Compensation in Movement Behaviours Following Exercise of Different Intensities in Older Adults.

By

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The above committee determined that the thesis is acceptable in form and content and that a satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate during an oral examination. A signed copy of the Certificate of Approval is available from the School of Graduate and Postdoctoral Studies.

ABSTRACT

The overall purpose of this thesis was to assess compensation in movement behaviours of older adults following exercise. Participants (n=28, 69.7±6.5 years) completed the following exercise protocols in random order, one week apart: moderate continuous exercise (MOD), high intensity interval exercise (HI), and sprint interval exercise (SPRT). A thigh-worn device (ActivPAL^{TM}) was used to measure movement behaviours at baseline (two weeks prior to exercise), day zero (the day of exercise), and the subsequent three days. Overall, compensation was observed in all movement behaviours but sleep. It appears that the greatest compensation occurred following SPRT, with increases in ST and decreases in LPA and MVPA. Fatigue could explain this compensation. Higher intensity exercise appears to have a more profound effect on future movement behaviour patterns than moderate intensity. This has important implications for prescribing high intensity exercises in older adults as it may increase ST, decrease LPA and displace current MVPA.

Keywords: compensation, movement behaviours, aging, high intensity

CO-AUTHORSHIP STATEMENT

This thesis includes a manuscript (Chapter 3) that has been submitted for publication. Co-authors include my supervisor, Shilpa Dogra; committee member, Meghann Lloyd and fellow Masters student Andrea Linares. Dr. Dogra was responsible for the idea and contributed to writing of the manuscript. Dr. Lloyd contributed to the design of the study and reviewed the final manuscript. Andrea Linares assisted with data collection and reviewed the final manuscript. Nikola Goncin recruited and collected data on all participants and was the sole author of this thesis, excluding the co-authored manuscript.

AUTHOR'S DECLARATION

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STATEMENT OF CONTRIBUTIONS

Part of the work described in Chapter 3 has been submitted for publication to the *Journal of Physical Activity and Aging,* using the title: Engaging in Exercise Leads to a Decrease in MVPA and an Increase in Sedentary Behaviour Among Older Adults. Co-authors for this paper included Shilpa Dogra, Meghann Lloyd and Andrea Linares.

As first author, I contributed to the design and methodology of the study, applied for ethics approval, recruited participants, collected and analyzed data, performed statistical analysis, and contributed significantly to the writing of the manuscript.

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LIST OF ABREVIATIONS

HI – High Intensity Interval Exercise

LPA – Light Physical Activity

MET – Metabolic Equivalent Unit

MOD – Moderate Intensity Continuous Exercise

MVPA – Moderate-to-Vigorous Physical Activity

PA – Physical Activity

SB – Sedentary Behaviour

SPRT – Sprint Intensity Interval Exercise

ST – Sedentary Time

Chapter 1. Introduction

1.1 Thesis Overview

Research on physical activity consistently indicates that moderate-to-vigorous physical activity (MVPA) can improve cardiorespiratory fitness (Gillen et al., 2016; Milanović, Sporiš, & Weston, 2015; Støren et al., 2017; W. J. Tucker, Angadi, & Gaesser, 2016). Improvements to cardiorespiratory fitness alongside accumulated weekly physical activity may decrease all-cause mortality (Jefferis et al., 2014). In contrast, sedentary time (ST), defined as any waking behaviour in the seated or reclined position under a low energy expenditure (≤1.5 METs) (Tremblay et al., 2017), is associated with an increased risk of all-cause mortality, independent of accumulated physical activity (Dunstan et al., 2010; Katzmarzyk, Church, Craig, & Bouchard, 2009). Solely engaging in physical activity, without managing the time spent engaging in sedentary behaviours, may not effectively reduce the risk of all-cause mortality. For health benefits, people may need to decrease ST while simultaneously meeting the physical activity recommendations, that is, a minimum of 150 minutes of moderate to physical activity per week (MVPA)(Tremblay et al., 2011).

ST represents the largest proportion of an adults' day and leaves limited waking hours for MVPA (Arnardottir et al., 2012; Biddle et al., 2018; Matthews et al., 2008). Alongside accumulating significant ST, a majority of older adults also fails to meet physical activity recommendations (Hallal et al., 2012; Matthews et al., 2008). Recent literature shows that between 3 and 13% of older adults are engaging in the recommended amount of MVPA per week (Colley et al., 2011; Jefferis et al., 2014). As older adults exhibit both the highest prevalence of ST and physical inactivity, they may be at a comparatively increased risk of all-cause mortality (Dunstan et al., 2010; Jefferis et al., 2014; Katzmarzyk et al., 2009). Although physical activity and ST may have independent effects on one's health (Blair & Brodney, 1999; Blair, Cheng, & Holder, 2001; Dunstan et al., 2010; Katzmarzyk et al., 2009), co-accumulation of these behaviours has been relatively unexplored. Collecting data on all four movement behaviours simultaneously may provide researchers the best opportunity to observe any changes to the time accumulated in the individual behaviours (described below); changes may both be observed within and between respective movement behaviours.

To observe movement behaviours simultaneously, data must be collected over a full day (24-hours) (Tremblay et al., 2016). In any given 24-hour time frame, older adults engage in behaviours that can be classified into any one of the four possible domains: ST, sleep, MVPA, and light physical activity (LPA)(Chaput, Carson, Gray, & Tremblay, 2014; Rosenberger, Buman, Haskell, McConnell, & Carstensen, 2016; Tremblay et al., 2016). The time spent in said behaviours can be collected through self-report or device based measures (accelerometer/inclinometer). Although distinct, these individual behaviours may have associations with one another. Excluding data collection on any one of the four movement behaviours (MVPA, LPA, Sleep and ST) may result in a failure to observe how changes to one behaviour is compensated for by the others. For example, if a participant increased total daily MVPA and no change to ST was observed, without collecting data on sleep and LPA, investigators would not be able to determine how the increase in MVPA duration was compensated for (Tremblay et al., 2016).

Compensation may be observed by changes to all, none, or a combination of the four movement behaviours mentioned above. For instance, following high intensity interval exercise (HI), we may observe an increase in ST, a decrease in LPA and MVPA, and no change to sleep duration. Furthermore, even within the same individual, movement behaviour compensation may differ following different intensities of exercise. For example, changes that may have been observed in the above example of HI may be different when observing changes after sprint intensity interval training (SPRT) or moderate intensity continuous training (MOD). Compensation may be observed immediately or anytime (day(s), week(s) or month) following physical activity.

Understanding how movement behaviour compensation differs following different intensities of exercise may improve our current understanding of movement compensation and concurrently aid in improving physical activity prescription and decreasing ST in older adults. As an example, if an older adult substantially increases ST following HI but in contrast decreases ST after MOD, it would be prudent to prescribe MOD. Literature published on observing movement behaviour compensation following physical activity in older adults is scarce. Therefore, there is a gap in the literature, in understanding how different exercise intensities affect movement behaviours. This information may supplement and ultimately improve exercise prescription for older adults.

The primary purpose of this thesis was to determine whether acute exercise bouts led to changes in movement behaviours in subsequent days among older adults. Data were collected on all four movement behaviours simultaneously through 24-hour continuous activity monitoring following three separate exercise protocols: MOD, SPRT and HI.

1.2 Research Questions

1. Does sedentary time, LPA, MVPA or sleep change in the days following participation in an acute bout of MOD, SPRT or HI in older adults?
2. Is there a relationship between exercise enjoyment or fatigue and changes to ST in older adults following an acute bout of MOD, HI or SPRT?

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Chapter 2. Review of Literature

2.1 Movement Behaviours

During the course of a typical 24-hour day, the behaviours we engage in can be categorized into one of four possible movement behaviours: moderate to vigorous physical activity (MVPA), light physical activity (LPA), sedentary behaviours (SB), and sleep (Chaput et al., 2014; Rosenberger et al., 2016; Tremblay et al., 2016). These four movement behaviours will be discussed extensively throughout this literature review.

In order to fully understand movement behaviours and their relationships with one another, it is imperative that data be collected on all four behaviours during the same 24-hour data collection period, rather than in isolation (Tremblay et al., 2016). Although each behaviour is considered distinct, it has become increasingly clear that they are closely related, and thus it is important to consider the four movement behaviours together. In 2016, a 24-hour model was developed to inform movement behaviour guidelines in children (Tremblay et al., 2016). Prior to the publication of the 24-hour model, recommendations for the time spent in each movement behaviour was generally prescribed separately (Colley et al., 2011; Tremblay et al., 2011). That is, recommendations for physical activity and ST were addressed individually instead of counselling both concurrently. Although there is literature that has addressed each individual movement behaviour in older adults, the 24-hour model, and potential associations amongst the four movement behaviours have not been carefully studied, and thus, this remains a gap in the literature.

Before discussing the relationships between different behaviours, it is important to understand how different behaviours are currently classified, how much daily time older adults are accumulating in each behaviour, and lastly, the patterns in which these behaviours are accumulated. This will allow us to better understand current movement behaviour patterns in older adults.

2.2 Behaviour Classification

The four movement behaviours (MVPA, LPA, ST and sleep) are determined using energy expenditure, that is, metabolic equivalent units (METs) (Ainsworth et al., 2011). A single MET is equal to the basal amount of energy expended at rest ($3.5ml/O_2/min^{-1}$) (Morris et al., 1993). Activities that require greater energy expenditure have higher MET values. For example, the energy requirement for household vacuuming would be 3.3 METs (Ainsworth et al., 2011).

2.21 Sedentary Behaviour (SB).

SB has been defined as any waking behaviour performed in the seated or reclined position, under a low energy expenditure ≤1.5 METs (Tremblay et al., 2017). For research purposes, different SB's performed throughout the day are summed together to represent a single number, that is, sedentary time (ST). Examples of SBs are watching television, playing video games, passive commuting to and from work, working at a desk and board games. Devices, such as accelerometers collect information on ST but not SB, as they do not capture the context of the sedentary activities (Doherty et al., 2013).

2.22 Physical Activity (PA).

PA is defined as any movement performed by the skeletal muscles that requires an expenditure of energy (Chodzko-Zajko et al., 2009); it can be separated into two distinct categories: MVPA and LPA (Tremblay et al., 2016). LPA is any PA that has an energy expenditure of 1.6-2.9 METs (Pate, O'neill, & Lobelo, 2008; Tudor-Locke, Washington, Ainsworth, & Troiano, 2009). LPAs are those in which an individual is moving around but at an intensity that is comfortable. The corresponding values on a rating of perceived exertion scale, for example, would be a rating of six to eleven (Peterson, 2007). Examples include activities of daily living, gardening, walking slowly, yoga, and cooking.

MVPA is any PA that requires an energy expenditure of ≥3.0 METs (Ainsworth et al., 2011). MVPAs are those that are performed at a moderate intensity and have a corresponding rating of perceived exertion of 12 or greater (Peterson, 2007). Examples of MVPA are briskly walking, golfing, and cycling at a wattage of 30 or greater. As intensity increases, activities may transition from a moderate energy requirement to a vigorous one, however all intensities ≥3.0 METs are classified under the umbrella of MVPA.

2.23 Sleep

Older adults require the least amount of sleep (7-8 hours) when compared across all age groups (Hirshkowitz et al., 2015). As a consequence of decreased sleep duration, the number of waking hours available for LPA, MVPA and ST increases. Sleep duration does not account for napping, which may be particularly important to consider with older adults.

2.3 Prevalence

Prevalence data are available on individual behaviours (i.e., daily ST, LPA, MVPA and sleep) from a number of countries, including Canada. To date, the majority of research on prevalence has been on individual movement behaviours.

2.31 Sedentary Time

ST makes up the largest proportion of an individual's waking hours. Older adults in particular, accumulate the most ST when compared to their younger counterparts

(Matthews et al., 2008). Over 40% of adults' report sitting for four or more hours per day (Hallal et al., 2012). This number increases to nearly 60% in samples of older adults (i.e. 60+) (Hallal et al., 2012). In a review using pooled device-measured data across multiple samples, total accumulated ST in older adults was 9.4 hours per day (Harvey, Chastin, & Skelton, 2015). Device measured ST was broken down further, into percentage of overall waking hours in adults >70 years by Davis et al. (2014). The total ST was observed to account for 70% of the total waking hours, or approximately 10 hours a day (Davis et al., 2014). Device based measures are considered the gold standard for measuring ST as self-report has been found to under report total ST (Chastin et al., 2018).

While the total daily ST is important, a growing body of research indicates that prolonged bouts of ST without breaks may have a more negative impact on health (Carson et al., 2014; Diaz et al., 2016). In a study by Diaz et al. (2016), ST was collected via accelerometers in participants ≥45 years old; approximately 70% of the sample was ≥65 years old. Total ST was broken down into bouts, bout duration, and percentage of total ST. It was observed that the majority of people in their sample (80%) engaged in at least one bout of prolonged SB (≥60 minutes). This number dropped to 30% when looking at bouts of SB ≥90 minutes. However, the highest percentage of ST (~44%) was performed in bouts ≥5 minutes (Diaz et al., 2016). In a similar Canadian study, Carson et al. (2014) reported that over 50% of each participant's total ST was accumulated in bouts of ≥20 minutes. Negative associations have been reported between sedentary bouts of ≥20 minutes and fitness in older women (Dogra, Clarke, & Copeland, 2017). With a predominant proportion of an individual's waking hours allocated to ST, few hours remain for engaging in LPA and MVPA.

2.32 Physical Activity

Current global and Canadian PA guidelines for older adults recommend accumulating 150 minutes of MVPA weekly, performed in bouts of ≥10 minutes and strength training twice per week (Tremblay et al., 2011; World Health Organization, 2010). Physical inactivity, or failure to meet these recommendations, has been established as a negative risk factor for a variety of health outcomes (Warburton, Nicol, & Bredin, 2006). In a study by Chen et al. (2015), different intensities of physical activity were observed through monitoring daily physical activity and ST in Japanese adults ≥65 years using tri-axial accelerometry. Energy expenditure thresholds were used to differentiate between LPA (1.6-2.9 METs) and MVPA (≥3 METs). The mean time spent in LPA and MVPA was 5.5 hours and 37.8 minutes per day, respectively (Chen et al., 2015). Alternatively, instead of using energy expenditure, Davis et al. (2014) used a traditional accelerometry approach (cut-points) of establishing time spent in different physical activities in adults ≥75 years of age. Cut-points were set at >100-499, >500-1951 and >1951 for very light physical, LPA and MVPA. The daily accumulated time in each intensity was reported in percentage of waking hours (M=14.4hrs) as 10.2%, 9% and 1.5% respectively (Davis et al., 2014). Arnardottir et al. (2012), similarly found that older adults spent less than 1% of total waking hours in MVPA. Older adults are spending <4% of their total waking hours engaging in MVPA, clearly failing to meet physical activity recommendations and thus increasing their risk of chronic conditions (Warburton et al., 2006).

Using self-reported measures, marginally higher values were reported through Canadian survey data; approximately 13% of older adults engaged in ≥150 minutes of

MVPA (Colley et al., 2011). A vastly larger, but noteworthy result, was found using the National Health and Nutrition Examination Survey (NHANES); >60% of older adults were meeting physical activity recommendations (J. M. Tucker, Welk, & Beyler, 2011). It is important to note that self-report measures have been found to over-estimate almost all intensities of physical activity (Dogra, Ashe, et al., 2017; Grimm, Swartz, Hart, Miller, & Strath, 2012); thus, it is possible that actual PA time is lower than what has been reported in previous research using self-report. In comparison, current research suggests that accelerometers are more accurate at capturing most physical activities with the exception of activities involving significant upper limb movement, such as holding/lifting weights and swimming (Bauman et al., 2011; Welk, 2002).

The impact of LPA on health in older adults has recently received greater recognition (Fishman et al., 2016; Matthews et al., 2008). As such, limited research has been conducted on current LPA levels in older adults. Therefore, research is needed in order to better understand LPA levels in older adults using device based measures.

2.4 Movement Behaviour Patterns

Although underreported, gender differences have been observed in all movement behaviours, and have important implications for gender specific movement behaviour prescription.

