuals with spinal cord injury (SCI) face many challenges with regards to maintaining their continuity of participation. Barriers cited often include problems with accessing facilities, mundane, monotonous or boring exercises and expensive equipment that is often not adapted for wheelchair users.
AIM: To compare the physiological responses and user preferences between conventional heavy-bag boxing against a novel form of video game boxing, known as exergaming boxing.
DESIGN: Cross-sectional study.
SETTING: Exercise laboratory setting in a university medical center.
POPULATION: Seventeen participants with SCI were recruited, of which sixteen were male and only one female. Their mean age was 35.6±10.2 years.
METHODS: All of them performed a 15-minute physical exercise session of exergaming and heavy-bag boxing in a sitting position. The study assessed physiological responses in terms of oxygen consumption, metabolic equivalent (MET) and energy expenditure between exergaming and heavy-bag boxing derived from open-circuit spirometry. Participants also rated their perceived exertion using Borg's category-ratio ratings of perceived exertion.
RESULTS: Both exergaming (MET: 4.3±1.0) and heavy-bag boxing (MET: 4.4±1.0) achieved moderate exercise intensities in these participants with SCI. Paired *t*-test revealed no significant differences (P>0.05, Cohen's *d*: 0.02-0.49) in the physiological or perceived exertional responses between the two modalities of boxing. Post session user survey reported all the participants found exergaming boxing more enjoyable.
CONCLUSIONS: Exergaming boxing, was able to produce equipotent physiological responses as conventional heavy-bag boxing. The intensity of both exercise modalities achieved recommended intensities for health and fitness benefits.
CLINICAL REHABILITATION IMPACT: Exergaming boxing have the potential to provide an enjoyable, self-competitive environment for moderate-vigorous exercise even at the comfort of their homes.

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Key words: Physical exertion - Exercise - Outcome assessment (health care) - Video games - Boxing - Metabolic equivalent.

Exercise is beneficial for individuals with spinal cord injury (SCI) as it has been shown to increase aerobic fitness, augment muscle strength,[1] improve self-perception,[2] and reduce complications related to a wheelchair-dependent sedentary lifestyle.[3, 4] However, individuals with SCI most often occupy the lower range of physical activity,[5] and their activities of daily living are usually inadequate to produce health benefits.[6] Wheelchair sports may not be perceived as analogous or equally enjoyable as able-bodied sports participation, eliciting disappointment in individuals with SCI.[7] Upper body exercises are often recommended, but the availability of accessible facilities may be restricted, and appropriate equipment for these modalities (*e.g.*, arm cranking, wheelchair propulsion, arm and leg cycling) can be perceived as mundane, monotonous or boring.[8, 9]

Video game console producers have released their own versions of movement controlled devices that enable integrating active body movements of sports exercise into an interactive video-gaming environment, termed "exergaming." In physical rehabilitation, exergaming can simulate real-life sports activities within a relatively safe environment.[10] The effects of exergaming on heart rate (HR), oxygen consumption (VO_2), metabolic equivalent (MET) and energy expenditure (EE) have been extensively investigated.[11, 12] Still, only a handful of these studies monitored effectiveness/compliance in pre-post interventions, measured EE *via* indirect or direct calorimetry, and even fewer have focused on populations with physical disabilities.[9, 12]

This study sought to investigate whether there would be any significant differences in physiological responses between heavy-bag boxing and its exergaming equivalent (punching air), while surveying user-perceived enjoyment and motivation of the two exercise modalities. Boxing was chosen because it can produce amongst the highest energy expenditure compared to other forms of classical exergaming, and is more likely to be "dose-potent" for achieving fitness and health benefits.[11, 13] The study also sought to determine whether exergaming (Move Boxing) might meet current exercise intensity guidelines for health benefits as recommended by the American Heart Association (AHA) and the American College of Sports Medicine (ACSM) [14] or SCI Action Canada©,[15] even when deployed in a sitting position.

Materials and methods

Ethical approval for this study was provided by the University of Malaya Medical Ethics Committee (MECID 201410-609) and it was registered under the Malaysian National Medical Research Register (NMRR), NMRR-15-83-23888. A convenience sample size of seventeen individuals with SCI volunteered to participate in this cross-sectional study. The participants were recruited from the spinal cord injury rehabilitation outpatient clinic, University of Malaya Medical Centre, as well as through passive "snow-ball recruitment." Snowball recruitment referred to our non-probability sampling derived by recruiting future participants among acquaintances from existing participants. All participants provided written informed consent, received physician's clearance to participate in the study and were considered at low risk of developing a cardiovascular event during vigorous exercise according to the AHA-ACSM guidelines.[16] The participants were evaluated into their respective American Spinal Injury Association (ASIA) Impairment Scale (AIS) classifications.[17] A summary of the inclusion and exclusion criteria were as follows:

The inclusion criteria were: 1) SCI; 2) no cognitive deficits and ability to follow instructions; 3) SCI >2 years after trauma; 4) age between 18 and 65 years.

The exclusion criteria were: 1) previous history of neurological lesions; 2) current shoulder injury/anomaly; 3) cardiovascular risk precluding vigorous exercise participation.

Experiment and physiologic measurements

The participants attended 3 sessions, provided by a certified physician and an engineer, in an exercise laboratory setting on separate days; day 1 for informed consent, health screening and physiologic measurements, and the next two days for each boxing intervention of exergaming or heavy-bag boxing, set at a minimum of 2 days and maximum of 14 days apart. Exergaming boxing utilized a 65-inch (1.65-m) high-definition, light emitting diode television to project the game, which is run by a video game console, with two controllers and a sensor camera (all components by Sony Interactive Entertainment Inc., Tokyo, Japan). The television's screen center was placed at the participant's eye level and set 2.5 m away. The conventional heavy-bag boxing utilized a 1.65-m, 35-kg punching bag hung in suspension with 3 sizes of boxing gloves (0.28, 0.34, and 0.40 kg) available (all equipment by Fitness Concept Pvt Ltd, Subang Jaya, Malaysia). A disc game (Sony Interactive Entertainment Inc., Tokyo, Japan) was used as the exergaming software for boxing.

All the participants had no prior experience with using the video game console, the controllers, or the exergaming software running on it. The exergaming mode was set to "free play" (the easiest level) since none of the participants had any experience with the game-play. Each participant was given between 10-15 minutes of playtime and briefing prior to initiating the sessions in order to familiarize themselves with each exercise modality. A fifteen-minute exercise duration was predetermined for both the modalities of boxing since it was sufficient to generate a physiological steady state in adults [18, 19] and met the shorter bouts of accumulative exercise recommended by ACSM.[20] Representative cardiorespiratory data for the exercise period was averaged over the 15 minutes. Participants were instructed to simulate a typical boxing match for both modalities.

Before each exercise session, resting heart rate and VO_2 were determined in a supine position for 15 minutes. Resting heart rate was determined by marking the lowest observed HR. The last 3 minutes were evaluated as the physiological response at rest. To avoid bias, the order of boxing interventions was randomized and neither the researchers nor the participants' accompanying persons or caregivers were allowed to provide verbal encouragement during all sessions. Participants were instructed to refrain from smoking, consuming alcohol or caffeine 24 hours prior to the testing sessions to avoid interfering with performance. All participants completed both sessions.

HR was determined using a heart rate monitor (RS 800, Polar Electro, Kempele, Finland) while VO_2, EE, total energy expenditure, minute ventilation and MET were assessed using a validated indirect calorimeter (Cosmed Quark PFT, Rome, Italy). The calorimeter's gas sensors were calibrated before and after each session with a certified mixed gas content of 5% carbon dioxide, 16% oxygen and balance of nitrogen. In addition to physiological data, participants' Borg category-ratio ratings of perceived exertion (RPE) was used; 0 to 10, with 0 being "nothing at all" and 10 being "very, very strong." [21] At the end of both boxing sessions, participants answered a written survey self-constructed by the authors, related to their views on the use of exergaming compared against heavy-bag boxing. The questions included user preferences in the domains of:

— easier to learn;
— more enjoyable;
— comfortable to use;
— motivate to exercise more frequently;
— motivate to exercise longer;
— more challenging;
— more immersive;
— pain distraction;
— easier to assemble; compact;
— preference for home training.

Statistical analysis

Data was processed using SPSS v. 22.0 (SPSS Inc., Chicago, IL, USA) and Excel 2013 (Microsoft Corp., Redmond, WA, USA). Data was assessed for normality distribution using Shapiro-Wilk test and provided evidence that all the data for both groups were normally distributed ($P>0.05$). Paired *t*-test was used to compare the two modalities of exercise for the physiological and perceived exertion variables. Cohen's *d* was used to determine the effect sizes between the two modalities of boxing and between groups with injury levels T4 and above or T5 and below. Independent *t*-tests were used to assess any significant differences between the variables within the AIS classification as well as heart rate measures between groups with injury level T4 and above and T5 and below. Fisher's exact test was used to detect significant differences in the post session preference survey. All data are presented as means and standard deviations. The significance level was set at $P<0.05$ and Cohen's *d* effect size of 0.2 was considered small and 0.5 medium.[22]

Results

The participants who volunteered included sixteen males and only one female with an age range between 20 and 51 years, with a mean of 35.6±10.2 years. The physical characteristics of participants were summarized in Table I. Four of the 17 participants had a level

TABLE I.—*Participants' physical characteristics.*

Characteristics	Values
Gender, M/F, N.	16/1
Age (years)	35.6±10.2
Stature (m)	1.6±0.1
Body mass (kg)	63±14
BMI (kg/m^2)	23±4.6
Level of injury (T4 and above/T5 and below), N.	4/13
AIS (A/B/C/D), N.	11/3/2/1
Time since injury (years)	14.1±5.6

Values presented as mean±SD if not otherwise indicated.
BMI: Body Mass Index; AIS: American Spinal Injury Association (ASIA) Impairment Scale.

of injury of T4 and above with AIS classification of A or B. The time since injury for participants ranged between 5 to 22 years with a mean of 14.1±5.6 years.

Both exergaming and heavy-bag boxing achieved moderate intensities of exercise with 4.3±1.0 MET and 4.4±1.0 MET being achieved, respectively, in a sitting position. Paired *t*-test revealed no significant differences in the physiological or perceived exertional responses between boxing modalities and pairwise comparison effect sizes were generally small to medium (Table II).

Independent *t*-tests revealed no significant differences in the physiological or perceived exertional responses between boxing modalities amongst the AIS categories (Table III). We grouped participants with AIS classification B, C and D together since the numbers were too small for comparison separately. Independent *t*-test also detected no significant differences between heart rate measures in groups with injury level T4 and above and those with level T5 and below, again with generally small to medium effect sizes for pairwise comparisons (Table IV).

The post session user preference survey reported that all of the participants found exergaming boxing was the more enjoyable and Fisher's exact test was not performed for this response. There was a significant preference ($P<0.05$) for exergaming boxing over heavy-bag boxing among responses in four categories; 1) comfortable to use; 2) motivates to exercise for longer; 3) easier to assemble; and 4) preference for home training. Figure 1 shows the participants' perceptions about both modalities of boxing, portrayed as percentages of respondents.

TABLE II.—*Physiological and perceived exertional measures of heavy-bag and exergaming boxing.*

Variables	Rest	Heavy-bag	Exergaming	Cohen's *d*	95% CI	
					Lower	Upper
VO_2 (mL/min)	232±57	942±182	922±154	0.12	-86.39	73.33
VO_2 (mL/kg/min)	3.7±0.8	15.4±3.4	15.0±3.3	0.12	-1.49	1.69
EE (kJ/min)	4.6±1.3	19.3±3.3	18.8±3.3	0.16	-1.41	1.72
$\Sigma EE_{15\text{-}min}$ kJ	n/a	292± 51	293±51	0.02	-24.22	24.26
MET	1.0±0.2	4.4±1.0	4.3±1.0	0.10	-0.37	0.58
HR (bpm)	76±11	135±17	143±17	0.49	-7.60	8.57
VE (L/min)	7.2±2.4	35.8±10.1	39.0±10.7	0.32	-4.77	5.12
Borg CR10 RPE	n/a	7.2±1.3	7.7±1.7	0.34	-0.47	0.96

Values presented as mean±SD if not otherwise indicated. Paired *t*-test detected no significant differences in the values between exergaming and heavy bag boxing ($P>0.05$). VO_2: oxygen consumption; EE: energy expenditure; $\Sigma EE_{15\text{-}min}$: total energy expenditure during 15 min of exercise; MET: metabolic equivalent; HR: heart rate; VE: minute volume; Borg CR10 RPE: modified Borg category-ratio rating of perceived exertion; n/a: not available.

TABLE III.—*Physiological and perceived exertional measures amongst AIS categories.*

AIS categories	Heavy-bag				Exergaming			
	VO_2 (mL/kg/min)	HR (bpm)	MET	Borg CR10 RPE	VO_2 (mL/kg/min)	HR (bpm)	MET	Borg CR10 RPE
A (N.=11)	15.7±3.5	135±13	4.5±1	7.4±1.6	15.3±3.6	149±15	4.4±1.1	7.7±2.0
B, C, D (N.=6)	14.9±3.7	134±24	4.2±1	7.0±0.6	14.5±2.9	132±17	4.1±0.9	7.7±1.4

Values presented as mean±SD if not otherwise indicated. Independent *t*-test detected no significant differences in the values between AIS categories ($P>0.05$).
AIS: American Spinal Injury Association (ASIA) impairment scale; VO_2: oxygen consumption; MET: metabolic equivalent; HR: heart rate; Borg CR10 RPE: modified Borg category-ratio rating of perceived exertion.

TABLE IV.—*Heart rate measures between individuals with injury level T4 and above and T5 and below.*

Groups	Injury level ≥T4	Injury level ≤T5	Cohen's *d*	95% CI	
				Lower	Upper
Heavy-bag	138±22 bpm	134±17 bpm	0.24	-21.32	9.48
Exergaming	136±16 bpm	145±18 bpm	0.54	-9.24	16.22

Values presented as mean±SD if not otherwise indicated. Independent *t*-test detected no significant differences in the values between categories ($P>0.05$).

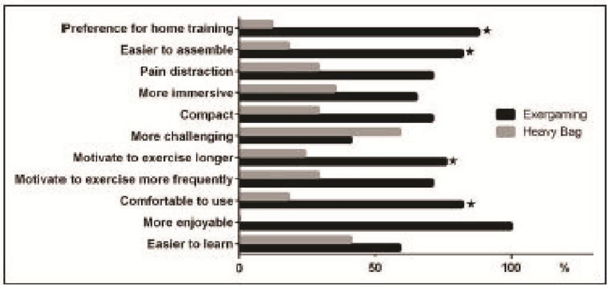

Figure 1.—Participants' preferences on exergaming *versus* heavy-bag boxing portrayed as percentages of respondents.
The star indicates a statistically significant preference (P<0.05) for exergaming boxing over heavy-bag boxing.

Discussion

This study reported that there were no significant differences in the physiological or perceived exertional responses between boxing using a conventional heavy bag *versus* video-game console exergaming. The unique finding was that both modalities were equipotent in terms of exercise cardiorespiratory and perceptual responses, with small to medium effect sizes (Cohen's *d*: 0.02-0.49). Absolute exercise intensities derived from open-circuit spirometry reported metabolic exercise intensities of 4.3±1.0 MET and 4.4±1.0 MET for exergaming and heavy-bag boxing, respectively. Self-reported exertion, using the modified Borg RPE scale, revealed participant-perceived moderate-to-vigorous exercise intensities for both boxing modalities. Our findings demonstrated that boxing in a sitting position via exergaming achieved the recommended physical activity guidelines proposed by AHA-ACSM [14] or SCI Action Canada© [15] to improve aerobic fitness and maintain cardiovascular health. However, the minimum recommended guidelines stipulated by ACSM for physical activity,[20] may be inappropriate for persons with SCI, as their fitness levels, measured by peak oxygen consumption (VO_{2peak}) are generally considered lower than for able-bodied persons.[23, 24] Exergaming boxing was perceived as more enjoyable by all participants, with a significantly higher inclination (P<0.05) to motivate them to exercise longer, as opposed to conventional heavy-bag boxing. In addition, a significant number of participants (P<0.05) said that they would prefer having exergaming as their home training program. Within the limits of this cross-sectional study, exergaming carries the potential to increase physical activity, while promoting improved aerobic fitness, by making it fun or enjoyable and easily available within the comfort of their homes.

The mean oxygen cost while exergaming in this study, 15.0±3.3 mL/kg/min, was comparable to arms-only rowing exercises of 15.7±1.5 mL/kg/min,[25] but was lower than arm crank cycling 18.4±1.7 mL/kg/min,[26] although the latter were reported as VO_{2peak} values. Based on the RPE and VO_2 from the current study, and VO_{2peak} values derived from similar studies,[26, 27] we estimated that our participants achieved 60% of their VO_{2peak} whilst boxing during both modalities. Increasing difficulty levels while exergaming may see higher achievable peak VO_2 values, as this initial study was done in "free play," *i.e.* the easiest mode. When comparing our findings to other types of exergaming modalities, such as the Wii Boxing in standing positions in different populations, the HR responses and MET intensities were similar (Table V).[13, 28, 29] However, VO_2 were reportedly much higher when done in a standing position among able-bodied people [28] and individuals with cerebral palsy.[29] Interestingly, VO_2 while Move Boxing

TABLE V.—*Physiological and perceived exertional measures of boxing types of exergaming modalities* [13, 28, 29] *compared to the present study.*

Variables	This study	Perusek *et al.* (2014) [28]	Hurkmans *et al.* (2011) [13]	Hurkmans *et al.* (2010) [29]
Intervention (population)	Move Boxing (SCI)	Wii Boxing (AB)	Wii Boxing (Stroke)	Wii Boxing (CP)
Positions	Sitting	Standing	Standing	Standing
HR (bpm)	143±17	138±24	106±20	134±21
VO_2 (mL/kg/min)	15±3.3	19.6±5.7	11.9±3.3	17.5±3.8
Borg CR10 RPE	7.7±1.7	11.4±2.0†	5.3±2.7	5.4±1.9
MET	4.3±1.0	5.6	4.1±0.7	5.0±1.1

Values presented as mean±SD if not otherwise indicated.
SCI: spinal cord injury; AB: able-bodied; CP: cerebral palsy; VO_2: oxygen consumption; MET: metabolic equivalent; HR: heart rate; Borg CR10 RPE: modified Borg category-ratio rating of perceived exertion.
† Original Borg Scale (6-20) used for RPE.

in a sitting position in our study were higher compared to Wii Boxing in a stroke population [13] in standing position. The current study reported higher RPE and HR compared to the other interventions, but VO_2 and MET were not different. This cross-study similarity suggests that boxing in a sitting position, which primarily involves using arm muscles that were in close proximity to the heart, heightens the ability to perceive exertion, but lower VO_2 compared to a standing position where leg musculature were recruited for body stabilization and movement.[30]

To the best of our knowledge, this was the first study that sought to quantify oxygen consumption of exergaming boxing using the Playstation Move®, a newer technology released in 2012, against conventional heavy-bag boxing in individuals with SCI. In previous literature, the Nintendo Wii® system (released in 2006) was reported to produce lesser energy expenditure compared to the Xbox Kinect®.[31] It was possible that, because of the higher quality equipment specifications augmented by Playstation Move's controllers,[32] physiological and perceived exertional measures (VO_2, EE, HR, and RPE) of both modalities of boxing in this study were similar. Such similarity of physiological responses were not observed when the exergaming interface used the Nintendo Wii controllers,[28] for which HR ($P<0.001$) and RPE ($P<0.0001$) were significantly higher during conventional heavy-bag boxing.

Jacobs *et al.* observed that spinal cord lesions occurring at the neurologic level of T4 and above may potentially yield diminished cardiac acceleration, with HRs plateauing around 130 bpm.[33] However, in our study, four of the participants had spinal injury at the level of T4 and above, but independent *t*-test detected no significant differences in the heart rate measures between the two groups and the effect sizes between the values were small to medium ($P>0.05$, Cohen's *d*: 0.24-0.54). There were also no significant differences in physiological or perceived exertional responses amongst the AIS categories for both modalities of boxing in this sample population. In other studies, physical capacity have been reported to differ significantly between SCI injury types,[34] and the physical capacity in SCI individuals with tetraplegia can decrease by more than 50% compared to their able-bodied counterpart.[35]

The values of VO_2 from our study falls within the "fair range" of physical fitness parameters when compared to normative values in individuals with SCI.[24] Isolated arm crank cycling exercises have been shown to improve VO_{2peak} by 25% over a period of 8 weeks training,[36] and exergaming might be expected to promote the same level of fitness improvement when deployed within an aerobic training program. In chronic SCI, upper body exercises have the potential to improve physical fitness up to 10-30% of VO_{2peak}, although aerobic fitness improvements have been observed more consistently in those with paraplegia, than with tetraplegia.[37] Previous studies have reported that "hybrid" exercises using functional electrical stimulation (FES) plus active arm ergometry, can improve cardiorespiratory responses by 10-20% [26, 38] — more than isolated upper limb or lower limb exercises alone. However, large scale deployment of such combined exercise has been constrained by the high cost of equipment, limited availability and that it requires trained personnel to monitor participants during intervention. FES hybrid exercise is also not suitable for SCI individuals with lower limb amputation, non-intact lower motor units or have poor sensory perception for muscle contraction. Additionally, participants attending FES hybrid exercises, potentially face risks of pain, skin burns and autonomic dysreflexia during deployment, which calls for alternative exercise approaches that are relatively more tolerant. Exergaming selectively eliminates reliance on such specialized equipment and may promote its extensive use for a larger group of individuals with SCI, especially amongst community-dwelling individuals. Preliminary data now support the use of combined active-arm and passive-leg exercise (AAPLE) to increase cardiorespiratory fitness, that may be more advantageous owing to its lower cost and simpler setup preparation involved.[39] In view of this, further work in creating AAPLE-type of exergaming modalities that are enjoyable, cheap to deploy, as well as "dose-potent" and can be targeted toward individuals with SCI is warranted to allow variation in types of exergaming exercises. Future considerations in the study could include biomechanical analysis and gross kinematics while exergaming.

Limitations of the study

Some limitations of the current study constrain our findings. First, the majority of participants recruited were of AIS category A (N.=11) and only one participant was in category D. This prevented us from comparing data amongst the four AIS categories, whereby we had to group classifications B, C and D together for secondary statistical analysis. Second, a convenience sample population was collected that included only one female participant. This is unsurprising as individuals with SCI have higher male prevalence than females.[40] However, participants' views on the modalities of boxing might differ if the gender distribution had been more equal in this study. Third, this study did not investigate biomechanical analyses of muscle activity, which would have been difficult to replicate during each boxing modality, and for which muscle activation and timing data might have been inconclusive. Biomechanical analysis would not have served to determine the exercise intensity of exergaming boxing (our primary question) as traditional exercise prescription guidelines have used oxygen consumption or heart rate. Finally, our study only included data on participants' body mass index, a poor indicator of obesity, which may have affected the energy expenditure of our sample population, due to the effect of high body adiposity on cardiorespiratory and metabolic responses during exercise.

Conclusions

Exergaming boxing, whereby participants "punch air" in a quasi-competitive environment, evidently produces analogous physiological and perceived exertional responses as conventional heavy-bag boxing in a sitting position. Both boxing modalities produced adequate "dose-potency" prescribed for health benefits. In the context of comprehensive rehabilitation, exergaming boxing using a commercially-available video console can be viewed by clinicians as "as good as" and found to be more enjoyable than conventional heavy-bag boxing. However, further work is needed to ascertain its clinical efficacy for improving aerobic fitness and muscular strength in a longitudinal study.

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CHAPTER 5: UPPER BODY EXERCISES FOR INDIVIDUALS WITH SPINAL CORD INJURY: COMPARING EXERGAMING TO ARM CRANKING

5.1 Abstract

Background: Upper body exercise for individuals with spinal cord injury (SCI) is essential for improving health and fitness but is often constrained to conventional arm crank ergometer (ACE). Exergaming, a form of active video gaming, can provide an alternative upper body exercise that is dose-potent (moderate-vigorous intensity). **Objective:** This cross-sectional study sought to assess Ratings of Perceived Exertion (RPE) and Physical Activity Enjoyment Scale (PACES) for three types of exercise, Move Boxing (MB), Move Kayaking (MK) and ACE, when conducted within similar heart rate (HR) training zones. **Methods:** Biomechanical descriptions, RPE and PACES scores were taken for each session. Analyses of variance with Hedge's g were used for significant differences and effect sizes in HR, RPE and PACES scores between the three types of exercises and injury category. **Results:** The average HR was not different (p=0.489) between exercises (ACE: 110±15, MB: 114±19; MK: 115±17). Tetraplegia (ACE: 95±6, MB: 100±8, MK: 97±12) had lower (p=0.005) average HR than paraplegia (ACE: 117±12, MB: 121±18, MK: 123±13) but when normalised to peak HR was not different (p=0.098). The RPE and PACES were significantly different (p=0.022) between the three types of exercises. ACE produced a lower RPE than both exergames (p=0.002) while Move Boxing was more enjoyable than both ACE (p=0.001) and Move Kayaking (p=0.003). **Conclusion:** All three exercises achieved vigorous intensity (70-80% of peak HR) for individuals with tetraplegia and paraplegia. Move Boxing was found to be difficult but more enjoyable than conventional ACE when done within similar HR training intensities.

Keywords: Video games, Boxing, Kayaking, Perceived Exertion, Ergometry, Heart Rate

5.2 Introduction and review of the literature

Individuals with spinal cord injury (SCI) heavily rely on their upper body musculature for physical as well as athletic activities. In view of this, exercise performance in this population is influenced by key physiological differences between the upper and lower body musculature. Comparisons have been made in studies investigating the dynamics between arm and leg exercises for individuals with SCI. In particular, "hybrid" exercise involving active arm plus passive or functional electrical stimulation (FES) leg cycling have steadily been introduced in rehabilitation therapies as these provided some evidence of greater fitness improvements (Brurok *et al.*, 2011; Taylor *et al.*, 2014). However, wide scale deployment of arm plus leg hybrid exercise has largely been confined to rehabilitation centres with adequate funding, and where trained personnel have suitable skills. Narrow indications (Estigoni *et al.*, 2014; Tong *et al.*, 2017) and risk of autonomic dysreflexia (Ashley *et al.*, 1993) during FES-evoked leg exercise prevents wide-scale participation for individuals with tetraplegia, amputated or severe muscular contractures of the lower limbs. Additionally, physical training using isolated lower limb exercise in this population was suggested as inadequate in intensity (Hasnan *et al.*, 2013) to provide health benefits or improve cardiorespiratory fitness. This still calls for some components of upper body exercises to be essential in maintaining "dose-potent" physical activities among individuals with SCI. The term "dose-potent" physical activities is understood to mean a moderate-vigorous aerobic exercise intensity, performed within bouts of 10 minutes as a minimum, sufficient to enable improvements in fitness and reduce risk of cardiovascular diseases.