Gender differences have been reported for total ST in many of the studies above. Men have been observed to engage in more SBs, for longer periods of time (Marshall et al., 2015). Harvey et al. (2015), found that men accumulated an additional 30 minutes of device measured and 9 minutes of self-reported ST. Marshall et al. (2015) also reported that men engaged in an additional 42 minutes of device measured ST.

Differences in the time spent in physical activities also differs between genders. Men generally spend more time engaging in MVPA than women; however, women spend more time engaging in LPA (Arnardottir et al., 2012; Colley et al., 2011; Evenson, Buchner, & Morland, 2012). In contrast to the majority of research above, Chen et al. (2015) found that women spent more time in both LPA and MVPA than men. Eastern versus western cultural differences may partially explain the contrasting results found by Chen et al. (2015). To summarize, all but one article that was reviewed reported that women spent more time than men engaging in LPA while men engaged in more MVPA and ST. This pattern may present this way in older adults as women have traditionally had the burden of caring for the household (i.e. vacuuming, cleaning dishes, cooking) (Amagasa et al., 2017; Seguin et al., 2012) while men accumulated more occupational physical activity. This may be important as gender specific movement behaviour prescription may be beneficial in developing a 24-hour model for older adults.

Section Summary. Older adults accumulate the least amount of daily MVPA and conversely, the highest daily ST compared to any other age group. LPA may be important for the health of older adults. On average, women accumulate more LPA than men, while men engage in more MVPA and total ST. With the paucity of movement behaviour research in older adults, there is a need to collect data in the context of a 24-hour day, on all four movement behaviours to better understand the patterns of daily movement behaviour. There is also a need to expand our understanding of how the time accumulated in any one behaviour will affect the time accumulated in another; this remains a gap in the literature.

2.5 Movement Behaviour Compensation

The majority of movement behaviour research until now has investigated the accumulation of individual movement behaviours (Davis & Fox, 2007; Davis et al., 2014; Hallal et al., 2012; Harvey, Chastin, & Skelton, 2013; Matthews et al., 2008). As this area of research has developed, there has been increased recognition of the importance of collecting data on all four movement behaviours simultaneously, rather than individually (Chaput et al., 2014; Rosenberger et al., 2016; Tremblay et al., 2016). The simultaneous collection of movement behaviour data in the context of a 24-hour day may provide a clearer picture of whether or not changes to one movement behaviour may be compensated for by changes in another. A key consideration when collecting this data is treating each 24-hour day as a finite amount of time in which all four movement behaviours are collinear (Pedišić, 2014), that is, when time spent engaging in any one behaviour changes, time spent engaging in the others must be adjusted. For example, an increase to the time spent engaging in MVPA may be compensated for by either an increase in ST, a decrease in LPA, or a decrease in sleep. Owen et al. (2011) identifies that these movement behaviours can be accumulated across a variety of different domains. For instance, the accumulation of ST may occur in four distinct domains: transport (e.g., driving to work), occupation (e.g., desk job versus manual laborer), household tasks (e.g., gardening, mowing the lawn) and leisure time (e.g., TV viewing, theatres, gym) (Owen et al., 2011). Moreover, compensation may not occur immediately after said behaviour but happen over the course of the next day, week or even month. For example, a person may engage in high intensity exercise and compensate by sleeping longer the following day or engage in higher volumes of ST throughout the week when compared to their regular pattern of behaviour. Little research has investigated movement behaviours simultaneously, particularly in older adults or following different intensities of exercise. We know very little about the impact that different intensities of exercise may have on the movement behaviours in older adults. Exploring this relationship may better equip health care professionals in recommending or prescribing exercise.

2.51 Activity Stat

The “Activity Stat” was proposed by Rowland (1998), as a compensatory, biological response to energy deficits, theorizing that the human body is in a constant need of an energy equilibrium (e.g., homeostasis). This theory suggests that the human body uses energy as finite currency, which can be consumed in a single day, week or even month and any additional energy expenditures (e.g., high intensity exercise) must be compensated for by changes to the accumulation of one’s movement behaviours. Physical activity requires a greater energy demand than sedentary activities (Ainsworth et al., 2011) and this energy demand produces a systematic imbalance which can only be compensated for through the conservation of energy (e.g., movement compensation). For instance, if an adult were to run a marathon, their activity preference following the race may be an increase in ST or increase in sleep (e.g., watching television, reading a book, or playing video games). Similarly, a person may attend an exercise class in the morning and choose to take the elevator instead of the stairs or skip their evening walk and watch television. Based on the “Activity Stat,” people compensate for an increased energy expenditure by conserving energy after the said activity. This post-activity compensation may not always present as an increase to ST, rather it can yield different patterns in different populations, affecting any number of the four movement behaviours (MVPA, LPA, ST, sleep).

According to Rowland (1998) the magnitude of movement behaviour compensation would be largest after high energy expenditure activities, that is, higher intensities of exercise would lead to greater compensation than low or moderate intensity exercise of equal duration. To observe this possible compensation, Paravidino, Mediano, and Sichieri (2017), monitored ST in overweight boys after acute bouts of moderate and vigorous exercise (n=24) separated by ≥21 days, using accelerometers. Both exercises were matched for duration (55-minutes) and consisted of four 10-minute intervals with 5-minute rest periods in-between. The rest periods were identical for both exercise conditions (<64% of maximum heart-rate), whereas the 10-minute intervals of exercise were either walking at a moderate intensity (64% to 76% of maximum heart-rate) or running at a vigorous intensity (77% to 95% of maximum heart-rate) depending on the exercise condition (moderate or vigorous). Daily ST was monitored for the following 6 days after the moderate and vigorous exercise sessions. The vigorous condition had the most immediate effect on total daily ST with higher compensation (i.e., increase in ST) during the first four days following exercise however, the moderate and vigorous conditions were not statistically different from one another. Both the moderate and vigorous conditions were statistically different from the control, with fluctuating increases in total daily ST ranging from 21 to 86 minutes (Paravidino et al., 2017). Moreover, following exercise, participants also accumulated between 7 and 50 fewer minutes of MVPA each day with the largest comparative increases (compared to control) on days two through five (Paravidino et al., 2017). Some research has argued that the increase to ST after high intensity exercise may not be inevitable, rather it may be influenced and offset by a behavioural intervention (Kozey-Keadle et al., 2014). Kozey-Keadle et al. (2014) recruited middle-aged, obese adults who were then divided into four distinct groups: control, exercise, behavioural intervention and exercise combined with a behavioural intervention. The exercise regimen involved 5 sessions a week of moderate intensity exercise over twelve weeks; the duration and/or intensity of exercise increased at week two, three and seven. Two groups (behavioural intervention and exercise, combined with a behavioural intervention) participated in a behavioural intervention which consisted of weekly meetings that targeted reducing ST and increasing non-exercise physical activity. Baseline ST was assessed by wearable monitor for seven days prior to the intervention and then repeated every third week of the intervention. Approximately 50% of the participants in the control and exercise group increased total ST, whereas both behavioural intervention groups significantly decreased their ST and increased non-exercise physical activity when compared to the control (Kozey-Keadle et al., 2014). This sample of middle aged adults had very high daily ST at baseline (≥10 hours), which may help explain the effectiveness of the behavioural intervention when compared to the control and exercise groups.

Movement behaviour compensation can also be assessed through total daily energy expenditure, that is, changes to daily energy expenditure may be indicative of changes to movement behaviour patterns. Di Blasio et al. (2012), used this method of measuring movement behaviour compensation in menopausal women (mean +/- SD age, 55.89 +/- 1.83). Instead of observing changes to movement behaviours following exercise, Di Blasio et al. (2012), concentrated on assessing total daily energy expenditure during an exercise regimen. Participants were asked to perform a moderate intensity walking protocol four times per week, for 13 consecutive weeks while wearing an accelerometer intermittently each week (three days). Daily energy expenditure was calculated each week by taking an average of the three days the accelerometers were worn. It has been reported that performing moderate intensity exercise increases energy expenditure, and permitting there are no changes to LPA, ST or sleep, total daily energy expenditure would be expected to increase (Ainsworth et al., 2011; Di Blasio et al., 2012). Despite an increase in total exercise time, daily energy expenditure did not change while performing the moderate intensity walking regimen (Di Blasio et al., 2012). Although moderate intensity walking increased energy expenditure in the moment, the absence of change to total daily energy expenditure suggests that the increased energy requirement was compensated for elsewhere during the day. Although movement behaviours were not assessed, we may expect this compensation to arise from an increase in ST, sleep or a decrease to LPA. Total daily energy expenditure may have a ceiling, which once reached is compensated for with changes to movement behaviour patterns (Melanson, 2017). Collecting data on all four movement behaviours may have aided in contextually understanding where compensations occurring during the exercise regimen. Colley, Hills, King, and Byrne (2010), expand on these methods, collecting data on all four movement behaviours alongside total daily energy expenditure through accelerometry, in their eight-week moderate intensity walking intervention. Colley et al. (2010) reported little change to total daily energy expenditure but observed an increase to ST, decrease to LPA and a significant decrease in non-exercise energy expenditure during the intervention. Although similar results were reported by Di Blasio et al. (2012), the addition of separating daily energy expenditure into the four movement behaviours is crucial in recognizing which behaviours are involved in compensation (Colley et al., 2010). Failing to assess all four movement behaviours simultaneously may lead to erroneous conclusions.

Movement behaviour compensation has generally been framed as an increase to ST, however compensation may occur differently in different populations. For example, one domain in particular that accounts for a large portion of a working adult's day is the workplace. As a laborer, a work day may compose considerable workplace physical activity, whereas an office worker might accumulate greater ST. Nooijen et al. (2018) hypothesised that a transition from an active occupation to a sedentary one or vice versa would be compensated with either an increase or decrease to non-work-related physical activity or ST. To illustrate, if an employee took on a more sedentary occupation, there may be an increase to non-work-related physical activity or a decrease in ST outside of the workplace. Nooijen et al. (2018) reported that non-work-related exercise appeared to increase if there was a transition from a physically intensive occupation to a more sedentary one and the opposite when transitioning from a sedentary to a more active occupation. A future direction for this research may be to observe whether or not these changes are similar in older adults whom have recently retired, drastically changing their everyday day routines.

Movement behaviour compensation can occur over varying increments of time and in varying magnitudes. A paucity of research exists on the daily differences in movement behaviours after engaging in different intensities of physical activity (Ridgers, Timperio, Cerin, & Salmon, 2014). Observing daily differences in movement behaviours after exercise may be more representative of compensation rather than observing differences over longer periods of time (e.g., week or month). Ridgers et al. (2014) recruited a group of children to participate in a seven-day study where data were collected on total daily MVPA, LPA and ST via accelerometers. The researchers used this data to find the correlations between current day movement behaviour patterns to the following day(s) movement behaviour patterns. ST was positively correlated with an increase to MVPA and LPA while negative correlations were found between: MVPA and next-day LPA and MVPA, LPA and next-day LPA and MVPA, ST and next-day ST (Ridgers et al., 2014). See figure 2 for the visual representation of current and following day movement behaviour patterns

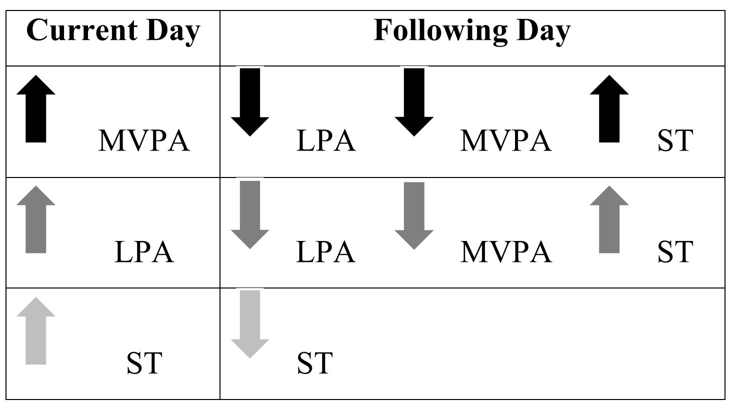

Figure 1: Current day increases to moderate-to-vigorous physical activity (MVPA), light physical activity (LPA) or sedentary time (ST) and its respective correlations to the following days' movement behaviours. Upward facing arrows depict an increase in time and downward arrows depict a decrease. Data from Ridgers et al. (2014).

Not all movement behaviour research supports the "Activity Stat" theory. For example, Marques, Ekelund, and Sardinha (2016), observed movement behaviour patterns after sport participation in children and found no compensatory effects to ST. Although sport participation increased daily MVPA, ST remained the same, independent of any gender differences (Marques et al., 2016). Interestingly, although sport participation was correlated with an increase in MVPA, children who participated in sports appeared to engage in fewer minutes of LPA and accumulated similar ST. Collecting data on sleep may have improved this study as sport participation, that is, an increase in MVPA, may have replaced sleep duration. Similar reports are found by Baggett et al. (2010), reporting an increase to MVPA and LPA after MVPA in adolescent girls. Although increases in ST were associated with increases in MVPA the following day, they do report that ST does replace same day MVPA (Baggett et al., 2010). Likewise in younger and middle aged adults, Nugent et al. (2018), measured ST after supervised exercise (MOD and HI) and reported that the time spent performing supervised exercise replaced ST. It is important to note that the “Activity Stat” theory does not account for energy intake. For example, as energy expenditure increases, increasing energy intake may work as a compensatory tool for protecting against an energy imbalance; this may then potentially affect movement behaviour compensation. Nevertheless, these studies identify a crucial problem in the interpretation of current and past compensation research, that is, a lack of simultaneous movement behaviour data collection. The inherent co-linearity of the four movement behaviours (MVPA, LPA, ST and sleep) suggests that a change to any one of the behaviours must be compensated for by a change in the time spent engaging in another and these changes are not exclusive to ST or MVPA. Furthermore, these studies have focused on either children or younger to middle aged adults, who may comparatively respond and compensate differently to high intensity exercise than older adults.

In the literature reviewed, very little has been discussed regarding age and gender differences, highlighting another gap in research. Gender differences in compensatory behaviour research related to physical activity has either gone unreported or failed to report significant differences (Nooijen et al., 2018). Additionally, age differences have not yet been explored, with a majority of current and past research recruiting children or younger and middle-aged adults (Colley et al., 2010; Di Blasio et al., 2012; Nugent et al., 2018, Paravidino et al., 2017; Ridgers et al., 2014). Nevertheless, differences may exist as older adults have been reported to have lower energy capacities (Davis & Fox, 2007; Lee, Sesso, Oguma, & Paffenbarger, 2003), which may lead to a comparatively greater movement behaviour compensation after exercise participation.

2.52 Methods of Measurement

An important consideration when reviewing movement behaviour research is the difference between self-report and device based measures. Self-report provides a better context to which specific movement behaviours are performed however, it considerably overestimates MVPA and underestimates ST (Grimm et al., 2012). Device based measures are more expensive and lack the contextual information obtained from self-report, but can differentiate between activity intensity and offer greater overall accuracy, particularly with the development of postural detection through inclinometers (Grant, Ryan, Tigbe, & Granat, 2006; Steeves et al., 2015). The ActivPAL™ monitor is currently considered the gold standard for measuring sedentary time (Chastin & Granat, 2010; Kozey-Keadle, Libertine, Lyden, Staudenmayer, & Freedson, 2011), and has also demonstrated good reliability in measuring free-living MVPA in adults (Barreira et al., 2016; Edwardson et al., 2017). Using a combination of self-report and device based measures may yield the most accurate results. A daily activity diary may compliment the more accurate device based measures.

Section Summary. There has been a lack of data on movement behaviours in older adults. However, as this field of study expands, it is abundantly clear that 24-hour data collection including all four movement behaviours is a necessary step for future research. Compensation may occur after any movement behaviour and is not exclusive to ST or MVPA, rather, compensation can occur in any of the four movement behaviours. Based on what has been observed in younger populations and because of their lower energy and functional capacities, we may expect a comparatively larger magnitude of compensation in older adults, especially following HI. Within the dearth of compensation research, no evidence is available on gender differences. Future compensation research should target gender differences as well as assess movement behaviour compensation in older adults, particularly following high intensity exercise.