Upper body exercises for individuals with SCI are often constrained to conventional arm crank ergometer (ACE) or wheelchair propulsion. Although hybrid (arm and FES-induced leg cycling) (Taylor *et al.*, 2014) or active arm with passive leg cycling exercises (West *et al.*, 2015) have reported greater improvements in peak performance, other studies have also reported that ACE (isolated upper body exercises) demonstrated similar effects on fitness (Akkurt *et al.*, 2017; Brurok *et al.*, 2011) and physical activity levels (PAL) (Bakkum *et al.*, 2015). However, this was only evident in training studies of longer durations (e.g. 12-16 weeks) (Akkurt *et al.*, 2017; Bakkum *et al.*, 2015; Pelletier *et al.*, 2015) as opposed to the shorter interventions (e.g. 4 weeks) (Heesterbeek *et al.*, 2005) often reported for hybrid exercise. Additionally, exercise integrated to a video game has shown evidence of engagement and increased perceptual enjoyment (Widman *et al.*, 2006), which can be pivotal in maintaining exercise adherence, as well as motivation (Mat Rosly, Mat Rosly, Hasnan, *et al.*, 2017). Unfortunately, upper body exercise equipment can be costly (Fitzgerald *et al.*, 2004), not commercially or widely available (O'Connor *et al.*, 2002) and may be more difficult to set up (Widman *et al.*, 2006). Recent commercially available game console technologies have allowed integrated body movements with video game effects in the form of "exergaming", as dose-potent exercises that can be used indoors that overcome exercise barriers related to transport, bad weather, social integration and home training feasibility (Mat Rosly, Mat Rosly, Davis, *et al.*, 2017) for individuals with neurological disability.

A previous pilot study on exergaming for individuals with SCI demonstrated that intensity classification based on ratings of perceived exertion (RPE) were consistently higher than metabolic equivalent of task (MET) or heart rate (HR) (Mat Rosly, Halaki, *et al.,* 2017). In addition, for individuals with SCI, exergaming boxing was found to be more enjoyable than the conventional heavy-bag boxing despite being dose-equipotent (Mat Rosly, Mat Rosly, Hasnan, *et al.*, 2017). The current study attempted to titrate exercise intensity within a constant submaximal steady-state, 70-80% of peak heart rate (HRpeak) during ACE and two types of exergaming exercises (Move Boxing and Move Kayaking). This study sought to determine whether RPE was affected by the type of exercise (exergaming versus ACE) or level of injury (tetraplegia versus paraplegia) even though they were performed within similar training intensities. This current study also investigated personal enjoyment ratings for both individuals with tetraplegia and paraplegia during exergaming compared to the conventional ACE. A biomechanical and kinematic description of the movements that were required during exergaming to achieve the targeted submaximal steady-state levels matched to the ACE was provided.

5.3 Methods

5.3.1 Participants

The Human Research Ethics Committee of the University of Sydney approved the study protocol (Project No: HREC 2016/864). Written informed consent was obtained from all participants prior to their participation. Participants were primarily recruited from a rehabilitation gymnasium that catered to individuals with physical disabilities at the Faculty of Health Sciences, University of Sydney, as well as through passive "snow-ball recruitment" in the community. All the 13 participants recruited completed a health-history questionnaire and were deemed to be at low risk to undertake vigorous exercise according to the American Heart Association® – American College of Sports Medicine™

(AHA-ACSM) guidelines (Balady *et al.*, 1998). Participants recruited received clearance from rehabilitation consultants to participate in the study. The participants were evaluated into their respective American Spinal Injury Association (ASIA) impairment scale (AIS) (Maynard *et al.*, 1997) and injury category (tetraplegia – C8 and above or paraplegia – T1 and below). The time since injury (TSI) for each participant was calculated in years. Eligible participants were those between the ages of 18 to 65 years, of non-traumatic or traumatic SCI aetiology occurring more than 2 years prior to recruitment. Participants were screened for shoulder joint impairments, cardiovascular risk precluding vigorous exercise participation and any previous history of stroke/brain lesions/illnesses affecting their cognitive functions or ability to follow verbal instructions. Previous experience with either ACE or exergaming exercise was not a prerequisite for participation.

5.3.2 Equipment and experimental measurements

Move Boxing (Sports Champion 2 ®, Sony Interactive Entertainment, Inc.) utilised the PlayStation 3® console with two PlayStation Move® controllers, a Sony Eye Camera® (all components by Sony Interactive Entertainment Inc., Tokyo, Japan), displayed on a 60 inch (1.52 m) television (LG Plasma, LG, Electronics Inc., Seoul, South Korea). A custom-made sensor embedded kayak paddle case integrated with the PlayStation Move controllers was used for Move Kayaking (Figure 5.1). The Move Kayaking exergame (Sega Games Co., Tokyo, Japan) was conceptualised and adapted for use in individuals with SCI (Mat Rosly, Halaki, *et al.*, 2017). In addition, a conventional ACE (Ergomed 840L, Siemens, Germany) run in active mode with incremental resistance was used for the arm cranking exercise. Participants' stature and weight were measured and used to calculate their body mass index (BMI). Abdominal circumference (AC) was measured with a measuring tape, at the level of the umbilicus. Active™ gloves (The Active Hands Company, Rumbush, United Kingdom) were used to affix the hands of participants with gripping difficulties (tetraplegia) to the handles of the ACE or the Move controllers. All participants completed an abbreviated questionnaire - The Physical Activity Scale for Individuals with Physical Disabilities (Washburn *et al.*, 2002) and their PAL were determined by the type, frequency and duration of moderate-vigorous intensity exercise participation (Ainsworth *et al.*, 2011). Physical activity status was classified as "active" if the participant reported engaging in moderate-vigorous intensity exercises lasting a minimum of 150 min per week (Cowan, 2016), and "sedentary" if otherwise.

The research design involved 4 exercise sessions performed on separate days with at least a 48-hour gap. The first session involved collection of resting physiological data followed by an incremental power output test using the ACE to derive the highest physical work capacity for each participant. Subsequently, three sessions were carried out comprising either submaximal exercise Move Boxing, Move Kayaking or ACE in a randomised order. Warm up and briefing sessions were given for about 10-20 mins prior to the start of each exercise sessions. HR was monitored with a polar HR monitor (Polar Electro, Kempele, Finland). In addition to physiological data, participants' 10-point RPE was collected; 0 to 10, with 0 being "nothing at all" and 10 being "very, very strong" (Borg, 1982). The degree of enjoyment following each exercise was collected using the modified Physical Activity Enjoyment Scale (PACES) containing five items that assessed their perceived enjoyment for each exercise (Graves *et al.*, 2010). Participants rated the extent to which they agreed with each item on a 7-tier Likert scale. For each of the three exercise types, participants' total responses were summed for a score ranging from 5 to 35 (from 5 = really disliked to 35 = really enjoyed). A video camera (Nikon Coolpix, Nikon Corporation, Shinagawa, Tokyo, Japan), mounted on a tripod positioned next to the participant, was used to record 60 seconds of each exercise session for analysis of gross upper body biomechanics.

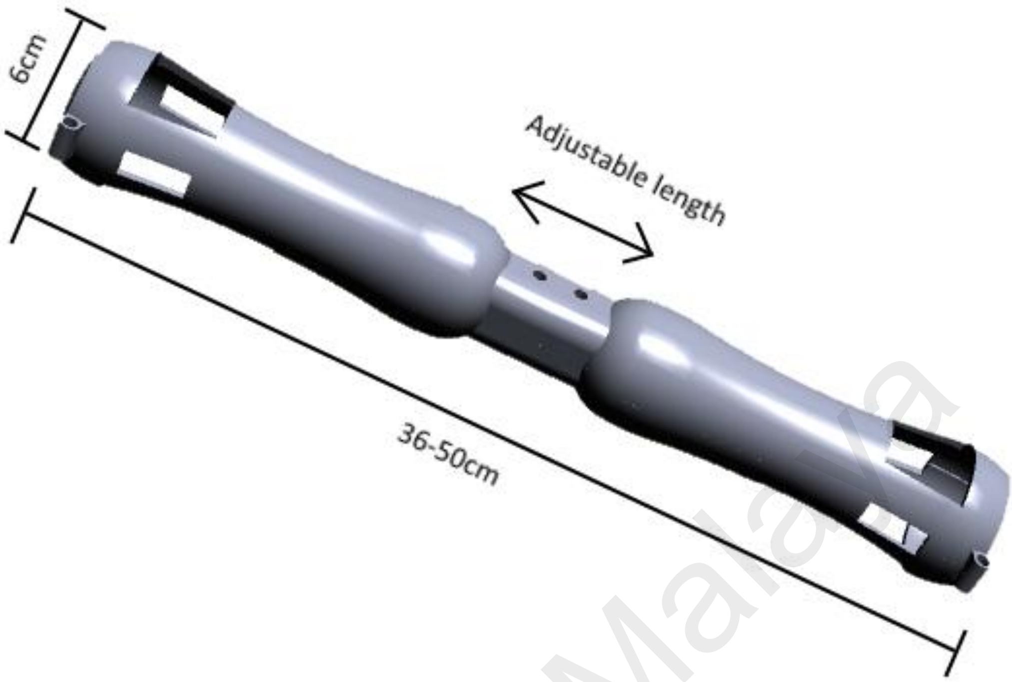

Figure 5.1: Move Kayaking paddle case

5.3.3 Exercise protocol

Resting physiological responses: Participants rested quietly in their wheelchairs for 15-20 minutes before the maximal test to establish resting heart rate (HRrest). The lowest observed HR during the final 3 minutes of resting period was identified as the HRrest.

Maximal physiological responses: Maximal physical work capacity was determined with arm cranking maximal tests conducted with the ACE. Twenty-four hours prior to the test, participants were advised to avoid heavy work that would affect their performance. Participants were required to arm crank at a revolution they were able to maintain based on their individualised performance with resistance increased 5-10 watts every minute until volitional fatigue. Termination of test was done when one of the following conditions were met (Maher & Cowan, 2016): i) participant requested to stop whether verbally or nonverbally or ii) participant unable to maintain their cadence for more than 15s. HRpeak was collected at the highest physical work capacity for each individual during incremental ACE. The HRpeak achieved was defined as the highest values recorded over a 30-second average maintained by each participant (de Groot, van der Scheer, *et al.*, 2016). The highest workload that was achieved and maintained for 30 seconds was recorded as peak power output (Maher & Cowan, 2016). All but participant number 13 (reluctant) performed this maximal effort assessment. HRpeak for this individual with paraplegia, was estimated using Tanaka et al's (Tanaka *et al.*, 2001) formula [HRmax = 208 - (0.7 x age)].

Submaximal physiological responses: Subsequent sessions, involving Move Boxing, Move Kayaking and ACE had participants exercised within 70-80% of their pre-determined HRpeak. The order of each exercise activity was randomised and conducted on separate days. The workload for ACE was increased by adding resistance to maintain an intensity of 70-80% HRpeak. For participants who did not initially reach their target HR during exergaming, arm weights (0.5 – 1 kg) were attached to each of their wrists during Move Boxing and/or Move Kayaking in order to increase the effort. In the event the arm weights added were still not sufficient to induce the desired HR-target band, the games' difficulty levels or speed were increased to achieve the HR. Participants performed each exercise activity at their respective workloads until a steady-state HR was achieved (approximately 1-2 minutes). Participants exercised at this steady-state HR for at least 10 minutes in each of the exercise type. After 5 minutes of each exercise, a 2-minute video was recorded to establish the biomechanical and kinematic descriptions.

RPE and PACES scores were collected at the end of the 10-minute continuous exercise session.

5.3.4 Data analysis

HR measurements were averaged (HRaverage) from the 3rd, 5th and 7th minutes during each exercise. Biomechanical and kinematic movements during one minute from the 2-minute video were analysed by two of the researchers, while a third provided assessments if there were any discrepancies in the two data sets. The number of revolutions, punches or strokes were recorded during ACE, Move Boxing and Move Kayaking, respectively. In addition, the mean height of the hand was categorised as waist, chest or shoulder levels for each participant during each exercise. Data were processed using SPSS version 23.0 (SPSS Inc., Chicago, Illinois, USA) and Excel 2013 (Microsoft Corp., Redmond, Washington, USA) and were normally distributed (Shapiro-Wilk test, $p>0.05$). Assessment for multicollinearity revealed Mauchly's test of sphericity was not significant ($p>0.05$) and Levene's test of error variances equality were also not significant ($p>0.05$), indicating equal variances.

A repeated measures analyses of variance (RM-ANOVAs) within-subject factor (exercise types: ACE, Move Boxing, Move Kayaking), between-subject factor (injury category) and the least significant difference (LSD) post hoc test were used to detect any significant differences in HRaverage ($b \bullet min^{-1}$), HRaverage (%HRpeak), RPE and PACES scores between the three types of exercises. The effect size (Hedges' g) was used to evaluate the size of the difference between the groups with tetraplegia and paraplegia for the three different exercise types. The effect size was classified as small (0.2), medium (0.5) and large (0.8) (Cohen, 1992). Pearson correlation coefficients were also computed to assess associations between HR, RPE, PACES score and the clinical demographics for each type of exercises. Correlation strengths were rated poor if 0.1 < r < 0.3, acceptable if 0.3 < r < 0.5 and good if 0.5 < r < 1.0 (Cohen, 2013).