2.6 Potential Moderators to Compensation

In the previous section, the "Activity Stat" was discussed, proposing that movement behaviour compensation occurs in response to an imbalance to an individual's energy system (i.e., homeostasis). This pathway, from a homeostatic imbalance to movement behaviour compensation may be a complicated, multifactorial one, affected by any number of potential moderators (Gill, Desai, Gahbauer, Holford, & Williams, 2001). In the following section, we will discuss how exercise enjoyment and fatigue may influence compensation in movement behaviour.

Current Day	Following Day	
↑ Enjoyment	↑ MVPA	
↑ Fatigue	↓ MVPA	↑ ST
↓ Sleep	↑ Fatigue	↑ ST

Figure 2: Examples of current day increases to enjoyment, fatigue or sleep and its proposed correlations to the following days' movement behaviours. Upward facing arrows depict an increase and downward arrows depict a decrease. Data from Baldwin, Datta, Bassett, Overstreet, and Schweighart (2016); Gill et al. (2001); McClain, Lewin, Laposky, Kahle, and Berrigan (2014).

2.61 Exercise Enjoyment

Enjoyment has been identified as a factor that may deter or motivate participation in both sedentary and physical activities (Hardy & Grogan, 2009; Tam-Seto, Weir, & Dogra, 2016). In particular, exercise enjoyment may function as a predictor of future physical activity, influencing an individual's future movement behaviours (Baldwin et al., 2016). That is, high perceptions of exercise enjoyment correlate with increases in physical activity and conversely, low perceptions of enjoyment may deter adults from engaging in physical activities (Hardy & Grogan, 2009). As seen in a study conducted by Dishman (1994), only half of older adults that begin an exercise program continue exercising past 3 months. In their twelve-month intervention, they discuss the importance of exercise enjoyment, reporting that baseline enjoyment in adults (n=238) was found to be a predictor of an increase to MVPA (Dishman, 1994). Participants that enjoyed a specific type of physical activity were more likely to not only increase exercise specific physical activity but total physical activity as well. Nevertheless, little is known of the effect of different intensities of exercise and their impact on enjoyment. This is important to understand among older adults as they engage in the least amount of daily MVPA

(Colley et al., 2011; Jefferis et al., 2014) and understanding which intensities are most enjoyable may aid in more informative exercise prescriptions and ultimately increase exercise adherence.

Furthermore, it is possible that enjoyment differs between exercise of different intensities, and that this enjoyment impacts movement behaviours in subsequent days.

2.62 Exercise Enjoyment Across Different Exercise Intensities

The enjoyment people experience with exercise may not be solely dependent on the mode or volume of exercise but rather the intensity (Dacey, Baltzell, & Zaichkowsky, 2008; Datta, 2016; Salmon, Owen, Crawford, Bauman, & Sallis, 2003; Vallerand & Young, 2014; Williams et al., 2006). Kilpatrick, Greeley, and Collins (2015) collected perceived enjoyment levels in 24 young adults (age: 22 ± 3) during and after different intensities of exercise. This study involved participants performing four distinct 20-minute exercise protocols, varying in intensity (moderate or vigorous) and continuity (continuous or intervals). Participants found the moderate-continuous and high-intensity interval protocols the most enjoyable, while the high-intensity continuous protocol was found to be least enjoyable (Kilpatrick et al., 2015). Similar results were found by Heisz, Tejada, Paolucci, and Muir (2016) in their sample of young adults, during a 6-week exercise intervention. Participants were randomized into two exercise groups (high intensity interval and moderate intensity continuous exercise) and exercised three times per week while rating their enjoyment levels at the end of each week. Both groups showed statistically similar enjoyment scores until week four, after which the perceived enjoyment values following high intensity intervals continued to increase while the moderate intensity continuous group began to decrease (Heisz et al., 2016). Both Heisz et al. (2016) and Bartlett et al. (2011) additionally collected perceived exertion during their moderate and high intensity exercise protocols and found that although the ratings of perceived exertion were significantly higher, participants still reported higher enjoyment levels during and after higher intensity exercise. Bartlett et al. (2011) matched both exercise protocols (moderate and high intensity) for duration and average intensity to eliminate any effect that total work may have had on enjoyment. Very little research has investigated exercise enjoyment following acute exercise. This is particularly concerning as older adults exhibit poor levels of exercise adherence, declining further with age (Picorelli, Pereira, Pereira, Felício, & Sherrington, 2014). Prescribing exercises that are enjoyable may increase total habitual physical activity and reduce compensation in older adults.

2.63 Perceived Fatigue

An adult's perceived fatigue or energy levels (e.g., sleepiness) may have moderating effects on future movement behaviours and ultimately affect next day functioning (Alapin et al., 2000). Whether perceived fatigue is a consequence of a physical (e.g., high intensity exercise) or a mental (e.g., chess, reading, etc.) demand, both result in a similar perception of fatigue/tiredness (Chervin, 2000); this perception of tiredness or fatigue may act as a mechanism to movement behaviour compensation. In a longitudinal study by Gill et al. (2001), community dwelling older adults were asked to participate in phone interviews which consisted of questions regarding activity restriction. In a 15-month median follow-up interview, when asked about activity restriction, over 75% of participants reported at least one episode of activity restriction. Gill et al. (2001) compiled the responses and reported that one of the most common reasons for inactivity was self-reported fatigue. Breaking down this reported activity restriction into its behavioural components (e.g., ST and Sleep) following high intensity exercise may help researchers understand how different levels of perceived fatigue may moderate movement behaviour compensation.

Perceived fatigue may not only affect whether a person chooses to engage in physical activity but may additionally affect their performance during said physical activity. Marcora, Staiano, and Manning (2009) used cognitively demanding tasks to induce mental fatigue in fit, younger adults and then measured cycling performance between non-fatigued and fatigue induced groups. In the 90-minutes prior to cycling, the control group was seated and asked to watch a video, while the experimental group performed various executive functioning tasks. All participants then performed an incremental, maximal cycling protocol which was performed to exhaustion. The mentally fatigued group experienced a significantly lower time to exhaustion as well as significantly higher ratings of perceived exertion when compared to the non-fatigued group (Marcora et al., 2009). This sample of younger adults had good-to-excellent cardiorespiratory fitness and it may be anticipated that older, less fit adults may perform comparatively worse to exercise in a fatigue induced state, possibly avoiding physical activity all together. Moreover, perceived fatigue, whether products of mental or physical tasks, may function as a moderator to subsequent movement behaviours (e.g., increase ST, decrease MVPA). For example, older adults may refrain from their daily, evening walk if they are feeling fatigued. The moderating effects of perceived fatigue on movement behaviours are still not clear, particularly in the older adult population and this highlights another gap in the literature. Understanding the effect that different intensities of exercise may have on fatigue and how these perceptions of fatigue influence future movement behaviours may help inform effective movement behaviour guidelines for older adults.

2.64 Sleep

As discussed in the previous section, sleep, LPA, MVPA and ST are collinear, (Pedišić, 2014), and as such, sleep is directly proportionate to the number of waking hours in an older adult's day. That is, decreasing or increasing sleep time will respectively increase or decrease the total amount of daily waking hours. In addition to having a direct impact on waking hours, a decrease in sleep may cause increased perceptions of fatigue and sleepiness the following day (Xiao, Keadle, Hollenbeck, & Matthews, 2014). Figure 3 below represents following day changes to waking hours, fatigue and sleepiness after current day increase or decreases to sleep.

Current Day	**Following Day**		
↓ Sleep	↑ Waking Hours	↑ Fatigue	↑ Sleepiness
↑ Sleep	↓ Waking hours		

Figure 3: Illustration of current day sleep duration and following day waking hours, perception of fatigue and sleepiness. Upward facing arrows depict an increase and downward arrows depict a decrease. Data from Xiao et al. (2014).

This combination of fatigue, sleepiness, shortened sleep durations and their effects on movement behaviours in older adults has been relatively unexplored. Alapin et al. (2000) identified in their sample of older adults (n=194) that over 50% reported problems falling asleep or maintaining sleep. Based on their sleep quality, older adults were placed in either a good or poor sleep category, and daytime fatigue, sleepiness and concentration levels were compared. The poor sleep group slept shorter durations, had increased self-reported fatigue, sleepiness and difficulty concentrating (Alapin et al., 2000).

A dearth of research exists on the associations between sleep, physical activity and sedentary behaviours, particularly in older adults. McClain et al. (2014) investigated the relationship between sleep, MVPA and LPA using the National Health and Nutrition Examination Survey (NHANES) in adults ≥20 years of age. They found that sleep duration was positively associated with MVPA, that is, as sleep duration increased, total time engaging in MVPA increased. Moreover, in older adult men (≥60), sleep was reported to have a negative relationship with ST, that is, as sleep duration decreased, ST increased (McClain et al., 2014). This relationship may be partly explained by an increase in total waking hours and thus an increase in potential hours for ST; however, the effect fatigue may have had on the increase in ST was not investigated. Xiao et al. (2014) investigated the association between different durations of sleep, MVPA and television viewing in a sample of older adults (n=239,896). Participants were classified in different categories of average daily sleep duration (<5, 5-6, 7-8, ≥9 hours) and then compared against average television viewing time and MVPA. The results showed that participants that slept more or less than 7-8 hours a night, spent less daily time engaging in MVPA and more time viewing television (Xiao et al., 2014). Contrary to the results in McClain et al. (2014), older adults spent less time engaging in MVPA if they slept longer than 7-8 hours, suggesting that there may be a different or a combination of mechanisms influencing MVPA engagement and television viewing other than sleep or waking hours.

In addition to the reported correlations with MVPA and television viewing time, poor sleep has been shown to compromise physical performance. Scott, McNaughton, and Polman (2006) tested reaction time after sleep deprivation in younger adults. Participants were separated into two groups, one which exercised (20 min at 50% VO_2) intermittently, every two-hours and another that engaged in sedentary activities over 30-hours of sleep deprivation; both groups were tested on reaction time every four hours. In both groups, sleep deprivation decreased reaction time and enjoyment, and increased fatigue. However, the magnitude of these changes were greater in the group that exercised intermittently (Scott et al., 2006). Although sleep deprivation in older adults has not yet been investigated, many older adults are poor sleepers (Alapin et al., 2000) and this poor sleep may effect fatigue and enjoyment. It is therefore imperative that changes to sleep duration be considered when assessing compensation to assist in understanding how each movement behaviour affects one another.

Section Summary. Enjoyment is a particularily important factor for exercise adherence and future physical activity engagment. Little research has investigated enjoyment following different intensities of acute exercise in older adults. Understanding which intensities are considered most enjoyable may improve exercise prescription and potentially reduce compensation. In addition, it is essential that sleep duration be considered when assessing compensation. Poor sleep has a direct impact on waking hours and may also have an effect on enjoyment and fatigue in older adults. Sleep duration, perceptions of fatigue and enjoyment may all work as mechanisms in movement behaviour compensation. Nevertheless more research needs to investigate these relationships, especially in older adults as they reportedly engage in little daily MVPA and have poor exercise adherence.

2.7 Rationale

The highest prevalence of ST and inactivity is found in the older adult population (Evenson et al., 2012; Wullems, Verschueren, Degens, Morse, & Onambélé, 2016). Investigating daily ST in older adults may be a particularly important direction for future movement behaviour research as ST has been identified as an independent, modifiable health risk, irrespective of physical activity levels (Blair & Brodney, 1999; Blair et al., 2001; Dunstan et al., 2010; Katzmarzyk et al., 2009). Older adult women have been identified to engage in greater daily LPA than men, while men accumulate more daily ST and MVPA (Arnardottir et al., 2012; Evenson et al., 2012; Harvey et al., 2015). Investigating the relationship between ST and MVPA following acute exercise in older adults remains a gap in the literature.

Compensation in older adults may occur after engaging in exercise, however, it is unclear which movement behaviours are most affected (Di Blasio et al., 2012; Ridgers et al., 2014). Although ST and MVPA may be independently important, investigating all four movement behaviours (LPA, MVPA, ST and sleep) simultaneously, across a 24-hour day, may provide researchers the best opportunity to assess compensation. When investigating compensation throughout a 24-hour day, the co-linearity between the four movement behaviours suggests that any single change in duration to one behaviour will directly affect the others (Pedišić, 2014; Tremblay et al., 2016). For example, an increase in sleep duration would directly decrease the amount of time left in the day to engage in LPA, MVPA and ST. Furthermore, identifying the mechanisms of compensation may provide a greater understanding of how current physical activity recommendations may affect the accumulation of ST, LPA and sleep. In particular, understanding how ST and

LPA are accumulated following exercise may be important as ST has been associated with negative health outcomes, while LPA with health benefits (Evenson et al., 2012; Füzéki, Engeroff, & Banzer, 2017).

Exercise enjoyment has been identified as a predictor of future physical activity and exercise adherence (Baldwin et al., 2016; Dishman, 1994; O'Neill & Dogra, 2017; Vallerand & Young, 2014). Recent research in younger adults has suggested that HI may be more enjoyable than MOD; however, this has not been examined in older adults (Heisz et al., 2016; O'Neill & Dogra, 2017). Additionally, little research has investigated the relationship between exercise enjoyment, LPA and ST following acute HI.

Sleep and fatigue have been identified as potential moderators to changes in MVPA and ST (Gill et al., 2001; Xiao et al., 2014). Increase or decreases to sleep duration may affect fatigue and both sleep and fatigue have been reported to have independent associations with ST and MVPA (McClain et al., 2014; Scott et al., 2006). The impact sleep and fatigue have on future LPA, MVPA, ST and sleep has not yet been investigated in older adults.

Changes to movement behaviours in older adults following acute bouts of high and moderate intensity exercise is a gap in current literature. The accumulation of ST, LPA, MVPA and sleep after participation in different intensities of exercise may inform future activity recommendations. Moreover, exercise enjoyment, sleep duration and fatigue may moderate movement behaviour compensation following acute exercise.

2.8 Purposes and Hypotheses

Purpose 1:

To assess and compare sedentary behaviour (bouts and total ST), MVPA, LPA and sleep in the three days following participation in an acute bout of MOD, HI and SPRT in older adults.

Hypothesis 1:

We hypothesize that ST will increase in older adults following an acute bout of HI, SPRT and MOD. Moreover, we expect to see a disparity in the magnitude of compensation with the greatest level of compensation following HI and SPRT. Additionally, we expect to observe the greatest increases in ST the following day.

Purpose 2:

To investigate the relationship between self-reported exercise enjoyment and fatigue following acute MOD, HI and SPRT with the following day(s) total daily ST in older adults.

Hypothesis 2:

We hypothesize that ST and exercise enjoyment will have a one-way relationship. If exercise enjoyment is low following MOD, SPRT or HI, we expect to see an increase next-day ST; if enjoyment is high, we expect to see little change to ST. Fatigue is expected to have a positive correlation with ST, that is, if fatigue is high, ST will increase whereas if fatigue is low, ST will decrease.

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Chapter 3. Manuscript

Engaging in exercise leads to a decrease in MVPA and an increase in sedentary behaviour among older adults.

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3.1 Abstract

The objective of this study was to assess changes in 24-hour movement behaviours (sedentary time, light intensity physical activity (LPA), moderate-vigorous PA (MVPA), and sleep) following an acute bout of exercise in older adults. Participants (n=28, 69.7±6.5 years) completed a maximal exercise test and the following exercise protocols in random order, at least one week apart: moderate continuous exercise (MOD), high intensity interval exercise (HI), and sprint interval exercise (SPRT). A thigh-worn device (ActivPAL^{TM}) was used to measure movement behaviours at baseline and the three days following exercise. Repeated measures analysis of variance indicated that participants decreased MVPA following all exercise sessions, decreased LPA following HI and SPRT, and accumulated more prolonged sedentary bouts following all exercise sessions ($p<0.05$). It appears that older adults compensate for acute exercise by decreasing MVPA and increasing sedentary behaviours. These findings have implications for exercise prescription and counseling in older adults.

3.2 Introduction

Older adults will soon make up 30% of the western population (World Health Organization, 2015). Aging is associated with an increased risk of several chronic diseases (Barone Gibbs et al., 2017; Rosenberger, Buman, Haskell, McConnell, & Carstensen, 2016), all-cause mortality (Owen, Healy, Matthews, & Dunstan, 2010), and decreased quality of life (Bowling et al., 2013; Copeland et al., 2017; Flacker, 2003). Each of these decrements can be attenuated by engaging in regular physical activity (Warburton, Nicol, & Bredin, 2006), and by reducing sedentary time (ST) (Copeland, 2019). Unfortunately, older adults are accumulating approximately 9.4 hours of ST per day (Harvey, Chastin, & Skelton, 2013), and only 3% of older adults are engaging in the recommended levels of weekly moderate to vigorous intensity physical activity (MVPA) (Colley et al., 2011; Jefferis et al., 2018). A meta-analysis by Ekelund et al. (2016), found that accumulating 60-75 minutes per day of MVPA may eliminate the deleterious effects of prolonged ST in adults. Achieving such a goal may not be feasible for most older adults. Furthermore, it is not clear if increasing MVPA to such levels would lead to compensation in other areas, that is, an increase in ST or a decrease in light intensity physical activity.

A small body of literature has explored such compensation in movement behaviours, that is, MVPA, light intensity physical activity, ST, and sleep (Colley, Hills, King, & Byrne, 2010; Di Blasio et al., 2012; Paravidino, Mediano, & Sichieri, 2017). The "Activity Stat" theorem introduced by Rowland (1998), proposes that increases in daily energy expenditure (i.e. exercising) may be compensated for by displacing future physical activity with sedentary time to preserve an energy balance. Total daily energy expenditure may have a ceiling, which once reached, may be compensated for through increased engagement in lower energy expenditure activities such as television viewing, that is to preserve energy homeostasis (Melanson, 2017). In a study by Di Blasio et al. (2012), post-menopausal older women were asked to perform a 13-week moderate intensity walking protocol which consisted of walking four times a week while wearing an accelerometer. Although the overall volume of physical activity increased during the intervention, total daily energy expenditure remained the same. In other words, while participants in the study increased their MVPA, their total daily energy expenditure remained the same, meaning they compensated for the walking by either reducing light intensity physical activity or by increasing ST. Compensation such as this can take place at any point over the 24-hour period, and can be achieved through compensation in one or more movement behaviours. While some studies suggest that compensation may not occur in children, adolescents, or middle-aged adults (Baggett et al., 2010; Marques, Ekelund, & Sardinha, 2016; Nugent et al., 2018), there is no research on compensation in older adults. Furthermore, limited research exists on the impact of engaging in different intensities of exercise on compensation.

Traditionally, moderate intensity continuous exercise has been prescribed for increasing cardiorespiratory fitness (Engels, Drouin, Zhu, & Kazmierski, 1998; Garber et al., 2011); however, high intensity interval training has increased in popularity due to the associated shortened time commitment and health and fitness benefits (Buman et al., 2010; Gibala, 2018; Gillen et al., 2016; Gist, Fedewa, Dishman, & Cureton, 2014; Tucker, Angadi, & Gaesser, 2016). However, there is some controversy over prescribing such intensities of exercise. In a debate paper it was noted that the prescription of high intensity exercise in highly sedentary populations may not be effective or feasible (Biddle & Batterham, 2015). This may be a particularly important consideration when working with older adults, as they may be more prone to compensate for engaging in high intensity exercise due to age related musculoskeletal changes and lower cardiorespiratory fitness (Ades & Toth, 2005; McGregor et al., 2013).

Based on literature available, it is unclear if older adults would compensate for exercise, or whether compensation would be greater following higher intensity exercise. Research from a sample of children indicates that ST increases and MVPA decreases following exercise, regardless of whether the exercise is of moderate or high intensity (Paravidino et al., 2017). Among middle-aged adults (51±10 years) who performed either high intensity interval (1min intervals at 90% peak heart rate with 1 min rest intervals) or moderate continuous exercise (20 min at 65% peak heart rate) over a two-week period, participants spent a lower percentage of their waking hours engaging in sedentary behaviours (Nugent et al., 2018). This positive finding may be because movement behaviour data was only collected on days seven through nine, which also coincided with prescribed exercise and behavioural counselling. It is not clear if the same trend would be noted if the exercise were acute in nature.

To date, few studies have looked at compensation in movement behaviours following acute exercise of any intensity, and to our knowledge, no studies have explored such compensation in older adults. If compensation does occur in older adults, we may need to consider different approaches to 24-hour movement behaviour counseling, as an increase in ST in an already sedentary population may negate the effects of exercise performed. Thus, the purpose of this study was to assess 24-hour movement behaviours following acute bouts of high intensity interval exercise and moderate intensity continuous exercise. We hypothesize that older adults will increases their ST and decreases their MVPA following acute exercise, particularly following higher intensities of exercise.

3.3 Methods

3.31 Study Design and Participants

This was a randomized crossover study. Participants were adults over the age of 60 years without any pre-existing medical conditions that would impede participation in high intensity cycling.

3.32 Experimental Protocol

Participants attended five laboratory sessions over 7 weeks (Figure 1). During the first laboratory session, participants were familiarized with each of the exercise protocols. During the second laboratory session, participants performed an incremental, maximal intensity exercise test on a cycle ergometer (Lode Excalibur, Netherlands) to obtain peak power output (PPO). Participants then performed one of three exercise protocols each week, in random order. At the beginning of the study, all exercise protocols were numbered (MOD =1, HI = 2, SPRT = 3) and the sequence that exercises were to be performed in were randomized using the RANDBETWEEN function in Microsoft Excel Version 16 (Microsoft Corporation, Redmond, WA, USA). All exercise sessions began with a 2-minute warm-up and ended with a 5-minute cool-down at 10% of PPO at a comfortable cadence (≥60 rpm). Exercise sessions were: 1) **MOD:** 20-minutes of continuous cycling at 50% of PPO, 2) **HI:** 1-min of cycling at 90% PPO, followed by 1-min of cycling at 10% of PPO, repeated 10 times, and 3) **SPRT:** three 20-second, supramaximal sprints at a workload of 0.05kg resistance/kg of body weight separated by 2-min active recovery intervals at a resistance of 50watts. Participants were instructed to initiate each sprint at their maximal cadence.

3.33 Measures

Height, Weight, and Peak Power Output (PPO). Height and weight were measured using an medical scale (Detecto Weigh Beam Eye-Level, Webb City, Missouri) in the first laboratory session. Peak power output was assessed during the second laboratory session using a cycle ergometer (Lode Excalibur, Netherlands). All participants performed an incremental, maximal cycling protocol which began at an intensity of 25 watts. Thereafter, intensity increased by 20 watts every minute until volitional exhaustion.

Movement Behaviours. Data on movement behaviours were collected using a thigh-worn device (ActivPal^{TM}, PAL Technologies Glasgow, Scotland). This device has been used previously in older adults, and has shown good accuracy (Grant, Dall, Mitchell, & Granat, 2008). Participants were instructed to wear this device for a 7-day period; a new and fully charged device was provided to the participant the following week at the beginning of their session (Figure 1). The device was heat sealed for waterproofing to ensure 24-hour wear and then attached using Flexifit adhesive dressing (Auckland, New Zealand) to the midline of the right quadriceps. Participants were instructed to wear the device at all times, including sleep and water based activities. A valid day was defined as ≥10 hours of waking wear time. Data were collected at 20hz; ST, LPA, MVPA and sleep were classified using a combination of postural detection (inclinometry), estimated cadence, and MET values through ActivPAL^{TM}'s proprietary software. These raw data were uploaded and processed into daily summary and event files using ActivPAL™'s PAL batch program (PAL Technologies Glasgow, Scotland). Daily summary files were used to obtain prolonged daily sedentary bouts that were ≥30 minutes in duration. Events files were handled further, using a validated, automated algorithm to extrapolate the time spent engaging in ST, MVPA, LPA and sleep in minutes per day (Winkler et al., 2016). In processing the event files, all non-wear/sleep time was first calculated. The longest bout in a 24-hour day that was ≥2 hours or any bout ≥5 hours without detectable movement was classified as non-wear/sleep (Winkler et al., 2016). The remaining time (waking hours) was then processed to calculate daily time spent engaging in LPA, MVPA and ST. Of note, MVPA was not calculated in 10-minutes bouts as per the physical activity guidelines (Tremblay et al., 2011), rather it was the total MVPA, accumulated in any length of time. Participants with ≥3 valid weekdays were used for data analysis as ≥2.5 days of wear time is necessary for reliable ST assessment (Sasaki et al., 2018).

Clinically meaningful cut-points were identified from the literature. For MVPA, changes ≥10 min/day were considered meaningful based on previous research and current physical activity guidelines (Chase, 2014; Hupin et al., 2015; Spartano et al., 2019; Tremblay et al., 2011; US Department of Health and Human Services, 2018). For ST, changes to total ST that were ≥30min/day, and an increase in the number of prolonged daily sedentary bouts (≥30min bout) of ≥1 bout were considered clinically meaningful (Aadahl et al., 2014; Diaz et al., 2017; Fitzgerald et al., 2015; Martin et al., 2015; Rosenberg et al., 2015). At this time, the data on LPA is too limited to be able to determine a clinically meaningful threshold. For sleep, we were not able to identify changes that would be deemed clinically meaningful for healthy older adults.

All study protocols were approved by the University of Ontario Institute of Technology Research Ethics Board and all participants provided written consent.

3.34 Statistical Analysis

Means and standard deviations were used to describe the sample. Independent samples t-tests were used to compare characteristics between men and women. Data comparing changes in sedentary behaviour (sedentary bouts and ST), MVPA, LPA and sleep after participation in an acute bout of exercise were analyzed using a 4 (baseline, MOD, HI and SPRT) x 3 (1^{st}, 2^{nd} and 3^{rd} day following exercise) repeated measures ANOVA. All data were checked for normality using the Shapiro-Wilk test. Tests of within-subjects contrasts were used for pairwise comparisons. Baseline movement behaviour was compared to movement behaviour data following MOD, HI and SPRT. Partial eta-squared values were used from the repeated measures ANOVA for the estimated effect size; effect sizes were considered small, medium or large when values were 0.01, 0.06 and 0.14, respectively (Cohen, 1969). Statistical tests were performed using SPSS version 25 (IBM Corp, Armonk, NY, USA). Main effects and interactions effects from the ANOVA were considered significant if $p < 0.1$, and comparisons were considered significant if $p < 0.05$

3.4 Results

A total of 32 eligible older adults provided written consent and began the study. Of these, two withdrew from the study due to scheduling conflicts and two failed to meet the device wear criteria of ≥10 hours daily for ≥3 consecutive days. A total of 28 participants (women: n=14, age = 69.1 ± 6.8 years; men: n=14, age = 70.3 ± 6.3 years) were included for data analysis. Although participants were instructed to wear their ActivPAL™ until the next laboratory session (7 days), over 20% of participants removed the device prematurely; adhesive tape failure and discomfort were the primary causes for early removal. All participants used for data analysis had ≥3 valid weekdays of accelerometer data. Descriptive characteristics for all participants can be found in table 1. Although our combined sample was active at baseline with an average of 81.5 ± 29.1 min/day of MVPA, there was a high variability in fitness levels. The range for peak power output for men was between 133 and 316 watts, while the range in women was between 113 and 202 watts. Men were significantly taller, heavier and accumulated nearly two additional hours of daily ST than women at baseline.

Table 1

Sample Characteristics by Gender.

	Men (n= 14)	Women (n= 14)	Combined Sample (n=28)
Age (years)	70.3 ± 6.3	69.0 ± 6.8	69.7 ± 6.5
BMI (kg/m^2)	25.1 ± 2.7	24.1 ± 3.8	24.6 ± 3.3
PPO (watts)	223.6 ± 55.4	148.3 ± 30.8*	185.9 ± 58.4
Height (cm)	176.3 ± 7.8	162.3 ± 7.5*	170.0 ± 10.2
Weight (kg)	77.9 ± 9.9	63.6 ± 9.4*	70.7 ± 12.0
Baseline ST (min/day)	607.5 ± 93.2	493.9 ± 139.7*	550.7 ± 130.1
Baseline MVPA (min/day)	85.1 ± 30.5	77.9 ± 28.4	81.5 ± 29.1
Baseline LPA (min/day)	56.4 ± 21.4	53.7 ± 18.6	55.1 ± 19.7
Baseline Sleep (min/day)	434.2 ± 129.1	483.3 ± 92.4	458.7 ± 113.0
Breaks in ST (breaks/day)	62.7 ± 13.6	53.4 ± 12.8	58.0 ± 13.8
# of prolonged daily sedentary bouts (≥30 min bout)	7.5 ± 1.5	6.7 ± 1.7	7.1 ± 1.6

Note. **p*<0.05 between men and women.

In the combined sample of men and women, no differences were found for total daily ST (mins/day) when comparing baseline to MOD, HI, and SPRT *(F*(6,162) = 1.914, *p* = 0.082*)(*Figure 4*)*.

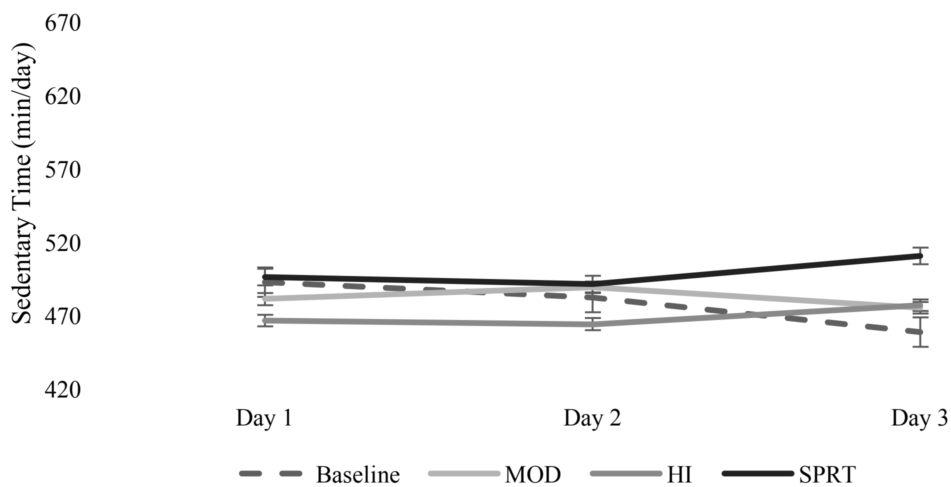

*Figure 4***.** Changes in sedentary time in the combined sample of men and women (means ±SD). *Note*. *p<0.05.

A main effect was found for prolonged daily sedentary bouts (*F*(2,54) = 2.847, $p = 0.067$, $\eta^2_P = 0.095$ (medium effect)) such that participants accumulated a greater number of prolonged sedentary bouts on day one compared to day three for all conditions (*F*(1,27) = 6.644, day 1: 7.6 ± 1.9 bouts, day 3: 6.9 ± 1.8 bouts, $p = 0.016$, η^2_P = 0.197(large effect), Figure 5).