5.4 Results

5.4.1 Data Summary

Participants' physical and physiological characteristics are described in Table 5.1. The mean ± standard deviation scores of overall HRaverage, RPE and PACES, are presented in Figure 5.2. The HR data, biomechanical descriptions, RPE and PACES scores during each exercises with significant pair wise comparisons are shown in Table 5.2. Tests of within-subject effects of HRaverage (b•min^{-1} and %HRpeak) during the three exercise types (p=0.489 and p=0.462) were not significant, indicating HR training zones were consistent. Within-subject factor RM-ANOVA showed significant differences in RPE (p=0.022) and PACES (p=0.002) scores. Both RPE and PACES scores were significantly different between exergaming (Move Boxing and Move Kayaking) and ACE (Table 5.2). However, tests of between-subject effects for HRaverage (p=0.005) and HR peak (p<0.001), based on injury category (tetraplegia versus paraplegia) were significantly different. RM-ANOVA between-subject factor reported no significant differences among the three types of exercises for RPE (p=0.367) and PACES (p=0.106). Hedges' g representing effect size measures between participants with tetraplegia and paraplegia are tabulated in Table 5.2 Pearson correlation found significant associations between HRaverage during exercise types with age (p=0.048, r=0.32) and TSI (p=0.003, r=0.46). However, there were no correlations observed between either RPE or PACES scores with age, TSI, BMI, AC or HR. Biomechanical descriptions of the exercise types are described in Table 5.3.

Table 5.1: Participants' physical and physiological characteristics

Characteristics		Values
Sex (M/F), n		9/4
Age (years)		37±12
Stature (m)		1.7±0.1
Weight (kg)		69±15
Abdominal circumference, (m)		1.0±0.2
Body mass index ($kg•m^2$)		23.6±4.8
Time since injury (years)		10±9
Injury category (tetraplegia/paraplegia), n		4/9
AIS (A/B/C/D), n		3/5/2/3
Physical activity level (active/sedentary), n		5/8
Resting heart rate ($b•min^{-1}$)	Tetraplegia	69±4
	Paraplegia	68±7
Peak heart rate ($b•min^{-1}$)	Tetraplegia	127±7
	Paraplegia	163±20
Peak power output (Watt)	Tetraplegia	15±9
	Paraplegia	47±6
Values are mean ± standard deviation unless otherwise indicated		
Abbreviations: M: male; F: female; AIS; American Spinal Injury Association (ASIA) impairment scale		

Table 5.2: Heart rate, perceived exertional measures and enjoyment scores of arm cranking and exergaming

Variable	ACE	MB	MK	[a]p (WS)	[b]p (BS)	[c]p (IE)
HRaverage ($b \cdot min^{-1}$)						
Tetraplegia	95±6	100±8	97±12	0.489	***0.005***	0.873
Paraplegia	117±12	121±18	123±13			
g [95%CI] (T vs P)	1.9 [-3.9, 7.7]	1.2 [-7.4, 9.9]	1.9 [-5.0, 8.8]			
Overall	110±15	114±19	115±17			
g [95%CI]	ACE vs MB 0.2 [-6.4, 6.8]	MB vs MK 0.05 [-6.9, 7.0]	ACE vs MK 0.3[-5.9, 6.5]			
HRaverage (%HRpeak)						
Tetraplegia	77±7	81±5	79±6	0.462	0.098	0.868
Paraplegia	72±7	74±9	75±7			
g [95%CI] (T vs P)	0.7 [-3.1, 4.6]	0.8 [-3.6, 5.2]	0.6 [-3.1, 4.2]			
Overall	73±7	76±8	76±7			
g [95%CI]	ACE vs MB 0.4 [-2.5, 3.3]	MB vs MK 0 [-2.9, 2.9]	ACE vs MK 0.4 [-2.3, 3.1]			
RPE						
Tetraplegia	6.0±1.2	7.5±1.3	7.3±1.3	***0.022***	0.367	0.500
Paraplegia	5.8±1.5	6.4±1.3	6.9±0.8			
g [95%CI] (T vs P)	0.1 [-0.6, 0.9]	0.8 [0.08, 1.5]	0.4 [-0.1, 0.9]			
Overall	5.9±1.4	6.7±1.4	7±0.9			
Pairwise comparison, p; g [95%CI]	ACE vs MB (***p=0.002***); 0.6 [-0.02, 1.1]	ACE vs MK (***p=0.037***); 0.9 [-0.5, 1.4]	MB vs MK (p=0.758); 0.3 [-0.2, 0.7]			
PACES						
Tetraplegia	20±7	32±2	25±6	***0.002***	0.106	0.560
Paraplegia	24±8	33±2	30±4			
g [95%CI] (T vs P)	0.5 [-3.7, 4.7]	0.5 [-0.6, 1.6]	1.0 [-1.5, 3.5]			
Overall	22.5±7.7	32.6±1.9	28.3±5.5			
Pairwise comparison, p; g [95%CI]	ACE vs MB (***p=0.001***); 1.7 [-0.4, 3.9]	ACE vs MK (p=0.076); 0.8 [-1.7, 3.4]	MB vs MK (***p=0.003***); 1.0 [-0.6, 2.6]			

Values are mean ± standard deviation unless otherwise indicated;
Abbreviations: [a]p (WS): Within subject (Exercise type) p value; [b]p (BS): Between subject (Injury type) p value; [c]p (IE): Interaction effect (Exercise x Injury type) p value; T: Tetraplegia; P: Paraplegia; g: Hedge's g; CI: Confidence interval; ACE: Arm crank ergometer; MB: Move Boxing; MK: Move Kayaking; HRaverage: average heart rate; %HRpeak: percentage of heart rate peak achieved; RPE: rating of perceived exertion (10 point scale); PACES: Physical activity enjoyment scale (35 point scale)

Table 5.3: Biomechanical descriptions during arm cranking and exergaming

	Exercise Type	Difficulty level	Hand height level	Power output/ resistance load added	[a]Speed per minute
Tetraplegia	ACE	Not Available	Chest (n=4)	5-11 watt	41-63
	MB	Freeplay (n=4)	Chest (n=2)	0 kg (n=2)	68-70
			Waist (n=2)	0 kg (n=2)	56-58
	MK	Sprint Freestyle (n=4)	Waist (n=4)	0 kg (n=2)	53-71
				1 kg (n=1)	58
				2 kg (n=1)	70
Paraplegia	ACE	Not Available	Chest (n=9)	23-55 watt	54-80
	MB	Freeplay (n=6)	Chest (n=6)	0 kg (n=5)	66-92
				1 kg (n=1)	55
		Bronze level 2 (n=2)	Chest (n=2)	0 kg (n=1)	87
				1 kg (n=1)	88
		Bronze level 3 (n=1)	Chest (n=1)	0.5 kg (n=1)	66
	MK	Sprint Freestyle (n=8)	Chest (n=2)	0 kg (n=1)	78
				0.5 kg (n=1)	36
			Shoulder (n=6)	0 kg (n=3)	48-76
				1 kg (n=3)	42-80
		Kayak Slalom (n=1)	Shoulder (n=1)	2 kg (n=1)	53

Values are mean ± standard deviation for power output and range for speed;
Abbreviations: ACE: Arm crank ergometer; MB: Move Boxing; MK: Move Kayaking [a]Speed: Number of revolutions/punches/strokes per minute

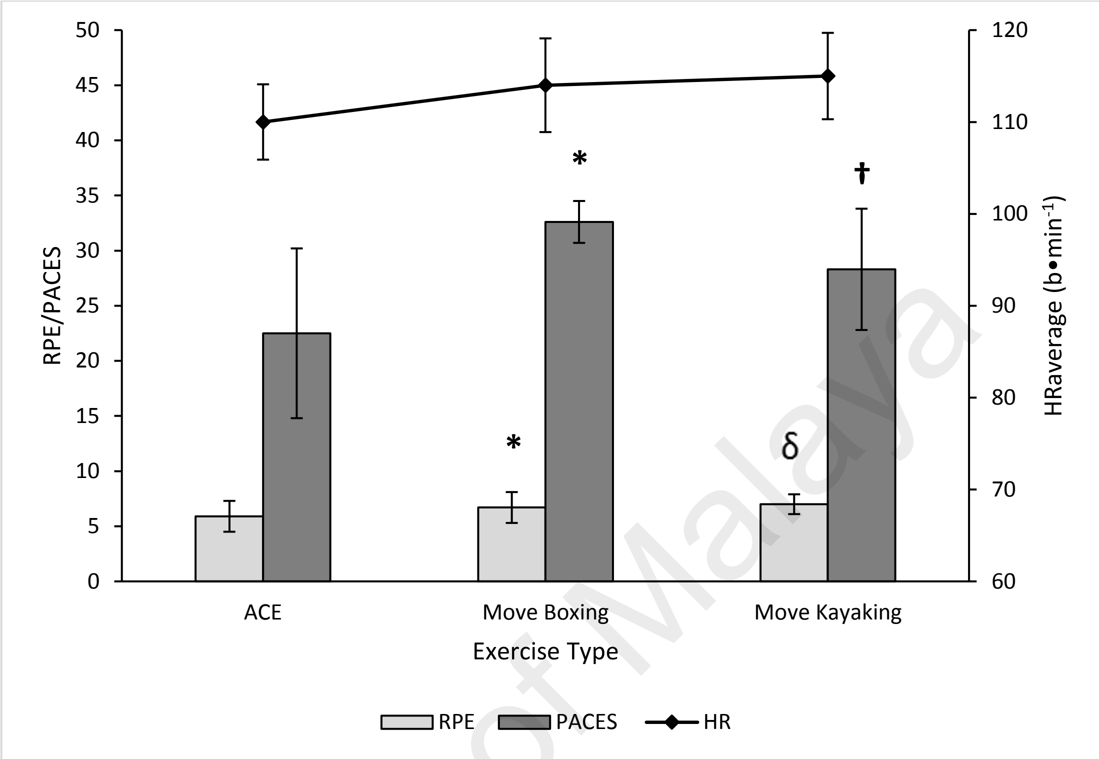

Figure 5.2: Mean ± standard deviation of RPE, PACES and HRaverage for the different exercise types.

Significant differences: *ACE versus Move Boxing, δACE versus Move Kayaking and †Move Boxing versus Move Kayaking ($p<0.05$). **Abbreviations:** RPE: Rating of perceived exertion (10 point scale); PACES: Physical activity enjoyment scale (35 point scale); HR: Heart rate; ACE: Arm crank ergometer. [RPE: p=0.022, (ACE vs Move Boxing, p=0.002), (ACE vs Move Kayaking, p=0.037), (Move Boxing vs Move Kayaking, p=0.758)] [PACES: p=0.002, (ACE vs Move Boxing, p=0.001), (ACE vs Move Kayaking, p=0.076), (Move Boxing vs Move Kayaking, p=0.003)]

5.5 Discussion

This current study demonstrated that exergaming (Move Boxing and Move Kayaking) were able to produce vigorous intensity exercise equal to that during ACE based on percentage of HRpeak for individuals with SCI. Thus, exergaming could be considered as a viable exercise alternative that has "dose-potency" (meeting the required intensity) as recommended by exercise guidelines for health benefits (Martin Ginis *et al.,* 2018; Tweedy *et al.*, 2017). Exercise intensity was titrated according to percentage of HRpeak to maintain the same relative intensity throughout the three exercise types with no significant differences shown. Although the intensity of each exercise was standardised based on HRpeak, participants reported higher RPE during exergaming (Move Boxing and Move Kayaking) compared to ACE. However, RPE was not significantly different between the two groups (tetraplegia versus paraplegia) during each exercise types. The upper body movements required during exergaming to achieve the same exercise intensity may have been perceived as "harder" than the conventional ACE. Accordingly, factors such as "focus" and "engagement" inherent in exergaming, may have positively affected their RPE compared to the conventional ACE (Mat Rosly, Halaki, *et al.*, 2017).

Biomechanical descriptions indicated that all participants with tetraplegia played Move Kayaking with strokes at the waist level. This may have resulted from muscle paralysis that restricted their movements during kayaking strokes (Trevithick *et al.,* 2007). Additionally, the group with tetraplegia played the easiest mode of Move Boxing (freeplay) and Move Kayaking (sprint freestyle) to achieve the targeted HR training zone. For participants with paraplegia, roughly a third of them needed to play harder exergaming modes (for Move Boxing) and two-thirds kayaked at higher hand heights (shoulder level) to achieve vigorous intensity. Speed and resistance loads added for the group with paraplegia were generally higher than the group with tetraplegia for both ACE and exergaming. These indicated that participants with paraplegia indeed had higher functional and fitness levels.

The exercises performed in this current study were isolated upper body training that did not include lower limb musculature. Both upper body and arm plus leg exercises have been shown to improve cardiovascular fitness and health equally the same. However, the FES-hybrid is superior since it also improves the muscular condition of paralysed lower limbs. Exergaming is advantageous since it is more enjoyable, motivating and engaging, in addition to being relatively more affordable with lesser side effects. Despite this, potential issues related to upper body overuse-related injuries, such as shoulder joint ligament tear, muscle strain, tendon sprains or stress fracture may occur. Although this has never been reported before in exergaming, the high speed and external force required during gameplay can lead to these side effects if users are inadequately informed regarding overusing.

The PACES scores suggested that exergaming (Move Boxing and Move Kayaking) was perceived as more enjoyable than the conventional ACE. The order of enjoyment was Move Boxing, followed by Move Kayaking and finally ACE. PACES scores were similar among the paraplegia and tetraplegia groups, indicated by non-significant interaction effects between exercise type and injury category. Injury category does not influence exercise enjoyment among adults with SCI, but larger study sample sizes would be needed to evaluate this further. A study on three different exergame systems in populations with neurological disability have reported positive correlations between PACES scores and HR intensity (Malone *et al.*, 2016). Additionally, exergaming was also found to be significantly more enjoyable, easier to set up, motivating to participate in and feasible in a sitting position (Mat Rosly, Halaki, *et al.*, 2017; Mat Rosly, Mat Rosly, Hasnan, *et al.*, 2017). The added benefit that exergaming may have is its ability to propagate motivation, higher frequency and longer duration of exercise when deployed in an exercise intervention (Fitzgerald *et al.*, 2004; Mat Rosly, Mat Rosly, Hasnan, *et al.*, 2017). In the context of clinical rehabilitation impact, perceived "harder" exercise intensity among individuals with SCI may not affect their level enjoyment. This indicated that higher enjoyment during physical training may be able to motivate participation, improve duration and frequency as well as overcoming perceived difficulties to exercise.

Exergaming has also reported evidence of distracting pain and lowering perceived difficulties (Mat Rosly, Mat Rosly, Hasnan, *et al.*, 2017) while exercising, compared to conventional methods. Psychological frameworks suggested that determinants of exercise behaviour were associated with enjoyment of the activity and access to facility (Sallis & Hovell, 1990) that may increase motivation to exercise. This is in view of exercising being usually perceived as a "negative or neutral" experience but video game play is almost always perceived as a "positive" experience (Astorino & Thum, 2018; Fitzgerald *et al.*, 2004). While exergaming has the potential to increase PAL according to health and fitness guidelines (Mat Rosly, Halaki, *et al.*, 2017; Mat Rosly, Mat Rosly, Davis, *et al.*, 2017), the majority of previous studies have focused on cross-sectional inferred outcomes (Burns *et al.*, 2012; Mat Rosly, Mat Rosly, Hasnan, *et al.*, 2017) with limited evidence on longitudinal interventions (Widman *et al.*, 2006). Future studies could improve this field of research by conducting longitudinal observations with larger sample sizes for both groups of injury categories.

5.6 Limitations

However, the current study has several limitations that may have constrained the findings. Firstly, the use of HR has known pitfalls for use in individuals with tetraplegia, as injuries above T4 display blunting of cardiac acceleration (Jacobs & Nash, 2004). This was evident in the current study, where HRaverage during the exercises were significantly different ($p<0.05$) between the group with tetraplegia and paraplegia. However, HR was deemed most practical or acceptable measurement to use during exergaming as compared to RPE or VO_2peak (Burns *et al.*, 2012; Franklin, 1989). Titration of exercise intensity based on VO_2peak can be difficult to control and imprecise during high intensity exergaming. Additionally, RPE can be overestimated during upper body exercises and is usually constrained to a lower intensity or in those with poor exercise tolerance (Astorino & Thum, 2018; Kressler *et al.*, 2012). HR measurements in titrating exercise intensities do not correlate well with VO_2 during exergaming (Burns *et al.*, 2012; Mat Rosly, Halaki, *et al.*, 2017), and studies that reported good correlation between HR and VO_2 were confined to upper and lower limb hybrid exercises (Jacobs *et al.*, 1997), in the able-bodied (Franklin, 1989) or individuals with SCI levels below T4-T6 (Bar-On & Nene, 1990). The modified Borg RPE (10 point scale) was used instead of the 6-20 point scale, that did not allow for HR-RPE associations or comparisons (Borg, 1982) for this current study. The modified Borg scale was used since it was based on psychophysical relationships, anchored to a simple category of expressions and easily understood for the participants with SCI (Borg, 1982).

Secondly, from the current study, the participants were not typically sedentary, with a pre-existing interest to exercise (they were mostly recruited from gym facilities), which explained their willingness to participate in the study. This may have affected the PACES scores during the exercises, whereby the majority of participants who were recruited enjoyed exercising in general. Future studies may need to focus on a highly sedentary population with SCI that might benefit more from the introduction of this new exercise type, exergaming. Finally, the body fat percentage of the participants in this study cannot be easily determined and relied on BMI instead. BMI is a poor indicator of obesity (Silveira *et al.*, 2017) and may have affected the exercise dose response for individuals with greater BMI. Even though metabolic syndrome may be high (39%) in a population with chronic SCI, it is not significantly associated with physical activity nor fitness level (de Groot, Adriaansen, *et al.*, 2016). Currently, BMI remains as the most widely used measure in a population with SCI since alternative metrics have yet to be determined and validated (Silveira *et al.*, 2017).

5.7 Conclusion

All three exercise types reported in this study (ACE, Move Boxing and Move Kayaking) were able to produce vigorous intensity exercises for individuals with SCI regardless of their injury category or severity. Move Boxing was found to be difficult but more enjoyable than conventional ACE for individuals with SCI when done within the same vigorous intensity training zones.

CHAPTER 6: DISCUSSION AND CONCLUSION

6.1 Description of exercise habits, quantification of physical activity levels and energy expenditure for spinal cord injury health research

The ability to quantify energy expenditure and assess physical activity level (PAL) in community-dwelling individuals with spinal cord injury (SCI) have been recognized as an important measurement in the global context of healthy living and the burden of disease due to sedentary behaviours (Kriska & Caspersen, 1997; Noreau & Shephard, 1995). Physical activity is the bodily movement that is associated with increased energy expenditure (Caspersen *et al.*, 1985) above resting levels derived from skeletal muscle contractions, while energy expenditure represents the metabolic demands of a living organism to sustain life via its organ systems (Caspersen *et al.*, 1985; Tanhoffer *et al.*, 2012). The best practice and highest quality methodology employed to quantify PAL and energy expenditure have been synonymously referred to as a "criterion method" or "gold standard". Validation of PAL in community-dwelling population with SCI has largely focused on external instruments involving the use of accelerometers (Kiuchi *et al.*, 2014; Nightingale *et al.*, 2014), motion sensors (Knippenberg *et al.*, 2017), self-reported measures (de Groot *et al.*, 2010; Ginis *et al.*, 2005) or using the doubly labelled water (Tanhoffer *et al.*, 2015) for energy expenditure quantification. A common strategy to assess total daily energy expenditure has been the doubly labelled water technique which is a summation of several components that include physical activity energy expenditure, resting energy expenditure and thermic effect of food (Hills *et al.*, 2014). However, in the context of field-based interventions, the use of such instruments are impractical as it is time-consuming, expensive and can be uncomfortable for participants (Nightingale *et al.*, 2017).

For large epidemiological studies, questionnaires developed to assess PAL and quantify energy expenditure in a population with SCI are more desirable in the context of feasibility, ethically and financially. Current available studies from review of the literature (Nightingale *et al.*, 2017) found only two questionnaires befitting PAL assessments and energy expenditure quantification after SCI – the Physical Activity Scale for Individuals with Physical Disabilities (PASIPD) (Washburn *et al.*, 2002) and the Physical Activity Recall Assessment for Spinal Cord Injury (PARASCI) (Ginis *et al.*, 2005). Other questionnaires available, were not deemed befitting PAL assessments and energy expenditure quantification after SCI. The Leisure Time Physical Activity Questionnaire for Spinal Cord Injury (Martin Ginis *et al.*, 2012), was designed to only capture "light", "moderate" and "heavy" intensity leisure time physical activities (LTPA), without the ability to differentiate the type of activities of daily living (ADL) performed. This questionnaire was similar in form to the widely used International Physical Activity Questionnaire for able-bodied population (Craig *et al.*, 2003; Martin Ginis *et al.*, 2012). However, the Physical Activity and Disability Survey (Kayes *et al.*, 2009) only had one item which assessed the intensity of structured exercises, while intensities for ADL or LTPA were never assessed. Table 6.1 provides a comparative summary of the PASIPD and the PARASCI questionnaires, the two common ones in use for research and clinical utility. The PASIPD questionnaire was preferred for this thesis as it can be self-administered by participants with SCI without requiring the use of a trained interviewer. It is also more feasible for large epidemiological studies from a financial perspective and accommodating, as it only requires 10 to 15 minutes to complete.

The PASIPD was developed to compare ADL during the past 7 days among all physical disability types including cerebral palsy, stroke and chronic back pain (Washburn *et al.*, 2002). It provides in-depth information on the frequency and duration of each individual ADL and estimates these in metabolic equivalents of a task (MET) per day. It can also be used to report the duration and frequency of the activities performed in average hours per week. Currently, the PASIPD questionnaire is only available in two languages (English and Dutch), and Chapter 3 of this thesis sought to modify the adapted PASIPD English to be relevant in the Malaysian context, translate an additional Bahasa Malaysia and validate both versions. The questions in the PASIPD were designed to be short (Washburn *et al.*, 2002), to increase the number of participants, and simple, a comprehension equivalent to a 12 year old to target those in the lower education level. A simple comprehension level is recommended since the compulsory education level in Malaysia is only up to primary education (7-12 years old).

The adaptation of a questionnaire designed from the western, developed socio-cultural perspective for use within the Malaysian context has several key points to consider. In particular, within the Malaysian setting, some participants with SCI have requested the adapted English version of the PASIPD questionnaire instead of the Bahasa Malaysia variant. The reason behind this was that these participants tended to be more familiar with certain English words as opposed to their Malaysian equivalents, Bahasa Malaysia. The post-British colonisation period (Schneider, 2003), has instilled English as a second language and made it the medium in most tertiary education in Malaysia. The novelty of the Malaysian adaptation of the PASIPD questionnaire was that it provided both the adapted English and Bahasa Malaysia versions, validated for use within the Malaysian population with SCI. Previous studies in adapting questionnaires related to PAL estimation (Chu & Moy, 2015; Ismail *et al.*, 2015), have only provided validation of the

Bahasa Malaysia rendition, which did not represent the Malaysian cultural language customs. The combined data for both versions of the PASIPD demonstrated good construct validity index for the Malaysian population with SCI.

Individuals with SCI reported a change in activities related to lawn work (ICC=0.05, Bahasa Malaysia version) and vigorous sports (ICC=0.20, English version) in the reliability validation. This indicated that the habits change on a weekly basis but quantification of PAL overall was strongly correlated (r = 0.87). The change in weekly exercising habits might be due to transportation issues and health concerns affecting regular dose-potent aerobic exercise participation as demonstrated. The majority of community-dwelling individuals with SCI relied on training facilities for dose-potent exercises (Lundström *et al.*, 2014). Thus, they might have encountered difficulties in participation during these occurrences and attended to ADL at home instead. However, the overall PAL assessments for SCI population provided good reliability using the PASIPD.

Table 6.1: Comparative summary of the two questionnaires for physical activity level assessments in individuals with spinal cord injury

<table>
<tr><th>PASIPD</th><th>PARASCI</th></tr>
<tr><td>Free</td><td>Available at $150 (RM600)</td></tr>
<tr><td>Measure is given free</td><td>Assessment measures must be purchased</td></tr>
<tr><td>Answer format: Objective</td><td>Answer format: Subjective, with patient required to view the question pamphlet format or briefed by the interviewer first</td></tr>
<tr><td>Self-administered (physical/online) or by interview (telephone, face-to-face)</td><td>Requires a trained interviewer</td></tr>
<tr><td>Covers activities during the past 7 days</td><td>Covers activities during the past 3 days</td></tr>
<tr><td>10-15 minutes to complete</td><td>30-45 minutes to complete</td></tr>
<tr><td>Examples of activities were given based on MET values derived from able-bodied individuals</td><td>No examples given, but description of intensity categories were described in detail</td></tr>
<tr><td>Designed for population with different types of physical disabilities</td><td>Designed specifically for the population with SCI</td></tr>
<tr><td>Weak to good construct validity index</td><td>Good to excellent construct validity index</td></tr>
<tr><td>Weak criterion validity</td><td>Weak criterion validity as measured with muscle strength and aerobic capacity</td></tr>
<tr><td colspan="2">Both questionnaires were unable to capture lifestyle activities that can differentiate individuals with different disability characteristics and did not correlate to physical fitness</td></tr>
<tr><td colspan="2">Abbreviations: SCI: Spinal cord injury; PASIPD: Physical Activity Scale for Individuals with Physical Disabilities; PARASCI: Physical Activity Recall Assessment for Spinal Cord Injury</td></tr>
<tr><td colspan="2">References:
1. Washburn, R. A., Zhu, W., McAuley, E., Frogley, M., & Figoni, S. F. (2002). The physical activity scale for individuals with physical disabilities: Development and evaluation. Archives of Physical Medicine and Rehabilitation, 83(2), 193–200.
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3. van den Berg-Emons, R. J., L'Ortye, A. A., Buffart, L. M., Nieuwenhuijsen, C., Nooijen, C. F., Bergen, M. P., . . . Bussmann, J. B. (2011). Validation of the Physical Activity Scale for Individuals with Physical Disabilities. Archives of Physical Medicine and Rehabilitation, 92(6), 923-928
4. Ginis, K., Latimer, A., Hicks, A., & Craven, C. (2005). Development and evaluation of an activity measure for people with spinal cord injury. Medicine and Science in Sports and Exercise, 37(7), 1099–1111.</td></tr>
</table>

6.2 Barriers to dose-potent exercise and leisure time physical activities

Current available studies have focused on barriers to LTPA in general, or barriers associated with injury level (Hundza *et al.*, 2016), mobility (Martin Ginis, Papathomas, *et al.*, 2017) or personally active identity (Cowan *et al.*, 2013; Stapleton *et al.*, 2014). The types of LTPA performed were described, but most of the studies did not associate specific types of LTPA with the barriers reported (Martin Ginis, Arbour-Nicitopoulos, *et al.*, 2010; Martin Ginis, Latimer, *et al.*, 2010). Additionally, studies that associated barriers specifically with moderate-vigorous intensity aerobic exercise participation have only been conducted within Canada (Ginis *et al.*, 2012; Rauch *et al.*, 2017). The first objective of this thesis sought to identify significant associations related to aerobic exercise participation within moderate-vigorous intensity – described as "dose-potent" for fitness improvement, with the various barriers identified. The results from this study (Chapter 4) reached two conclusions related to exercise within the context of a developing country such as Malaysia. The first conclusion was that participation in dose-potent aerobic exercise was lesser than LTPA in general (Mat Rosly *et al.*, 2018). Dose-potent aerobic exercise participation was also significantly associated with age, ethnicity and issues with transportation, health concerns or exercising difficulties (Mat Rosly *et al.*, 2018). The barriers to dose-potent aerobic exercise participation were not significantly associated with injury level (tetraplegia versus paraplegia) or completeness of injury (AIS A to D) (Mat Rosly *et al.*, 2018).