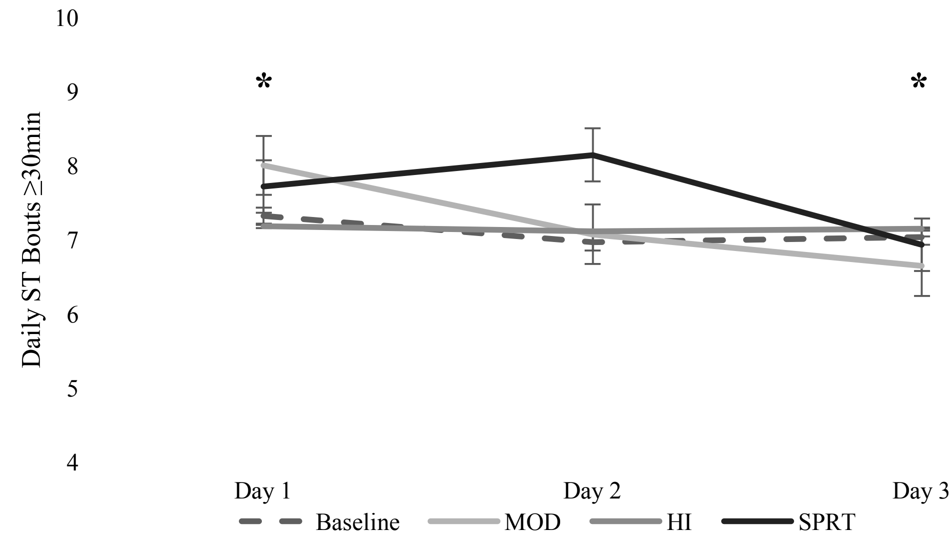

*Figure 5***.** Changes in prolonged sedentary bouts in the combined sample of men and women (means ±SD). *Note*. *p<0.05.

In the sample of men only, there was a main effect of days for ST ($F(2,26) = 3.506$, $p = 0.045$, $\eta^2_P = 0.212$ (large effect)), such that daily ST was greater on day one compared to day two ($F(1,13) = 8.802$, day 1: 628.9 ± 89.7 min, day 2: 581.3 ± 90.7 min; $p = 0.011$, $\eta^2_P = 0.404$ (large effect)) and day three ($F(1,13) = 5.294$, day 3: 597.3 ± 110.6 min, $p = 0.039$, $\eta^2_P = 0.289$ (large effect), Figure 6).

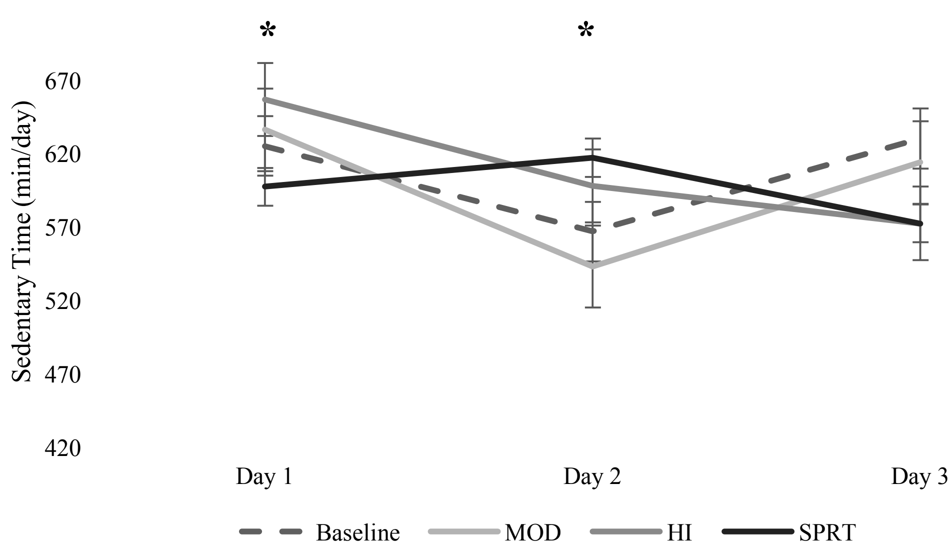

*Figure 6***.** Changes in sedentary time in the sample of men (means ±SD). *Note*. *p<0.05.

A main effect was also found for prolonged sedentary bouts in the sample of men ($F(2,26) = 3.677$, $p = 0.039$, $\eta^2_P = 0.220$ (large effect)) such that men accumulated a greater number of prolonged daily sedentary bouts on day one compared to day three across all conditions ($F(1,13) = 10.194$, day 1: 8.5 ± 1.5 bouts, day 3: 7.6 ± 1.7 bouts, $p = 0.007$, $\eta^2_P = 0.440$ (large effect), Figure 7).

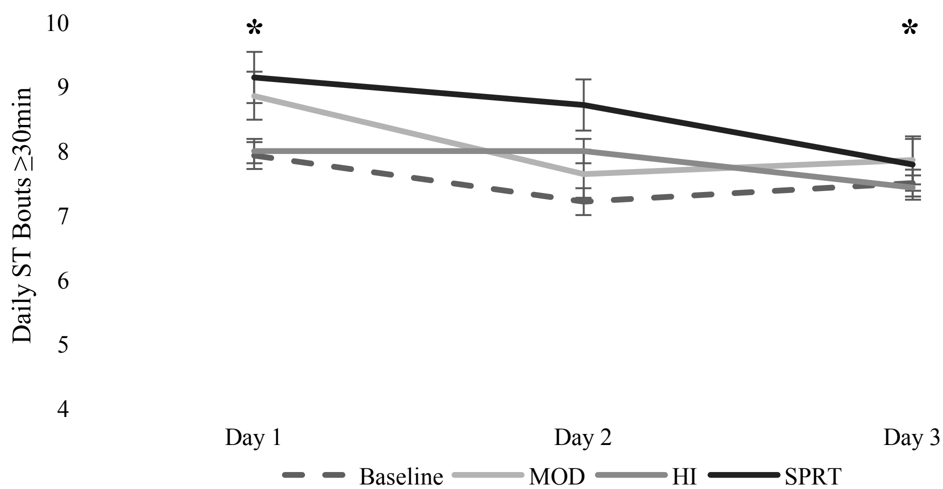

*Figure 7***.** Changes in prolonged sedentary bouts in the sample of men (means ±SD). *Note*. *p<0.05.

In the sample of women only, no significant differences were found for total daily ST ($F(6,78) = 0.650$, $p = 0.690$, $\eta^2_P = 0.048$ (small effect), Figure 8) or number of prolonged daily sedentary bouts ($F(6,78) = 1.905$, $p = 0.090$, $\eta^2_P = 0.128$ (medium effect), Figure 9).

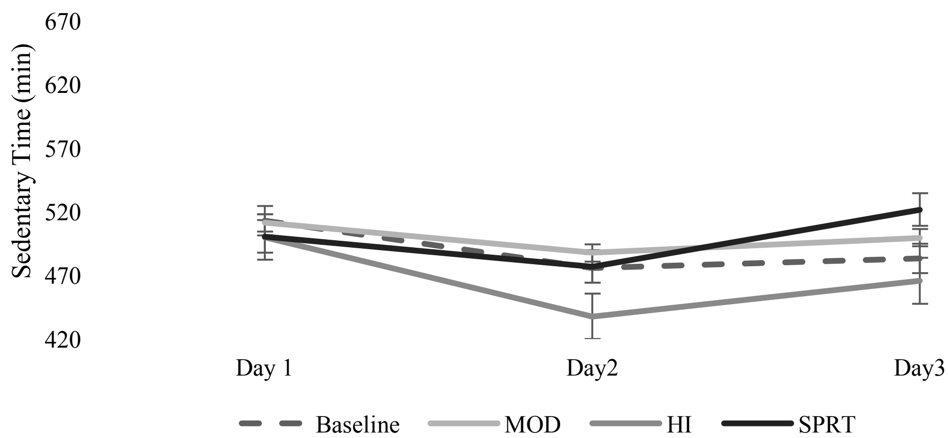

*Figure 8***.** Changes in sedentary time in the sample of women (means ±SD). *Note*. *p<0.05.

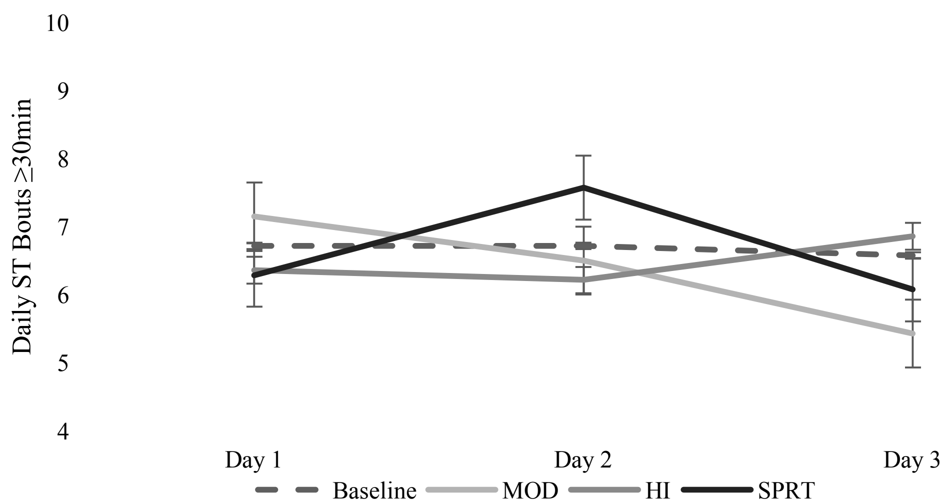

Figure 9. Changes in prolonged sedentary bouts in the sample of women (means ±SD). *Note*. *p<0.05.

Several participants had meaningful increases in daily ST when comparing baseline to MOD (n=9; m: n=4, f: n=5), HI (n=15; m: n=7, f: n=8), and SPRT (n=12; m: n=7, f: n-=7). Many participants also had meaningful increases in the number of prolonged daily sedentary bouts from baseline following MOD (n=6; m: n=5, f: n=1), HI (n=7; m: n=5, f: n=2) and SPRT (n=10; m: n=7, f: n=3; Table 2). Some participants also had meaningful decreases in prolonged sedentary bouts from baseline following MOD (n=5; m: n=1, f: n=4), HI (n=6, m: n=1, f: n=5) and SPRT (n=4; m: n=1, f: n=3).

Table 2

Number of Participants with Meaningful Differences Following MOD, HI and SPRT when Compared to Baseline in Men and Women.

	Men (n=14)			Women (n=14)			Combined Sample (n=28)		
	MOD	HI	SPRT	MOD	HI	SPRT	MOD	HI	SPRT
# of prolonged daily sedentary bouts increased by ≥1 bout	5	5	7	1	2	3	6	7	10
↑ in ST ≥30min/day	4	7	5	5	8	7	9	15	12
↓ MVPA ≥10min/day	6	6	5	7	7	7	13	13	12

Note. * Increases are denoted by the symbol ↑ and decreases by ↓.

In the combined sample of men and women, there was a main effect for MVPA for conditions ($F(3,81) = 2.801$, $p = 0.045$, $\eta^2_P = 0.094$ (medium effect)) such that participants accumulated less daily MVPA following exercise compared to baseline. Daily MVPA following MOD ($F(1,27) = 7.053$, 69.9 ± 25.9 min/day, $p = 0.013$, $\eta^2_P = 0.207$ (medium effect)), HI ($F(1,27) = 4.445$, 72.6 ± 31.2 min/day, $p = 0.044$, $\eta^2_P = 0.141$ (large effect)) and SPRT ($F(1,27) = 4.929$, 72.1 ± 22.8 min/day, $p = 0.035$, $\eta^2_P = 0.154$ (large effect)) were lower compared to baseline (81.5 ± 29.1 min/day, Figure 10).

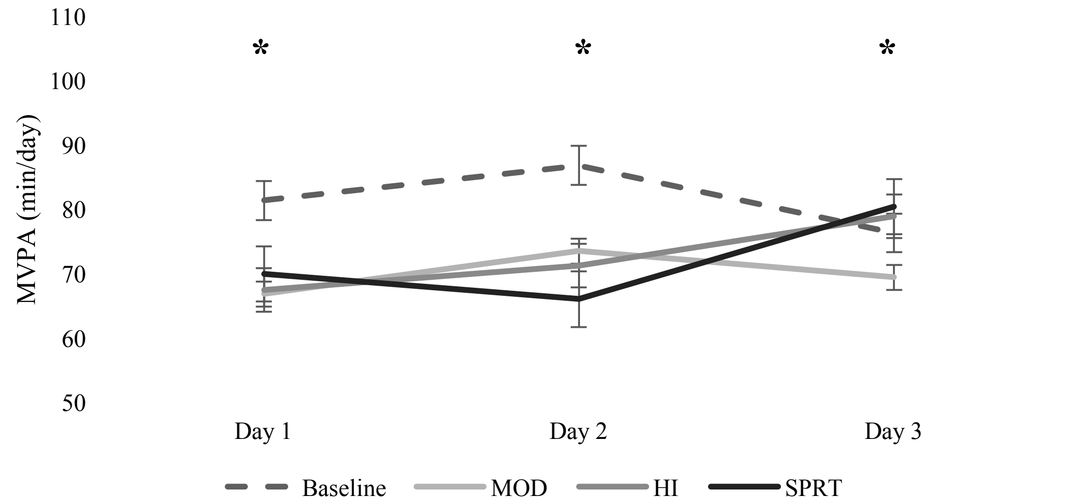

Figure 10. Changes in moderate-to-vigorous physical activity in the combined sample of men and women (means ±SD). *Note*. *p<0.05.

In the sample of men only, there was an interaction between conditions and days for daily MVPA ($F(6,78) = 2.848$, $p = 0.015$, $\eta^2_P = 0.180$ (large effect)) such that men decreased daily MVPA from day two to day three at baseline but increased from day two to day three following SPRT ($F(1,13) = 9.370$, day $2_{baseline}$: 93.2 ± 36.4 min, day 2_{SPRT}:64.0 ± 26.7 min, day $3_{baseline}$: 77.9 ± 34.7 min, day 3_{SPRT}: 91.1 ± 31.3 min, $p = 0.009$, $\eta^2_P = 0.419$ (large effect), Figure 11).

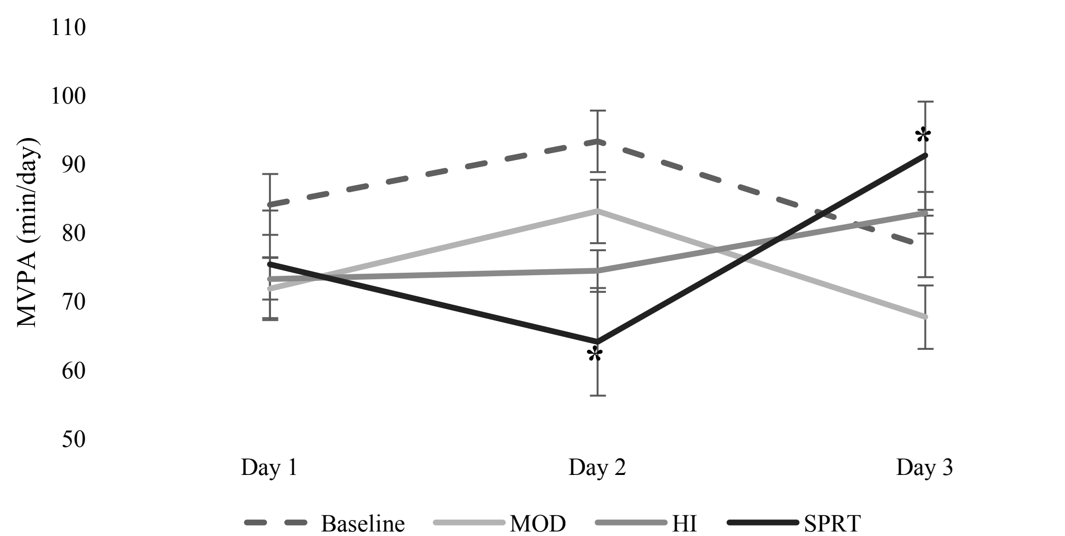

Figure 11. Changes in moderate-to-vigorous physical activity in the sample of men (means ±SD). *Note*. *p<0.05.

In the sample of women only, there were no significant differences for MVPA ($F(6,78)$ = 0.421, p =0.863, η^2_P = 0.031 (small effect), Figure 12).