Being of an older age (more than 35 years) was a significant predictor for dose-potent LTPA participation (Mat Rosly *et al.*, 2018). Similar observations were seen in another study sample with SCI (Jörgensen *et al.*, 2017) and among the able-bodied population (Choi *et al.*, 2017). Motivation and refining healthcare facilities might improve exercise participation among the older age population with SCI. Additionally, it was reported that different ethnicities were significantly associated with dose-potent aerobic exercise participation (Mat Rosly *et al.*, 2018). A multitude of factors can form a dynamic influence towards participation that is related to experience, social support from friends, family and the community. Diverse cultural and spiritual beliefs may form different perceptions towards an individual with SCI's outlook in life, as well as influencing community-reintegration and subsequent quality of life (Jones *et al.*, 2016; Monden *et al.*, 2014; Wilson *et al.*, 2017). Those from a higher socioeconomic background (higher household income, developed nations) have reported more personal barriers related to the individual's characteristics, such as laziness, lack of motivation or boring and monotonous exercises, compared to the lower socioeconomic group (Cowan *et al.*, 2012; Roberton *et al.*, 2011).

Combining the literature on barriers to LTPA from the narrative review in Chapter 2 with the results from Chapter 4 of this thesis, suggested that the four integrated themes established were representative. The barriers to LTPA study from Chapter 4 (Mat Rosly *et al.*, 2018) used the established socioecological model by Martin Ginis et al (Martin Ginis *et al.*, 2016) to describe the levels of barriers reported. However, here, it can be established that the four themes identified from the narrative review (Chapter 2); personal characteristics (exercise is difficult), physical limitations (age, health concerns, pain), socio-environmental (ethnicity) and policies (transportation difficulties, costly exercise equipment, inaccessible facilities) constitute the holistic themes identified within the Malaysian setting.

6.3 Determinants of dose-potency in activities and exercises

Categorisation between types of SCI was done based on anatomical level of injury (paraplegia versus tetraplegia) or the American Spinal Injury Association: ASIA impairment scale (AIS). Anatomical level of injury can be further divided into: High tetraplegia (C1-C4), low tetraplegia (C5–C8), high paraplegia (T1-T6) and low paraplegia (T7 and below) or based on neurological SCI level - specifically high paraplegia (T1–T8), and low paraplegia (T9–L4) (Krassioukov, 2009; Myers *et al.*, 2010; Pelletier *et al.*, 2013). A significant difference in peak oxygen consumption (VO_2peak), peak heart rate (HRpeak) and peak power output was observed between adults with tetraplegia and those with low paraplegia (Pelletier *et al.*, 2013). Individuals with tetraplegia reported attaining about 60% of peak performance capacities compared to the able-bodied (Machač *et al.*, 2016). In particular, cervical types of SCI could only achieve approximately 70% of the able-bodied HRpeak (Machač *et al.*, 2016). Heart rate (HR) and ratings of perceived exertion (RPE) have limitations for use among individuals with SCI, even during functional electrical stimulation (FES)- leg exercises (Crosbie *et al.*, 2009; Hasnan *et al.*, 2013; Jacobs *et al.*, 1997). This was explained by the diminished feedback from the leg musculature in individuals with SCI and they are unable to perceive accurate exertion during FES-assisted leg exercise – characterised in peripheral fatigue (Crosbie *et al.*, 2009; Hasnan *et al.*, 2013; Jacobs *et al.*, 1997). However, a more recent pilot study, using total-body recumbent stepper, provided evidence of using RPE in a population where HR was unreliable (McCulloch *et al.*, 2015). The use of HR in determining levels of intensity can be challenging as individuals with tetraplegia have unreliable HR measurements (Tanhoffer *et al.*, 2015) and those with injuries above T4 experience blunting of cardioacceleration (Jacobs & Nash, 2004), sometimes to a point where “exercise” HR would only be slightly elevated above resting levels (Chapter 4).

The pilot study in Chapter 4, (Mat Rosly, Halaki, *et al.*, 2017) on exergaming for individuals with SCI demonstrated that HR elevation and MET values consistently underreported the intensity of exercise as opposed to RPE. MET have been shown to produce lower values in a study sample with SCI due to the limited muscle use in view of paralysis (Burns *et al.*, 2012; Mat Rosly, Halaki, *et al.*, 2017), increased fatigability due to poorer motor function (van der Scheer, de Groot, Tepper, *et al.*, 2015) and lower physical peak performance (Perrier *et al.*, 2017). MET cost associated with upper body training efforts are heavily influenced by the architectural features (resistance, terrain, 3-dimension arm axial rotation and range of motion) of each exercise type. In the case of exergaming training platform, different types of motion sensor capture and interface can detect the depth of motion and rotation, promoting higher muscle activation, recruitment and subsequent energy expenditure (Chen *et al.*, 2017; Knippenberg *et al.*, 2017; Mat Rosly, Halaki, *et al.*, 2017; Tanaka *et al.*, 2012).

The differentiated RPE model (central versus peripheral), considers separate perceived signals distinctively: working muscles for peripheral RPE, and metabolic from the cardiorespiratory system for central RPE (Qi *et al.*, 2015). Differentiated RPE monitoring for aerobic exercise intensity prescription should be considered, but this subjective measurement relied on how individuals with SCI perceive central RPE versus peripheral RPE (Au *et al.*, 2017; Goosey-Tolfrey *et al.*, 2014). Self-reported intensity measurements have been recommended by experts familiar with the population with SCI (Martin Ginis *et al.*, 2011; Martin Ginis *et al.*, 2012; van der Scheer *et al.*, 2018). However, RPE was reported to be higher than MET or HR, when determining exergaming intensities due to factors associated with "engagement" and "focus" that can overestimate RPE (Mat Rosly, Halaki, *et al.*, 2017). Additionally, peripheral RPE were found to elicit higher intensities as opposed to central RPE reported in ACE for individuals with SCI (Lenton *et al.*, 2008; Pelletier *et al.*, 2015). Some studies have suggested that the limitation in RPE-HR-VO_2 relationship for individuals with SCI was due to peripheral (small active muscle mass) rather than central (heart or lungs) effort (Au *et al.*, 2017; Hopman *et al.*, 1998; Leicht *et al.*, 2012), though other studies demonstrated no significant differences (Goosey-Tolfrey *et al.*, 2014; Qi *et al.*, 2015). Absolute HR determination is a known limitation in a population with SCI, due to the impaired sympathetic responses, causing lowered HRpeak as opposed to non-SCI population (Iturricastillo *et al.*, 2016). There is good association between HR and VO_2, but this was not seen between HR and RPE in study samples with SCI (Jacobs *et al.*, 1997; Jung *et al.*, 2012).

6.4 Modelling perceived exertion in exercise grading for spinal cord injury

In the last experimental chapter of this thesis (Chapter 5), RPE was demonstrated to be consistently higher among participants with tetraplegia than paraplegia. This was shown across all three types of the exercises investigated (Move Boxing, Move Kayaking and ACE). It was evident that RPE was significantly higher during exergaming than the conventional ACE even though the intensity was kept approximately within the range of 70-80% HRpeak band. For this reason, exergaming (Move Boxing and Move Kayaking) was perceived to be of greater effort than conventional ACE which may have affected the RPE. It was reported that RPE could be influenced by "focus" and "engagement", which result in RPE being more difficult to rate during exergaming (Mat Rosly, Halaki, *et al.*, 2017). A study by Astorino et al. (Astorino & Thum, 2018) has shown that high intensity training (interval or in sprints) reported higher RPE than continuous types of exercise. These factors could influence RPE determination during different exercise types.

Neuromuscular stimulation and ACE exercises had demonstrated a strong linear relationship between VO_2 and HR measures in individuals with SCI during submaximal training (Goosey-Tolfrey *et al.*, 2014; Jacobs *et al.*, 1997; Jung *et al.*, 2012). However, RPE did not vary significantly with VO_2 or HR until relatively high exercise intensities (Goosey-Tolfrey *et al.*, 2010; Jacobs *et al.*, 1997), indicating HR could be used to titrate exercise intensity for individuals with paraplegia. In individuals with SCI, fatigability and reduced physical capacity are known issues that affect the likelihood for higher levels of RPE during sustained exercise performance (Dobkin, 2008; Haisma *et al.*, 2006; Kressler *et al.*, 2012; Simmons *et al.*, 2014). The greater intensity and repetition of movements during moderate-vigorous exercise can lead to faster muscle fatigue and compromise force production, which is more apparent among unfit individuals with SCI. This may be caused by an imbalance in oxidative stress responses during high intensity exercise in individuals with SCI.

In addition, global RPE (a combination of central and peripheral RPE) has demonstrated a non-linear association with cardiorespiratory outcomes (VO_2 and HR) (Hopman *et al.*, 1992; Lewis *et al.*, 2007). Interestingly, moderate-intensity exercise was shown to correlate better with peripheral RPE than either central RPE or global RPE during able-bodied ACE (Au *et al.*, 2017). However, Kressler's study (Kressler *et al.*, 2012) found that estimating exercise intensity using RPE against VO_2 peak may be limited by the level of SCI. Their study (Kressler *et al.*, 2012) showed that the RPE scale is suitable for determining the intensity of exercise but was limited to individuals with low exercise tolerance. Currently, the use of RPE measurements for a population with SCI is applicable but subjected to conditions associated with SCI level, fitness, type of training and the exercise intensity (van der Scheer *et al.*, 2018).

6.5 The physiological responses, changes and benefits of “dose-potent” aerobic exercise

Following discharge from intensive inpatient rehabilitation, individuals with SCI were more likely to develop rapid drop in their PAL (Buchholz *et al.*, 2003; Rimmer, 2012; Tanhoffer *et al.*, 2015; van den Berg-Emons *et al.*, 2008), fitness parameters (de Groot *et al.*, 2016) and adherence (Vissers *et al.*, 2008) to exercise training. Their exercise capacity usually stabilises between 1 to 5 years after intensive rehabilitation discharge (van Koppenhagen *et al.*, 2013). Physical exercise provided at an intensity-adequate (moderate-vigorous) dose-potent response is important to enhance functional recovery, improve physical capacity, stimulate community reintegration and optimise independence. Current available guidelines have advocated two approaches to exercise prescription for individuals with SCI, 150 minutes versus 40-90 minutes of moderate-vigorous aerobic exercises with resistance training per week (Martin Ginis, van der Scheer, *et al.*, 2017; Tweedy *et al.*, 2017). The prescription differs based on the goals of achieving either cardiorespiratory fitness, cardiometabolic health or muscle strength (Martin Ginis, van der Scheer, *et al.*, 2017; Tweedy *et al.*, 2017).

Although intensive and repeated exercise is required to improve functional recovery and fitness parameters, overtly strenuous physical training can also lead to potentially deleterious effects related to oxidative stress (Lam *et al.*, 2013). Oxidative stress is caused by overproduction of free radicals (mainly reactive oxygen species) that are not adequately controlled by the body’s antioxidant defence systems (Jia *et al.*, 2012). The oxidative stress response in the acute and chronic SCI have been poorly understood and these limitations may impact the prescription of exercise training parameters for a population with SCI. Furthermore, the susceptibility to oxidative stress during exercising is further exacerbated by changes highly related to chronic SCI such as nutrition, PAL, muscle fibre property or atrophy (Qin *et al.*, 2010). This highlights the importance of determining appropriate dose of exercise prescription in terms of intensity, frequency and duration. Further research to form evidence-based guidelines that are appropriate and safe for the population with SCI is needed.

Exercise can act as an anti-inflammatory therapy to prevent obesity by inducing interleukin-6 production which is responsible for circumventing adipose tissue accumulation in low-grade inflammatory diseases (da Silva Alves *et al.*, 2013). Additionally, individuals with SCI, performing regular physical exercise develop better body fat mass distribution and lower insulin resistance (D'Oliveira *et al.*, 2014). At an intensity exceeding 30-40% of VO_2peak, carbohydrate becomes the predominant fuel source during upper body exercises and sedentary individuals with paraplegia are more capable of oxidizing fat during voluntary ACE (Jacobs *et al.*, 2013). The intervention necessary to elicit the highest fat oxidation is equivalent to approximately 50% of total energy expenditure. Exercise has also been found to improve the antioxidant defense system, attenuating lipid and protein oxidation in adults with chronic SCI (Ordonez *et al.*, 2013). In the final study, Chapter 5, abdominal circumference and body mass index were not significantly associated with RPE. The prevalence of abdominal obesity in the population with SCI was reported to be similar to the able-bodied (Kim *et al.*, 2013) and might not have affected higher RPE intensity during upper body exercise.

In addition, the risk of bone fracture as a result of bone loss in a population with chronic SCI can be prevented by introducing repeated muscular contractions to stress and augment bone formation (Dolbow *et al.*, 2011). This can be achieved considerably through rapid exposure of exercise training that are adequate in intensity, frequency and duration. Although FES training has demonstrated significant increase in bone mineral density of the lower limbs, pharmacological interventions such as bisphosphonate therapy was found to be more effective in attenuating bone loss (Chang *et al.*, 2013). However, researchers and clinicians should take into consideration other factors influencing bone loss in chronic SCI such as age, gender, heredity and diet (Dolbow *et al.*, 2013).

6.6 Isolated upper body exercises versus assistive upper and lower limb hybrids

The objectives of this study focused on voluntarily activated muscle exercises (isolated upper body exergaming) rather than use of assistive technology such as, FES, body weight supported treadmill training (BWSTT) or exoskeleton powered suits. When comparing isolated upper body exercises against FES hybrid exercises (upper and lower body), high quality randomized controlled trial studies had reported both interventions showed similar cardiometabolic improvements (Bakkum *et al.*, 2015; van der Scheer, de Groot, Vegter, *et al.*, 2015). However, FES hybrids indeed promote greater lower limb bone mass, muscle mass and strength (Giangregorio *et al.*, 2012; Gorgey & Khalil, 2015) that is not provided in isolated upper body exercises. Exercise training programs have reported no common adverse effects for most types of interventions, except for musculoskeletal complications (pressure ulcers, skin burns, autonomic dysreflexia) related to FES training (Smit *et al.*, 2016; Warms *et al.*, 2014). The combination of the advantages and disadvantages of FES hybrids call for alternative exercise technologies that are relatively more tolerant and can safely be deployed as home-training programs.

The combination of greater physiological stress associated with upper body work with architectural or structural (grade, terrain) features could further increase the metabolic cost of wheelchair locomotion. Individuals with SCI relying on wheelchairs for ambulation experience greater physiological stress associated with upper body work during propulsion that are affected by the different architectural or structural features (Hashizume *et al.*, 2015). Prolonged strain on upper limb and shoulder joints during manual wheelchair use can result in complications related to shoulder muscle extensibility, greater pain and limited joint movements (Eriks-Hoogland *et al.*, 2016; Finley & Ebaugh, 2017). These overuse related injuries can be anticipated during isolated upper body exergaming, for example, shoulder joint ligament tears caused by high speed or muscle strains when doing the Move Boxing exercise. Additionally, passive or isolated FES-leg cycling may not necessarily provide adequate intensity for health improvements (Hasnan *et al.*, 2013) or increase lower limb muscle mass (Giangregorio *et al.*, 2012). Evidence indicated active arm, passive leg cycling exercise could provide similar improvements in cardiorespiratory indices to FES hybrid training (West *et al.*, 2015). These reasons indicated that upper body muscular training is still needed to achieve cardiovascular demands for fitness. Therefore, the FES-hybrid is seen as superior since it also improves the muscular condition and function of paralysed lower limbs, justifying the higher costs and associated side effects. However, exergaming has reported higher enjoyment, motivation and engagement that could promote longer adherence to exercise participation. Further work is needed to design an active arm-passive leg exercise and integrate it into exergaming for added motivation.

For individuals with SCI, exercising the upper body alone provide beneficial systemic effects and improve physical fitness (Kim *et al.*, 2015; Ordonez *et al.*, 2013; Rosety-Rodriguez, Camacho, *et al.*, 2014; Rosety-Rodriguez, Rosety, *et al.*, 2014). Indeed, without the involvement of leg stimulation exercises, the lower extremity musculature remains vulnerable to pathology with subsequent complications related to spasticity, muscle atrophy and bone loss. Electrical stimulation therapies (FES/FNS) and over-ground bionic ambulation (OBA) was shown to induce localized improvements in leg muscle mass and vasculature as well as improve ambulation associated with speed and walking distance (Benson *et al.*, 2016; Gorgey & Khalil, 2015; Jeffries *et al.*, 2015; Taylor *et al.*, 2014). However, these assistive devices did not produce significant changes in beneficial effects related to metabolic syndrome components, inflammatory status and visceral adiposity against conventional isolated upper body training regimens (Bakkum *et al.*, 2015; Giangregorio *et al.*, 2012). Furthermore, FES/FNS/OBA are currently not readily available outside clinical or laboratory settings for most of the community-dwelling individuals with SCI, as they can be expensive to deploy and usually require monitoring by trained specialised staff for potentially dangerous adverse effects. Therefore, a more ecologically viable exercise intervention, in combination with conventional approaches (e.g: ACE, upper body exergaming and physical therapies), should be used to develop viable training programs with sustainable feasibility and efficacy. As such, future studies should investigate the use of alternative exercise methods to identify, adapt and tailor a training program with suitable potential for each unique individual with SCI. In view of this, alternative assistive technologies that allow individuals with SCI to safely engage in routine LTPA within a more affordable range are needed.

6.7 Exergaming as an exercise training platform

6.7.1 Considerations for exergaming use

When using exergames for physical training, it is important to consider that most studies previously conducted were self-imposed and subjected to participants' level of enjoyment (Gaffurini *et al.*, 2013; Mat Rosly, Halaki, *et al.*, 2017; Mat Rosly, Mat Rosly, Davis, *et al.*, 2017; Mat Rosly, Mat Rosly, Hasnan, *et al.*, 2017; Roopchand-Martin *et al.*, 2014). The conventional types of exercise equipment (e.g ACE, wheelchair treadmill) allows titration of exercise intensity (moderate-vigorous), within a desired training zone by controlling the workload and speed. It was also reported that wheelchair rugby is the only type of sport classified as vigorous intensity and designed specifically for individuals with cervical SCI (West *et al.*, 2012). The exergaming environment (with its added versatility, dynamic response and player interaction) can be difficult to titrate exercise intensity within specific training zones. However, our final study (Chapter 5) has shown that it is possible by altering the player input mechanics, speed, difficulty level and adding resistance weights during gameplay. Additionally, exergaming can also achieve moderate or vigorous intensity by tailoring the gameplay according to the players' SCI category, function and position. This provided insight, that exergaming could be adapted as a vigorous intensity sport even for individuals with tetraplegia. For instance, Move Kayaking for individuals with tetraplegia may require longer paddle cases, chest straps, position recalibration, hand dominance or changing the gameplay settings (types of difficulty level/ latency response). These factors are important for achieving training zones during exergaming.

The studies conducted in this thesis (Chapters 4 and 5), did not require use of a head-mounted display or other special visual apparatus in order to feel immersed within the virtual reality exergaming environment. This both reduces the likelihood of developing side effects (dizziness, discomfort) and eliminate a source of encumbrance that might hinder the motor response of participants while exergaming. Although newer head-mounted displays and stereoscopic glasses are considerably less cumbersome than previous models, there are limited findings available regarding their use for rehabilitation and exercise training (Borrego *et al.*, 2018). Future work should consider potential improvements on the exergaming system by utilizing head-mounted displays, as it may immerse the participants in the exergaming experience further. Second, the user controls the movement within the exergaming environments, actively participating and promoting engagement during exercise. Unlike custom exergaming systems however, most commercially available exergames are not designed with specific rehabilitation goals in mind, but the use of the PlayStation system has several advantages over conventional exercise equipment (e.g ACE, heavy-bag boxing) or other virtual reality based training platforms. This can include being significantly more enjoyable, easier to set up, motivating to participate in and dose-potent feasible in a sitting position (Chapters 4 and 5) (Mat Rosly, Halaki, *et al.*, 2017; Mat Rosly, Mat Rosly, Hasnan, *et al.*, 2017).

6.7.2 How exergaming technology can overcome some barriers to exercise: The prescriptions, adaptations and recommendations for individuals with spinal cord injury

Among the most common barriers to exercising at a "dose-potent" intensity was reported to be perceived pain (Mat Rosly *et al.*, 2018). However, 70% of the pain reported in individuals with SCI were known to be of chronic neuropathic, non-nociceptive in nature, which is caused by injury to the neural nervous systems (Varoto & Cliquet, 2015). Neuropathic pain can be difficult to manage, and pharmacological interventions have only provided temporary symptomatic relief. There is not enough evidence to support reduction of chronic pain through non-pharmacological treatments in individuals living with SCI (Boldt *et al.*, 2014). To address these difficulties, video exercise environments in the form of exergaming have documented evidence of distracting pain whilst exercising (Mat Rosly, Mat Rosly, Hasnan, *et al.*, 2017; Pekyavas & Ergun, 2017). This may be attributed to the pathway mechanics of pain stimulation which could be overlapped by the visual and sensory feedback during exergaming. For instance, when comparing exergaming boxing against heavy-bag boxing (Mat Rosly, Mat Rosly, Hasnan, *et al.*, 2017), more than 50% of participants with SCI felt that the exergaming type distracted them from pain while boxing.

In the study investigating barriers related to LTPA participation, Chapter 4 (Mat Rosly *et al.*, 2018), a significant predictor of participation in intensity adequate LTPA was reported to be associated with the availability of transportation. Additionally, not having an exercise equipment at home reduced the odds of being an exerciser among adults with SCI (Cowan *et al.*, 2013). The ability to finance transportation costs and fitness facility fees were known prevalent barriers reported, but did not necessarily determine the likelihood of exercising. Home-based exergaming programs have the potential to overcome this important barrier. Further work and future studies should look into the feasibility of home-exergaming for individuals with SCI prior to deployment. The efficacy in promoting health benefits, fitness improvements, exercise adherence and maintaining motivation are key indicators of feasibility and efficacy. In a study sample with SCI in USA, significant differences were seen in reported barriers to LTPA among those with low household income, were unemployed or unable to work (Hwang *et al.*, 2016). Interestingly, this was not seen in the Malaysian study sample (Mat Rosly *et al.*, 2018), that represented a socioeconomic demography within a developing country. These findings echo the issue pertaining to personal financial barrier to LTPA participation that was discussed earlier (Chapter 4).

The study on barriers to LTPA within a Malaysian setting (Mat Rosly *et al.*, 2018), suggested that barrier prevalence was associated with participation. Prevalent barriers related to LTPA, from a combination of previous studies, demonstrated significant association to LTPA participation (Jörgensen *et al.*, 2017; Martin Ginis, Papathomas, *et al.*, 2017) or could affect the likelihood of participation (Cowan *et al.*, 2012; Cowan *et al.*, 2013). The sociodemographic setting could also impact the perceived barriers, which included personal characteristics, socio-environmental dynamics and the development of policies. LTPA programs need to focus on tailoring suitable training platforms for different SCI categories and impairments. Essentially, various different training regimens should be prescribed in a mix and match fashion to improve motivation, adherence and interest for the community-dwelling individuals with SCI. Exergaming programs have been shown to elicit more positive changes and is a more effective upper body physical training than conventional home-based exercise programs (Pekyavas & Ergun, 2017).

Strategic methods would be needed to address barriers considered as exercise prescription “blind-spots” (pain while exercising, no interest/lazy to exercise, afraid to leave home, not worth the time, exercise will make my condition worse or not improve my condition) that were reported by individuals with SCI for exercise participation (Mat Rosly *et al.*, 2018). Additionally, motivation is a strong driver to exercise participation, and this is particularly apparent among the active population with SCI (Crawford *et al.*, 2008; Kehn & Kroll, 2009). Predicted factors for home-based physical therapy adherence were strongly related to self-motivation and social support (Essery *et al.*, 2017). Barriers to exercising perceived by high income and low income adults with SCI vary in terms of psychosocial factors (Martin Ginis, Papathomas, *et al.*, 2017) or themes. Barriers related to personal characteristics were reported among the high income individuals (Cowan *et al.*, 2012; Mat Rosly *et al.*, 2018), whilst socioeconomic and environmental barriers were associated with the low income group. The key strength for deploying exergaming as a feasible equipment for LTPA or exercise is the perceived enjoyment, as reported by several studies among a population with neurological disabilities (Malone *et al.*, 2016; Widman *et al.*, 2006), including those with SCI (Mat Rosly, Mat Rosly, Hasnan, et al., 2017). Higher enjoyment scores were reported to improve motivation and maintain adherence rates to exercise (Pekyavas & Ergun, 2017; Widman *et al.*, 2006). Previous studies had demonstrated that higher quality exergaming gameplay were associated with higher intensity achievements and perceived enjoyment (Malone *et al.*, 2016; Mat Rosly, Mat Rosly, Hasnan, *et al.*, 2017). In addition, exergaming has the ability to provide an alternative form of sports competition that is vigorous in intensity, enhanced via a digital network environment (MacIntosh *et al.*, 2017). Exergaming can therefore be introduced as a moderate-vigorous intensity aerobic exercise training program, with the capability to provide higher enjoyment for individuals with SCI.