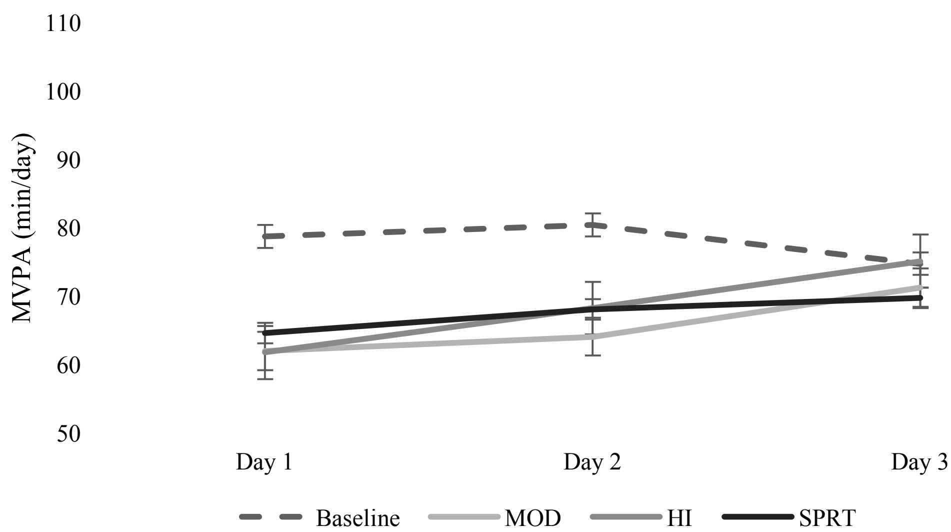

Figure 12. Changes in moderate-to-vigorous physical activity in the sample of women (means ±SD). *Note*. *p<0.05.

Compared to baseline, several participants had meaningful decreases in daily MVPA following MOD (n=13; m: n=6, f: n=7), HI (n=13; m: n=6, f: n=7) and SPRT (n=12; m: n=5, f: n=7; Table 2).

In the combined sample, an interaction between conditions and days was found for LPA ($F(6,162)$ = 1.910, p = 0.082, η^2_P = 0.066 (medium effect)), such that, LPA decreased following HI from day one to day two but increased from day one to day two at baseline (F(1,27) = 6.769, day $1_{baseline}$: 52.6 ± 22.2 min, day 1_{hi}: 56.0 ± 22.2 min, day $2_{baseline}$: 60.0 ± 25.7 min, day 2_{hi}: 50.0 ± 29.3 min, p = 0.015, η^2_P = 0.200 (large effect)); the same trend was found following SPRT ($F(1,27)$ = 6.050, day $1_{baseline}$: 52.6 ± 22.2 min, day 1_{sprt}: 51.8 ± 23.7 min, day $2_{baseline}$: 60.0 ± 25.7 min, day 2_{sprt}: 46.9 ± 21.0 min, p = 0.021, η^2_P = 0.183 (large effect), Figure 13).

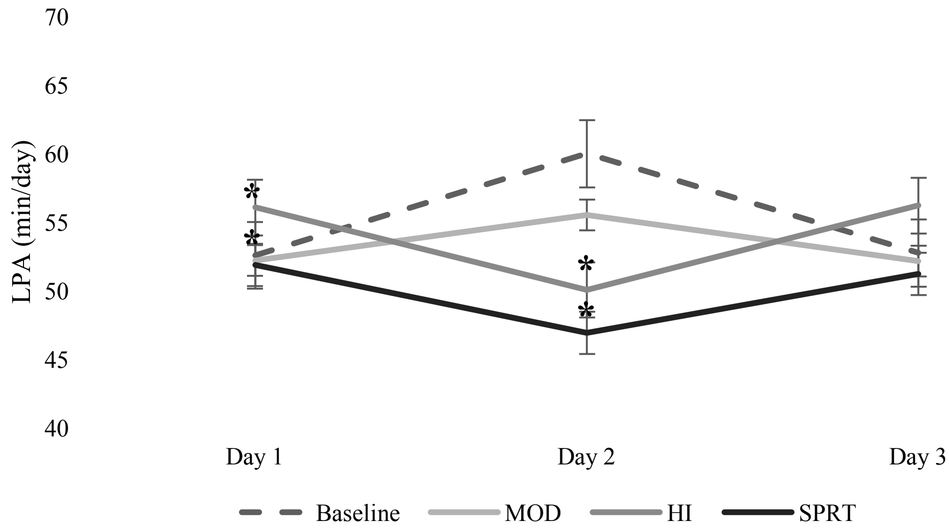

Figure 13. Changes in light physical activity in the combined sample of men and women (means ±SD). *Note*. *p<0.05.

This same interaction was also significant in the sample of men ($F(6,78) = 2.056$, $p = 0.068$, $\eta^2_P = 0.137$ (medium effect)). LPA decreased from day one to day two following HI but increased from day on to day two at baseline ($F(1,13) = 7.878$, day $1_{baseline}$: 52.6 ± 26.6 min, day 1_{hi}: 56.8 ± 31.6, day $2_{baseline}$: 65.0 ± 30.0 min, day 2_{hi}: 49.3 ± 20.5 min, $p = 0.015$, $\eta^2_P = 0.200$ (large effect)). Following SPRT, LPA also decreased from day one to day two but increased from day one to day two at baseline ($F(1,13) = 8.138$, day $1_{baseline}$: 52.6 ± 26.6 min, day 1_{sprt}: 51.4 ± 24.5 min, day $2_{baseline}$: 65.0 ± 30.0 min, day 2_{sprt}: 44.2 ± 22.1 min, $p = 0.014$, $\eta^2_P = 0.183$ (large effect), Figure 14).

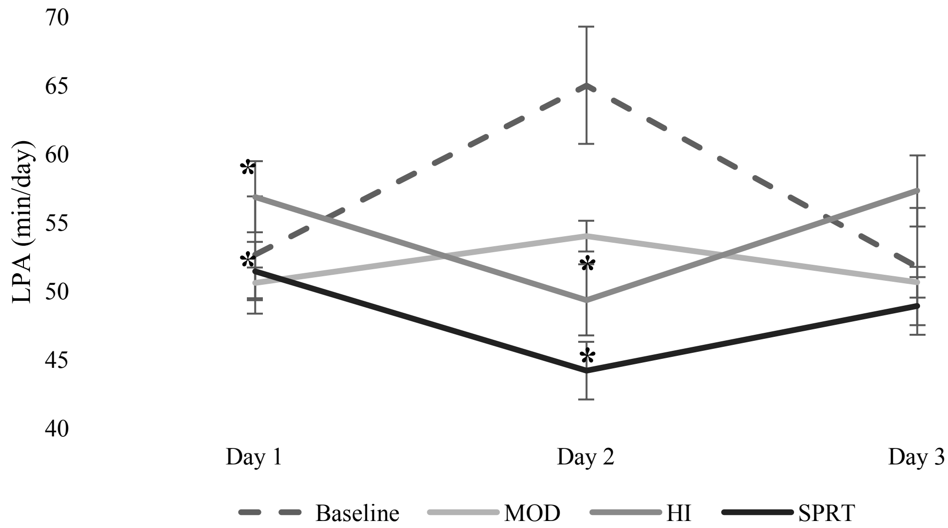

Figure 14. Changes in light physical activity in the sample of men (means ±SD). *Note*. *p<0.05.

No significant differences were found in the sample of women for LPA ($F(6,78) = 0.340$, $p = 0.914$, $\eta^2_P = 0.025$ (small effect), Figure 15).

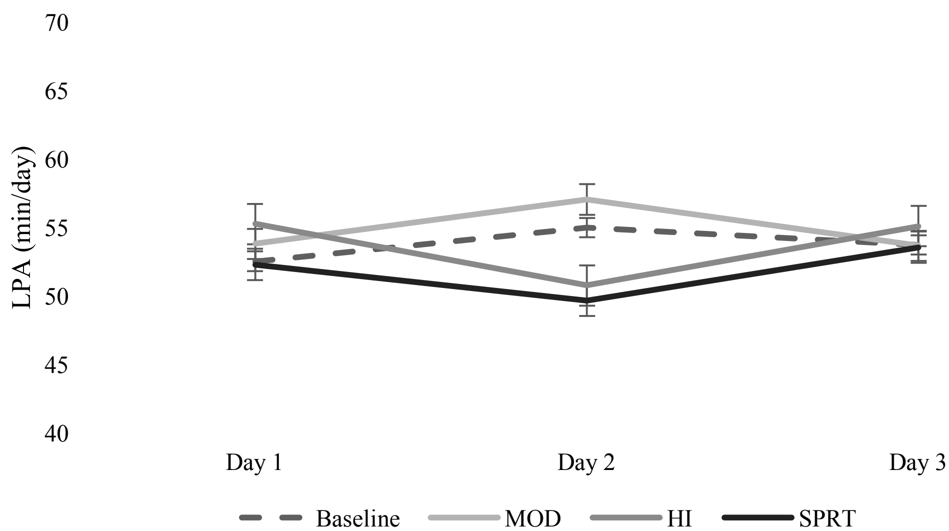

Figure 15. Changes in light physical activity in the sample of women (means ±SD). *Note*. *p<0.05.

In the combined sample, there were no differences in sleep duration ($F(6,162) = 0.835$, $p = 0.545$, $\eta^2_P = 0.030$ (small effect), Figure 16).

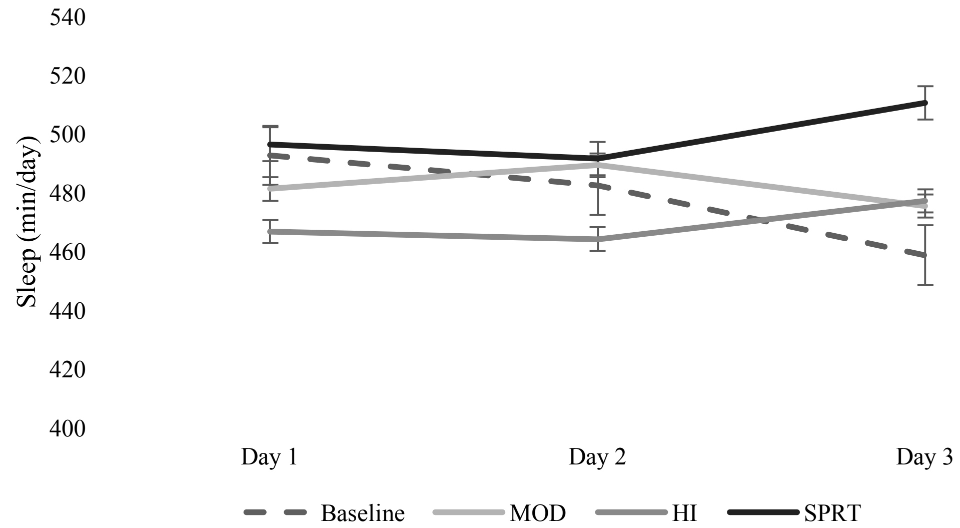

Figure 16. Changes in sleep duration in the combined sample of men and women (means ±SD). *Note*. *p<0.05.

In the sample of men, there was a main effect for days ($F(2,26) = 4.852$, $p = 0.016$, $\eta^2_P = 0.272$ (large effect)) such that men increased their sleep duration from day one to day two following all conditions ($F(1,13) = 9.019$, day 1: 462.3 ± 70.8min/day, day 2: 494.3 ± 55.6 min, $p = 0.010$, $\eta^2_P = 0.410$ (large effect), Figure 17).

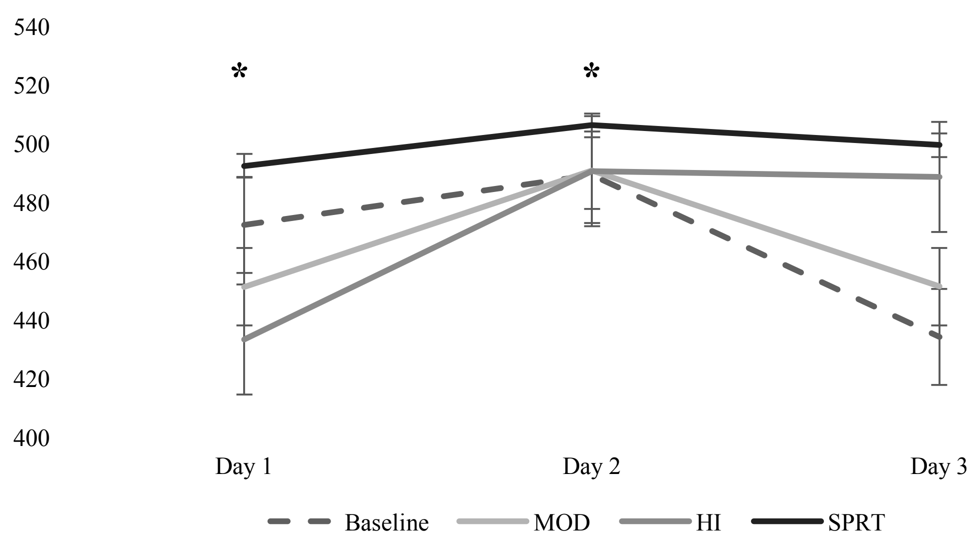

Figure 17. Changes in sleep duration in the sample of men (means ±SD). *Note*. *p<0.05.

In the sample of women, there was a main effect for days ($F(2,26) = 3.093$, $p = 0.062$, $\eta^2_P = 0.192$ (large effect)) such that women spent more time sleeping on day one than on day two for all conditions ($F(1,13) = 9.019$, day 1: 506.2 ± 51.7 min/day, day 2: 469.5 ± 46.9 min, $p = 0.029$, $\eta^2_P = 0.317$ (large effect), Figure 18).

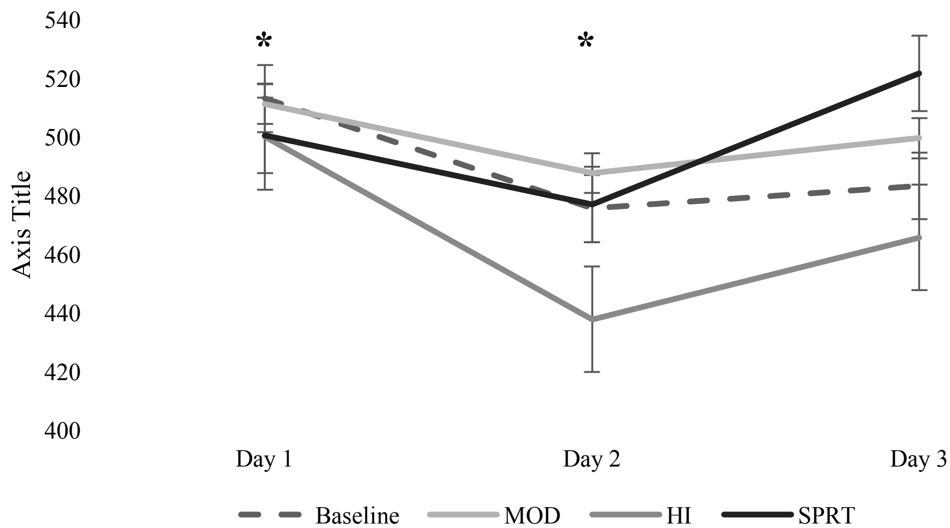

Figure 18. Changes in sleep duration in the sample of women (means ±SD). *Note*. *p<0.05.

3.5 Discussion

We sought to assess changes in 24-hour movement behaviours of older adults following participation in an acute bout of moderate or high intensity exercise. Our primary findings were: 1) MVPA decreased over the three days following participation in acute exercise when compared to baseline, regardless of the intensity of the exercise session, 2) participants had a greater number of prolonged sedentary bouts the day after exercise compared to the same day at baseline, and 3) LPA decreased in the days following exercise, but only exercise of high intensity. To our knowledge, this is the first study to assess compensation in movement behaviours of older adults following moderate and high intensity exercise. These findings have important implications for behaviour change counseling in older adults when they adopt a new exercise program. Further research is needed to understand longer-term impacts of engaging in various intensities of exercise.