6.7.3 Challenges of exergaming introduction in clinical applications

The first generation of exergames first emerged in the 1990s and a number of previous studies have demonstrated the effectiveness of exergames designed specifically to address targeted therapeutic goals for individuals with cerebral palsy, stroke or SCI (Cooper *et al.*, 1995; Fitzgerald *et al.*, 2004; O'Connor *et al.*, 2002). While effective and enjoyed by the different populations, these systems can be extremely expensive, with costs ranging from [USD10,000-50,000 (RM40,000-200,000)] (Guo *et al.*, 2006; O'Connor *et al.*, 2002) and often require participants to travel to a rehabilitation facility in order to use them. In contrast, commercially available exergame systems (such as the Xbox Kinect®, Nintendo Wii® or PlayStation Move®) are relatively low-cost [~USD300 (RM1,200)] and widely available, making them more conducive for home-based physical training. None of the included studies in this thesis performed a cost-efficacy analysis of exergaming compared to conventional exercises or other intervention programs. Some researchers assumed that exergames are less expensive than conventional therapies delivered on a regular basis by therapists in a hospital setting or at home. This is owing to the wide availability of off the shelf exergames that have been heavily commercialised, well-received and well-funded by their respective parent companies. This explains why exergaming equipment are relatively more affordable than other types of assistive technologies such as FES, OBA or BWSTT. Physical activities promoting health improvements in individuals with SCI were reported to benefit between USD290,000 (RM1,140,000) to USD435,000 (RM1,710,000) in lifetime costs, owing to lesser reliance on assisted care and fewer hospitalisations (Miller & Herbert, 2016). Further work is needed to demonstrate the feasibility and efficacy of exergaming programs within a home-based setting with cost-efficacy analyses.

In the exergame design process, the interdisciplinary collaboration of different disciplines is essential. This is important in tailoring different types of exergaming for each individual with SCI's physical limitations. The range of motion, flexibility and functional mobility differ heavily between levels of SCI (high/low tetraplegia, high paraplegia and low paraplegia). However, several issues during collaboration such as use of different terminologies in different disciplines, parallel developments taking place at different locations, allocating funding, human and technological resources, may hamper effective communication that complicates exergame development coordination. It is therefore recommended that team members related to exergaming physical training programs comprise of clinicians, physiotherapists, occupational therapists, engineers and exercise physiologists who are experts in their respective areas. Exergaming trainers should be skilled and knowledgeable on the exergaming console systems used, to allow for the utilisation of its full potential.

Designing an exergame specifically for individuals with SCI is extremely challenging, especially for those with upper limb impairment (tetraplegia). Their different levels of injury and motor function requires personalised modifications. For instance, the paddle case in Move Kayaking (Mat Rosly, Mat Rosly, Davis, *et al.*, 2017) for individuals with tetraplegia must be adjustable in length to allow a more simplified kayaking movement feasible for muscle paralysis occurring in the triceps, biceps, supraspinatus, upper trapezius, latissimus dorsi, serratus anterior or rhomboid (Trevithick *et al.*, 2007). Adaptation of the game controller's handles is needed to accommodate weak hand grips (tetraplegia) and may benefit from using specialised gloves such as the Active™ gloves (The Active Hands Company, Rumbush, United Kingdom). The game system's sensors also must be adjusted to allow in depth 3D motion capture to increase player engagement and avoid uncaptured user input. Poor recognition of arm axial rotation movement due to low depth resolution and prolonged latency period can cause frustration in players. Therefore, an interdisciplinary collaboration effort should be promoted to allow integrated exergaming developments geared for individuals with SCI. The most challenging future work would be to develop an exergaming training platform that combines both upper and lower limb hybrid exercises. This may provide better cardiometabolic improvements, as well as lower limb conditioning of the paralysed muscles, compared to isolated upper body exergaming.

6.8 Limitations and delimitations

The studies conducted for this thesis had several limitations that constrained the findings. Firstly, the use of the PASIPD questionnaire allows determination of average hours spent on moderate-vigorous aerobic exercise type of LTPA per week (Washburn *et al.*, 2002), but has been reported to have poor criterion validity and reliability (de Groot *et al.*, 2010; Jimenez-Pardo *et al.*, 2015 ; van den Berg-Emons *et al.*, 2011; van der Ploeg *et al.*, 2007). Other types of questionnaires designed for study samples of individuals with SCI, such as the PARA-SCI and Leisure Time Physical Activity Questionnaire for SCI reported good reliability (Ginis *et al.*, 2005; Martin Ginis *et al.*, 2012). However, the PASIPD was designed for participant self-administration, did not require use of a trained interviewer and financially more feasible for large epidemiological studies. Additionally, the PASIPD could be used for future work involving other types of physical disabilities within the Malaysian context. LTPA participation among adults with SCI could look into the time and frequency spent on moderate or vigorous (dose-potent) aerobic exercise. This can determine whether they fulfilled different durations (150 versus 40-90 minutes) recommended by the different guidelines (Martin Ginis, van der Scheer, *et al.*, 2017; Tweedy *et al.*, 2017).

Secondly, the exergaming types (Chapters 4 and 5) used to determine dose-potency were isolated voluntary activated upper body exercises that did not include any lower limb musculature to improve strength, muscle mass and bone density. However, the objectives of the thesis were to provide a dose-potent physical activity training platform for individuals with SCI that could address barriers related to costly equipment, boring exercises or no access to facilities. The use of RPE to determine intensity is psychophysical, constrained by factors associated with muscle paralysis, exergaming interactivity, greater body mass index, isolated upper body physical training or poor tolerance to exercise (van der Scheer *et al.*, 2018). The modified RPE (10 point scale) was used instead of the 6-20 point scale, and this may have had some constraints on the accuracy of the estimation. The 6-20 point Borg scale for RPE denoted HR associations and any discrepancy could be compared (Borg, 1982). However, the modified 10-point Borg scale was based on psychophysical relationships that referred to quantitative semantics (Borg, 1982). This modified Borg RPE scale was preferred as it was anchored to a simple category of expressions, without technical terminology and easily understandable for a population with SCI.

Peak performance capacities produced lower values in isolated upper body and laboratory-based incremental exercise testing compared to field-based maximal tests (West *et al.*, 2016). Titration of aerobic exercise using percentage of HRpeak, to achieve vigorous intensity training zones for the last study (Chapter 5), was limited to blunting of HR acceleration as a result of cervical SCI or high tetraplegia. However, it was the most practical or acceptable measurement to use during exergaming as compared to VO_2peak (Burns *et al.*, 2012; Franklin, 1989). Titration of exercise intensity based on VO_2peak during high intensity exergaming was hampered by hindrance and discomfort from the masks or mouthpieces. Cardiac output is considered the “gold standard” to determining peak aerobic exercise capacity of an individual (Jakovljevic *et al.*, 2008), with the ability to measure central metabolic capacity owing to determination of the heart performance. However, it has been replaced with VO_2peak, since the use was observed to be very limited in both laboratory and clinical settings (Jakovljevic *et al.*, 2014; West *et al.*, 2015) for exercise testing. The CO_2 rebreathing technique is unsuitable for those who are unable to tolerate the brief 20-30 seconds of the required rebreathing period and may produce large coefficient variations (Jakovljevic *et al.*, 2008; Vanhees *et al.*, 2000). Unpleasant side effects had been reported for CO_2 gas rebreathing during high-intensity exercises (Jakovljevic *et al.*, 2008; Vanhees *et al.*, 2000), due to the high concentration of CO_2 required (10%). Cardiac output rebreathing methods also require participants to breathe from a bag that was manually filled with approximately 1.5 to 2 times their estimated tidal volume and can be difficult to control during exergaming.

The participants recruited may not be representative of the general community-dwelling individuals with SCI and could be “the tip of the iceberg” active group that justified their willingness to participate in the exergaming studies. These participants may have enjoyed exercising in general and they did not represent markedly sedentary individuals with SCI who might benefit more from the introduction of exergaming. The available exergames piloted, that can be used for individuals with SCI were limited in number, four, comprising of Move Boxing, Move Kayaking, Move Gladiator Duel and Move Tennis. Other types of exergames reviewed, were too expensive, not workable in a sitting position, be feasibly dose-potent, or adaptable for individuals with tetraplegia, and future considerations should include hybrid (upper and lower limbs) exergaming. Lastly, all three of the laboratory findings reported were observational cross-sectional studies that did not include longitudinal interventions. Longitudinal studies are expensive to fund, but important to address the use of exergaming for health benefits, cost-efficacy, adherence and motivation.

6.9 Conclusion

Several studies conducted for this thesis have demonstrated and achieved the objectives related to exercise in the adult population with SCI. The Malaysian adaptation of the PASIPD questionnaire provided a validated measure (content, construct and reliability) to assess PAL and energy expenditure quantification among individuals with SCI that can be used in large-scale epidemiological studies. The novelty of the PASIPD adaptation was that it provided validation of both the adapted English and Bahasa Malaysia versions for use within the Malaysian setting. This represented the social context of the Malaysian population, where Bahasa Malaysia is the primary and English, the secondary language. Additionally, the PASIPD can be used in different types of populations with physical disabilities in future studies. However, further work is needed to assess the criterion validity based on types of SCI or different physical disabilities.

The second objective in this thesis described various LTPA participation rates and its associated barriers using the modified PASIPD questionnaire and items pertaining agreement to the barriers. This study was the first to report a quantitative description on the barriers specifically related to aerobic exercise type of LTPA of moderate-vigorous intensity (dose-potent) within an Asian country. The cross-sectional study focused on the SCI socioeconomic and demographic drivers to LTPA within a developing country. The prevalent barriers reported were consistent with issues within personal characteristics, physical limitations, socio-environmental dynamics and public policies. Age, ethnicity, transportation difficulties and health concerns were found to be significant predictors associated with participation to moderate-vigorous intensity exercise.

Following identification of barriers related to moderate-vigorous intensity aerobic exercise participation, the third objective of the thesis assessed value proposition around introducing exergaming as a viable training platform for individuals with SCI. The systematic review and pilot study reported evidence that exergaming (Move Boxing, Move Gladiator, Move Tennis and Move Kayaking) can achieve moderate-vigorous aerobic exercise intensity in a study sample with SCI, even with different neurological injury levels (tetraplegia versus paraplegia) or completeness of injury (AIS). Exergaming can provide a health beneficial LTPA alternative for the population with chronic SCI.

The last objective in the thesis compared exergaming to conventional exercise equipment by associating intensity with the perceived enjoyment. In particular, exergaming boxing (Move Boxing) was found to be equipotent to the conventional heavy-bag boxing counterpart, but had the advantage of significantly being more enjoyable, more comfortable to use, motivating longer use, easier to assemble and is the preferred platform for home-based training. Move Boxing, Move Kayaking and ACE were all able to achieve vigorous intensity despite being an isolated upper body exercise. However, Move Boxing has the advantage of being significantly more enjoyable than conventional forms of exercising, such as ACE or heavy-bag boxing. In addition, Move Boxing was perceived to be more difficult but had significantly higher enjoyment among individuals with SCI.

The reported studies proved that exergaming can be used to achieve dose-potent, isolated upper limb aerobic exercise training platform for adults with SCI. Exergaming has the advantage of being considerably more affordable to deploy, relatively safe, comfortable to use, easier to set up and an enjoyable exercise that can be considered for use among a population with SCI.

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LIST OF PUBLICATIONS AND PAPERS PRESENTED

PUBLICATIONS

1. Mat Rosly M, Mat Rosly H, Davis OAM GM, Husain R, Hasnan H. Exergaming for individuals with neurological disability: A systematic review. *Disability and Rehabilitation*. 2017;39(8):727-35.

2. Mat Rosly M, Halaki M, Mat Rosly H, Cuesta V, Hasnan N, Davis GM, et al. Exergaming for individuals with spinal cord injury: A pilot study. *Games for Health*. 2017;6(5):279-89.

3. Mat Rosly M, Mat Rosly H, Hasnan N, Davis GM, Husain R. Exergaming boxing versus heavy bag boxing: Are these equipotent for individuals with spinal cord injury? *European Journal of Physical and Rehabilitation Medicine*. 2017;53(4):527-34.

4. Mat Rosly M, Halaki M, Hasnan N, Mat Rosly H, Davis GM, Husain R. Leisure time physical activity in individuals with spinal cord injury in Malaysia: Barriers to exercise. *Spinal Cord*. 2018. doi**:** 10.1038/s41393-018-0068-0

ARTICLES UNDER REVIEW FOR PUBLICATION

1. Mat Rosly M, Halaki M, Mat Rosly H, Hasnan N, Davis GM, Husain R. Malaysian adaptation of the Physical Activity Scale for Individuals with Physical Disabilities. *Disability and Rehabilitation.*

2. Mat Rosly M, Halaki M, Mat Rosly H, Hasnan N, Husain R, Davis GM. Upper body exercises for individuals with spinal cord injury: Comparing exergaming to arm cranking. *Games for Health.*

CONFERENCE PROCEEDINGS

1. Mat Rosly M, Mat Rosly H, Husain R, Davis GM, Hasnan N. Assessing LTPA participation and barriers among community dwelling SCI in non-western culture. *55th International Spinal Cord Injury Society (ISCoS)*, Vienna, Austria. 14-16 September, 2016.

2. Mat Rosly M, Mat Rosly H, Husain R, Davis OAM GM, Hasnan N. Kayak Exergaming for Individuals with Spinal Cord Injury. *3rd International Conference on Movement, Health & Exercise (MOHE2016)*, Melaka, Malaysia. 28-30 September, 2016.

3. Mat Rosly M, Halaki M, Hasnan, N, Husain R, Davis GM. Assessment of cardiac output during exergaming and arm cranking. 15th Asian Society for Adapted Physical Education and Exercise (ASAPE 2018), Kuala Lumpur, Malaysia. 11-13 July, 2018.