As hypothesized, we found that older adults compensated for engaging in exercise with a decrease in MVPA in the subsequent three days. Approximately half of all participants decreased MVPA by ≥10 min/day in the subsequent days following each session. Although we did not measure perceived fatigue, we hypothesize that this compensation in MVPA may have resulted from some form of fatigue (i.e. musculoskeletal and cardiorespiratory fatigue) related to engaging in exercise. Older adults have been reported to experience greater soreness, musculoskeletal fatigue, and general fatigue following exercise, particularly exercise of high intensities (Eldadah, 2010; McAuley, Blissmer, Katula, & Duncan, 2000). In fact, sprint intensity exercise appeared to have the most negative impact on MVPA. Following sprints, participants continued to decrease MVPA for two full days. Repeated sprints have been reported to cause peripheral and central fatigue in younger populations (Racinais et al., 2007). Moreover, certain sprint protocols have been found to cause significant muscle damage, soreness, swelling and delayed onset muscle soreness for up to 72-hours post exercise (Howatson & Milak, 2009). Although our SPRT protocol was short in comparison to the sprints prescribed by Howatson and Milak (2009), it is feasible our older adults felt fatigued for multiple days following exercise. We suspect that in our sample of older adults, these exercise-induced effects impacted movement behaviours, even among those accustomed to regular moderate intensity exercise. Future research is needed to better understand whether compensation would persist if older adults engaged in a longer-term exercise program.

We also hypothesized that total sedentary time would increase and that the number of prolonged sedentary bouts would increase following higher intensities of exercise. While we did not find statistically significant increases in total sedentary time, several participants had meaningful increases in sedentary time, and we observed an increase in prolonged sedentary bouts following each exercise session. The greatest increase in sedentary bouts was seen after the sprint session, which yielded a medium effect (η^2_P = 0.083). Not surprisingly, research indicates that older adults who report feeling more fatigued accumulate higher sedentary time (Engberg, Segerstedt, Waller, Wennberg, & Eliasson, 2017; Van Roekel et al., 2016). Taken together with research that suggests that older adults have the greatest fatigability of all age groups (Eldadah, 2010), it follows that care should be taken when prescribing high intensity exercise to older adults as it may lead to compensation in sedentary behaviour. Future research accounting for older adults of different fitness levels is needed to better understand whether compensation would occur in those who are highly fit.

Of particular novelty, we also assessed changes in LPA in our study. LPA decreased in the days following high intensity intervals and sprints but not after the moderate intensity exercise session. This further supports the notion that compensation may be related to perceived fatigue, resulting from muscle damage, swelling, and delayed onset muscle soreness after participation in higher intensities of exercise, that is, higher intensity exercise may have a more prolonged, more dramatic effect on energy expenditure than volume alone. A small but growing body of research is looking at the benefits of LPA for health in older adults (Blair et al., 2014; Buman et al., 2010; Jefferis et al., 2018; Prince, Saunders, Gresty, & Reid, 2014). Our study emphasizes the importance of assessing changes in LPA in the context of the 24-hours.

We did not observe any trends in sleep duration in our sample of older adults. This may be due to the measurement we used for sleep. While this device has been used to assess sleep in the past (Van Der Berg et al., 2016), it is not considered the gold-standard for sleep. Furthermore, we only looked at sleep quantity, which was calculated as a lack of movement, in the reclined position, during late evening and night times. It is possible that exercise would influence sleep quality, particularly in an older population (King et al., 2008; Yang, Ho, Chen, & Chien, 2012). Future research is needed to understand how different intensities of exercise may affect sleep duration and sleep quality, and how these changes may impact the physical health of older adults.

We analyzed our data separately for men and women given the established differences in patterns of movement behaviour (Arnardottir et al., 2012; Colley et al., 2011; Evenson, Buchner, & Morland, 2012; Harvey, Chastin, & Skelton, 2015; Marshall et al., 2015). In line with the established differences, men were more sedentary at baseline than women. We also saw a trend in our sample of men, such that, sedentary time was greatest the day following exercise. A larger percentage of our sample of men were regular cyclists, which may have influenced how they approached performing the exercises. Many perceived the exercise sessions as a “performance challenge”, particularly during the high intensity sessions, which may have led them to do more work during the SPRT session thus causing greater muscle damage, soreness, and perceived fatigue. Another trend observed was related to gender-differences in compensation. While men had significantly greater ST on day one following exercise (large effect, η^2_P = 0.212), and significant decreases in LPA (medium effect, η^2_P = 0.137), women did not (ST: small effect, η^2_P = 0.057, LPA: small effect, η^2_P = 0.025). Some potential reasons we may have not seen the same changes in our sample of women were comparatively lower effort levels during exercise and a wider variability in movement behaviour patterns (i.e. ST, MVPA and LPA, sleep) following exercise.

There are several strengths and weaknesses to consider when interpreting the findings of this work. To our knowledge, this study was the first to investigate compensation following different intensities of acute exercise in older adults. Moreover, we assessed all four movement behaviours using a 24-hour wear protocol. Exercise sessions were separated by seven days to limit the effect of previous sessions. With regards to weaknesses, despite having a fairly homogenous sample of older men and women, we had significant variability in movement behaviours. Nevertheless, our baseline data are in line with findings from previous research that indicate that older adults accumulate approximately 10 hours of sedentary time per day (Harvey et al., 2015). It is possible that sedentary time may have a ceiling and we may be more likely to see changes in sedentary time in populations with low baseline sedentary time. In highly sedentary populations, like older adults, compensation may be observed elsewhere (i.e., LPA or MVPA). Given the variability observed, our sample size (n=28) may have lacked the power to detect smaller changes. However, our sample size neared 30, which has been considered by some as a low risk sample size for type two errors (Corder & Foreman, 2014; Pett, 1997). It should also be noted that we used a thigh worn device to measure sleep duration. Previous research indicate that wrist worn devices are better for objectively measuring sleep duration (Lauderdale, Knutson, Yan, Liu, & Rathouz, 2008). However, research using the same device as the one used in the current study indicates that sleep duration can be accurately measured (Van Der Berg et al., 2016). Nonetheless, future research should consider adding a wrist-worn device and/or a sleep diary to more accurately assess sleep duration.

In conclusion, it appears that older adults change their 24-hour movement behaviours following participation in an acute bout of exercise by decreasing MVPA, increasing sedentary behaviour, and a decreasing LPA. Exercise intensity may play an important role in this compensation. Future research assessing changes in movement behaviour patterns to long-term exercise programs is needed to better understand the impact of engaging in acute exercises of different intensities and durations on LPA, MVPA, sedentary time and sleep.

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Chapter 4. Thesis Discussion

4.1 Discussion

In addition to assessing compensation in the days following acute exercise in older adults, we also assessed same day compensation (day zero), fatigue, and exercise enjoyment. The results for each of these are presented and interpreted below:

4.11 Day Zero

We found that participants spent a larger percentage of wear time engaging in sedentary behaviours, and a smaller percentage of time in LPA following high intensity exercise (Table 3).

Table 3

Wear time and percentage of wear time following exercise on day zero.

	Baseline	MOD	HI	SPRT
Wear Time (min)	795.3	805.4	788.7	787.2
Sedentary Time (% wear time)	56.4± 0.1%	59.3 ± 0.1%	61.9 ± 0.1%	64.8 ± 0.1%*
LPA (% wear time)	5.8 ± 0.0%	4.9 ± 0.0%	4.0 ± 0.0%	4.0 ± 0.0%*
MVPA (% wear time)	9.0 ± 0.0%	10.3 ± 0.0%	9.0 ± 0.0%	7.9 ± 0.0%

Note. A One-way Analysis of Variance was used to assesses movement behaviours on day zero. *p<0.05.

It is important to note that these day zero measures were not included in the main analysis for a number of reasons. First, participants did not have the same wear time between conditions (Table 3). Second, while accelerometers were worn for the full 24-hours on the days following exercise, they were not worn prior to the session on day zero; many participants removed their accelerometers prematurely due to skin irritation or adhesive tape failure. Thus, wear time began at the beginning of each session, which were scheduled in the mornings, one-week apart. Although wear times were not identical, they differed by no more than 2% between baseline and exercise days (Table 3). For these reasons, same day movement behaviours were not included in the manuscript, but are included here.

No differences were observed in same day MVPA following any of the conditions. MOD, HI and SPRT sessions were included in this collection period, which may explain the lack of differences observed. Although not significant, participants appear to have engaged in less MVPA following SPRTs. The differences in wear time between day zero at baseline and day zero following SPRTs explain the small difference we observed. It appears that participants may have displaced their regular MVPA on day zero with the prescribed exercise. This may have important implications for prescribing acute exercise in older adults, as it may displace other physical activity, rather than increase overall MVPA levels.

Although we saw no changes in sedentary time in the three days following exercise, changes were observed for day zero; this is despite the fact that we were unable to include the portion of the day prior to their laboratory session (Figure 19).

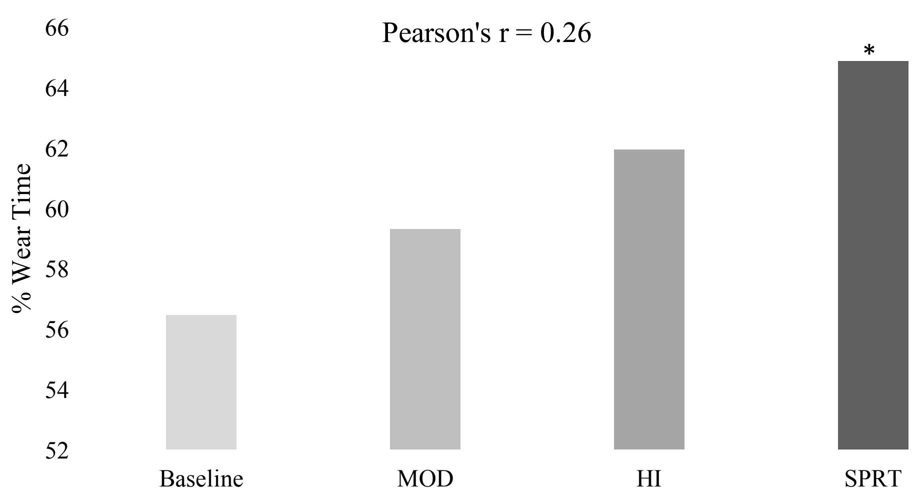

Figure 19. A One-way Analysis of Variance was used to assess the percentage of wear time participants engaged in sedentary behaviours at baseline and following exercise on day zero. *Note*. *p<0.05.

Following SPRTs, participants increased their total sedentary time when compared to baseline ($F(3,108) = 2.646$, $p = 0.053$, r = 0.26, (small effect)); this change accounted for approximately one hour of additional sedentary time. This should be interpreted cautiously because wear time following SPRTs was approximately eight minutes shorter than wear time at baseline (Table 3). This could have inflated the percentage of time participants were sedentary. Moreover, the SPRT protocol was 13-minutes shorter than all other protocols, which also may account for some of the increase in sedentary time we observed. Despite this, these reasons only account for a fraction of the difference observed and thus, we are confident that participants did in fact compensate following SPRT when compared to baseline. We also observed a trend, such that sedentary time was positively associated with exercise intensity. That is, the greater the intensity of exercise, the greater the percentage of wear time participants spent engaging in sedentary behaviours on day zero (Figure 19). Similar to our former analysis in the subsequent days, we assessed prolonged sedentary bouts on day zero. However, we found no significant differences between conditions.

Similar to our primary finding in the three days following exercise, participants spent less time engaging in LPA on day zero of SPRT ($F(3,108) = 3.481$, $p = 0.018$, $r = 0.29$, (small effect)). Here again, we see the greatest change following SPRTs, strengthening our hypothesis that perceived fatigue may be a mechanism to these changes. Moreover, we observed a trend, such that, higher intensities of exercises were negatively associated with LPA (Figure 20). The change we observed following SPRT on day zero, helps illustrate the collinearity shared between sedentary time and LPA (Pedišić, 2014). That is, the increase in sedentary time following SPRT appears to have displaced LPA. As such, it is imperative we understand that engaging in exercise will inherently displace another, or a combination of other behaviours (i.e., MVPA, LPA, sedentary time, sleep). Counselling older adults on these movement behaviours when beginning a new exercise program may help minimize the displacement of non-exercise LPA and MVPA, which have been reported to lead to health benefits (Blair et al., 2014; Buman et al., 2010; Jefferis et al., 2018; Prince, Saunders, Gresty, & Reid, 2014; Warburton, Nicol, & Bredin, 2006).

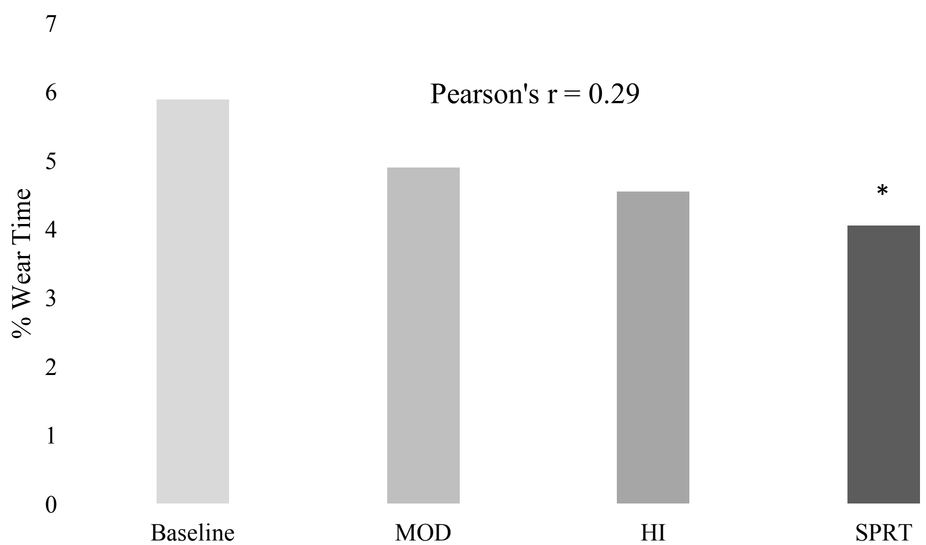

Figure 20. A One-way Analysis of Variance was used to assess changes in light physical activity on day zero at baseline and following exercise. *Note*. *p<0.05.

4.12 Fatigue

Self-reported, perceptions of fatigue were rated prior to and following each exercise, using a visual analog scale, numbered from zero to ten; a value of zero was indicative of no fatigue, and a value of ten was indicative of maximal fatigue (Appendix 1). Borg's Ratings of Perceived Exertion (RPE) scale (RPE)(Borg, 1998) was also used to assess the perceived exertion each minute during exercise. RPE was rated between six and twenty; a rating of six indicates no exertion, while a rating of twenty is indicative of maximal exertion (Appendix 2). These data are depicted in Figure 21.

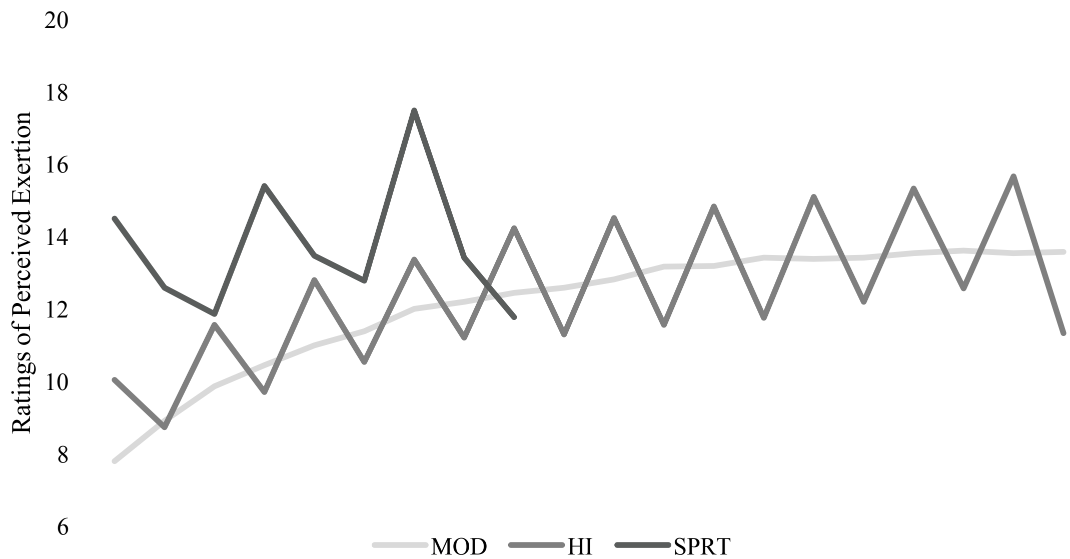

Figure 21. Ratings of Perceived Exertion (RPE) during MOD, HI and SPRT exercise (Borg, 1998).

Although it was the shortest protocol, participants reported the highest RPE during the SPRT protocol. Moreover, all exercise protocols were considered at minimum "somewhat hard" towards the end of the exercise. The difference in pre/post exercise fatigue scores was calculated and graphed (Figure 22).

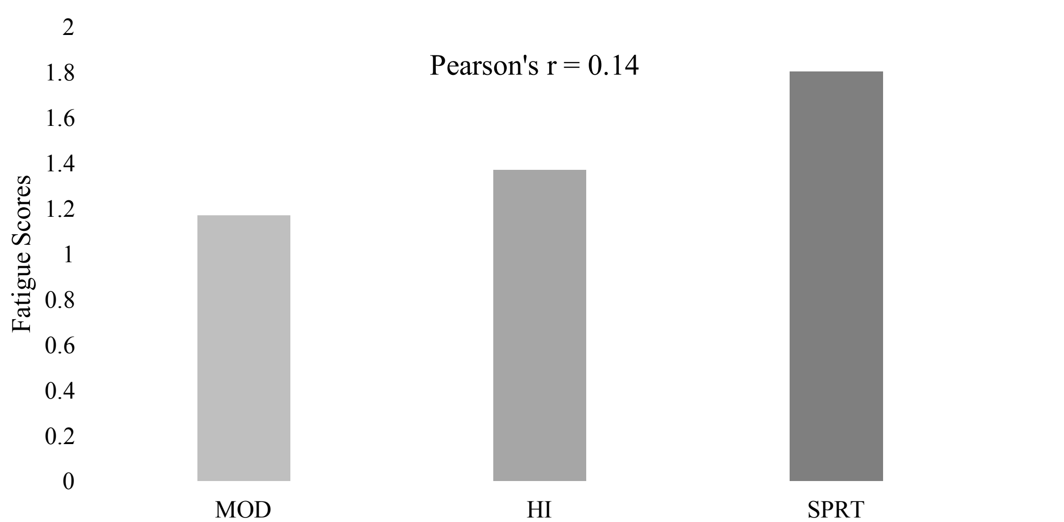

Figure 22. A One-way Analysis of Variance was used to assess differences in fatigue scores from pre-to-post exercise. *Note*. *p<0.05

Although we found no significance, a trend was observed, such that, perceived fatigue increased following each exercise protocol, particularly following higher intensity exercise. That is, the greater the intensity of exercise, the greater the difference in perceived fatigue scores from pre- to post-exercise. Although it was our shortest exercise protocol, SPRT appeared to induce the greatest perception of fatigue in older adults, likely due to intensity. This may be clinically important as perceived fatigue has been reported to restrict future physical activity (Gill, Desai, Gahbauer, Holford, & Williams, 2001) and has been associated with high sedentary times (Engberg, Segerstedt, Waller, Wennberg, & Eliasson, 2017; Van Roekel et al., 2016). Furthermore, the effects of a long-term, high intensity exercise intervention on perceived fatigue in older adults is still unknown. The trends we observed were following acute exercise and we suspect that once more accustomed to high intensity exercise, we may potentially find a lessened effect on perceived fatigue. It may be important to note that had our sample of older adults been less active at baseline, we may have observed higher RPE values during exercise, and potentially greater perceived fatigue. The majority of our sample exercised regularly and thus it is likely RPE and perceived fatigue would be greater in the general older adult population. Additionally, we may have seen different RPE and perceived fatigue scores had the exercises been performed on a treadmill or other mode of exercise instead of a cycle ergometer. Thus, the activity and motivation level of our participants may have impacted the magnitude of compensation following exercise, that is, greater RPE during exercise may have led to greater perceived fatigue and consequently greater compensation (i.e. increases in ST, decreases in LPA/MVPA). This might also help to explain the gender differences, that is, men put in more effort during exercise than the women.

4.13 Exercise Enjoyment

A trend was observed for exercise enjoyment, such that, enjoyment decreased as exercise intensity increased (Figure 23).

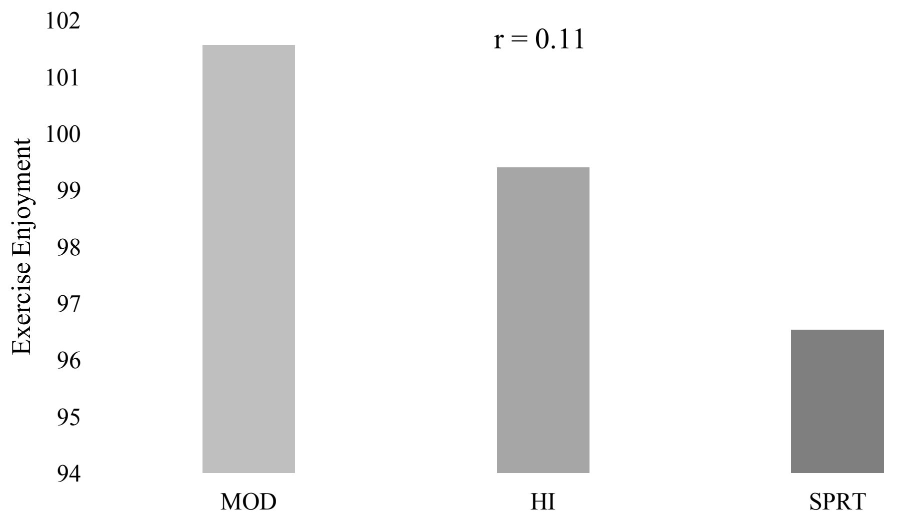

Figure 23. A One-way Analysis of Variance was used to assess physical activity enjoyment questionnaires scores following exercise. *Note*. *p<0.05, r = Pearson correlation

Exercise enjoyment was measured using an 18-item physical activity enjoyment questionnaire. Questions were answered using a bipolar likert scale, numbered from one to seven, and summed for a maximum score of 126; high scores were associated with greater enjoyment (Appendix 3). This questionnaire has been shown to have moderate test-retest reliability following cycling (Kendzierski & DeCarlo, 1991). In our sample of older adults, sprints were the least enjoyable exercise, while enjoyment was highest following moderate intensity exercise. Although enjoyment was lowest following sprints (96.5 ± 19.6), enjoyment was higher than expected following all exercise sessions. The participants in our study were keen on performing exercise and there may have been a self-selection bias within our sample. Participants appeared interested in exercise and fitness prior to participating and this may have had an effect their exercise enjoyment. Perceived enjoyment may have been vastly different in a less active sample of older adults. Our findings are not in line with reports found in younger adults (Bartlett et al., 2011; O'Neill & Dogra, 2017), and this contrasted finding may be explained by age related functional decline and lower cardiorespiratory fitness (Ades & Toth, 2005; McGregor et al., 2013). Exercise enjoyment is important to consider as it has been reported to motivate future physical activity (Datta, 2016; Hardy & Grogan, 2009). Moreover, enjoyment may affect compensation on day zero; participants may be comparatively less motivated to engage in their regular physical activity habits following less enjoyable exercise. To illustrate this point, although insignificant, the greatest MVPA on day zero was observed following the MOD protocol (Table 3), which corresponds as the most enjoyable protocol. Enjoyment may have had an effect on their desire to engage in other physical activities during the remainder of the day. In conversations following their exercise sessions, many of our participants that were regular cyclists viewed the MOD protocol as "boring" or "monotonous", while the opposite was reported by our non-cyclists. These comments imply that "training age" should be considered when prescribing high intensity exercise in older adults. In light of this, older adults may find high intensity exercise more enjoyable over time, which may attenuate or eliminate compensation. However, long term interventions are needed to explore exercise enjoyment following high intensity exercise in older adults.

4.2 Strengths

Exercise sessions were scheduled in the mornings, such that all participants had ≥10 hours of wear time following exercise on day zero. This has been used a minimum criterion for valid accelerometry wear elsewhere (Davis et al., 2011; Jefferis et al., 2014). Moreover, participants were scheduled to perform their exercise sessions during the same time slot each week, which allowed for similar wear time on day zero across all conditions. We assessed LPA, MVPA and sedentary time during the same data collection period, which allowed us to observe changes to any one of these behaviours. Exercise sessions were separated by seven days to limit the effect of previous sessions.

4.3 Weaknesses

We were unable to assess the full 24-hours on day zero. Many of our participants prematurely removed their accelerometers prior to attending their exercise sessions, primarily because of irritation between the adhesive and skin. Thus, we were unable to collect information on any movement behaviours prior to the start of their exercise session. Although wear times were comparable on exercise days, we were unable to accurately compare this data to the data collected in the subsequent three days because of significant differences in wear-time between day zero and days one to three. For self-reported fatigue, we used a simple visual analog scale. Assessing perceived fatigue through a visual analog scale may not give insight into the origin of said fatigue (e.g. physical, mental, cardiorespiratory). However, this scale has been used before, and has shown acceptable test-retest reliability (Kim, Jesus Lovera MD, Schaben, Bourdette, & Whitham, 2010; Krupp, Soefer, Pollina, Smiroldo, & Coyle, 1998). Nevertheless, given the time at which perceived fatigue was measured (day zero), we were only able to assess the association between perceived fatigue and subsequent movement behaviours on day zero. Finally, we calculated total MVPA, accumulated in any duration instead of solely tallying MVPA acquired in bouts of ≥10 minutes, as per the physical activity guidelines

(Tremblay et al., 2011). This method of measurement may have overestimated MVPA. Nevertheless, our participants appeared to be much more active than the national average (Colley et al., 2011; Jefferis et al., 2018). This may have affected their behavioural response to moderate and high intensity exercise.

4.4 Future Considerations

Given the results and limitations of our study, there are several changes that could be implemented in future studies. Fitting participants with an accelerometer the day prior to exercise would have allowed us to collect data on the entire 24-hours on day zero. Thus, we would have been able to compare day zero to the subsequent three days following exercise. This would have also allowed for the comparison of sleep patterns prior to, and following different intensities of exercise. As formerly mentioned, supplementing our thigh worn accelerometer with a sleep diary and/or wrist worn accelerometer would improve the accuracy of assessing sleep duration (Lauderdale, Knutson, Yan, Liu, & Rathouz, 2008). Moreover, this would have allowed for accurate assessment of all sleep components (i.e., sleep latency, duration, and quality/awakening episodes), rather than just duration. Although it was a secondary measure, fatigue measures could have been improved via supplementing our general fatigue analog scale with a neuromuscular fatigue measure using electromyography. Comparing maximal voluntary contractions before and after exercise on both the biceps brachii and vastus lateralis would have allowed us to assess both peripheral and central neuromuscular fatigue associated with acute exercise (Lepers, Maffiuletti, Rochette, Brugniaux, & Millet, 2002). This could have been used as a supplementary measure to the visual analog scale and may have provided further insight pertaining to the origin of fatigue rather than solely assessing the perception of fatigue. Moreover, to explore the association between movement behaviour change and fatigue in the subsequent days following exercise, future studies should consider measuring fatigue in the mornings following exercise, rather than solely on day zero. In consideration of our active sample of older adults, future studies should consider recruiting older adults that better represent the general population. Due to time constraints, a large proportion of our older adults were recruited out of convenience, from cycling clubs in the area. Including a more homogenous, generalizable sample could be accomplished by assessing baseline movement behaviours prior to participating in the study, and excluding participants that were significantly more active than the national average (Jefferis et al., 2014).

4.5 Conclusion

Older adults appear to compensate for engaging in exercise by increasing sedentary behaviour and decreasing physical activity on subsequent days. The magnitude of compensation following acute exercise appears to be proportional to the intensity it is performed under. There is increased interest in the health benefits of decreasing sedentary time (Fishman et al., 2016; Prince et al., 2014; Rosenberg et al., 2015), and increasing LPA in recent years (Blair et al., 2014; Buman et al., 2010; Jefferis et al., 2018; Prince et al., 2014). Thus, performing exercises that cause significant compensation (i.e., increases in sedentary time, decreases in LPA) may be problematic. In light of this, prescribing exercises that induce the least compensation, may lead to greater health benefits. It is unclear whether compensation is sustained during longer term exercise programs and given this, more research is needed to better inform which intensities and durations of exercise are least compensated for in older adults.

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APPENDIX

1. Borg Scale of Exertion

6 – No Exertion at all

7 – Extremely Light

8

9 – Very Light

10

11 – Light

12

13 – Somewhat Hard

14

15 – Hard (heavy)

16

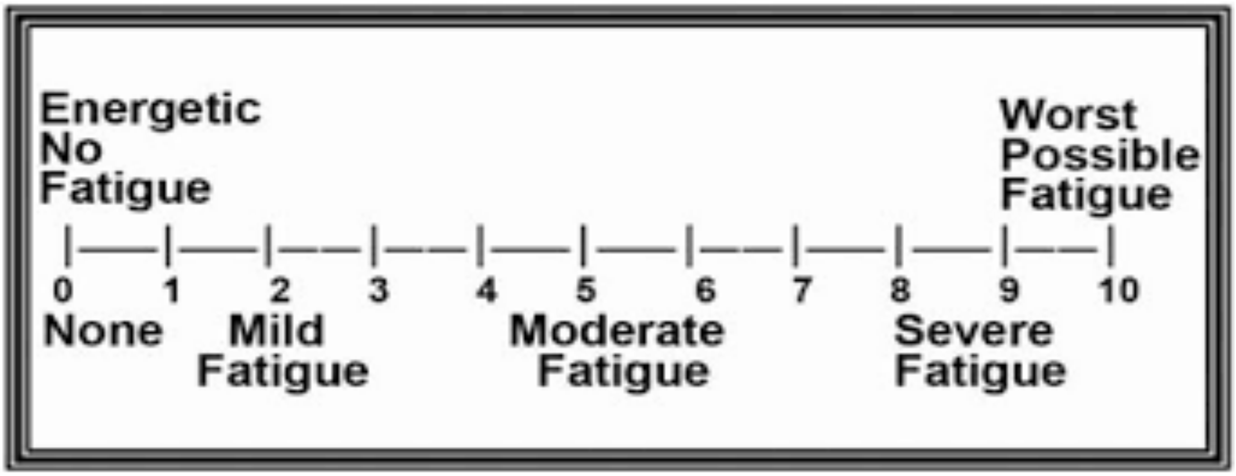
17 – Very Hard

18

19 – Extremely Hard

20 – Maximal Exertion

2. Visual Fatigue Analog Scale



3. Physical Activity Enjoyment Scale

Please rate how you feel at the moment about the physical activity you have been doing.

1 2 3 4 5 6 7

I enjoy it — I hate it

1 2 3 4 5 6 7

I feel bored — I feel interested

1 2 3 4 5 6 7

I dislike it — I like it

1 2 3 4 5 6 7

I find it pleasurable — I find it un-pleasurable

1 2 3 4 5 6 7

I am very absorbed in this activity — I am not at all absorbed in this activity

1 2 3 4 5 6 7

It's no fun at all — It's a lot of fun

1 2 3 4 5 6 7

I find it energizing — I find it tiring

1 2 3 4 5 6 7

It makes me depressed — It makes me happy

1 2 3 4 5 6 7

It's very pleasant — It's very unpleasant

1 2 3 4 5 6 7

I feel good physically while doing it	I feel bad physically while doing it

1 2 3 4 5 6 7

It's very invigorating	It's not at all invigorating

1 2 3 4 5 6 7

I am very frustrated by it	I am not at all frustrated by it

1 2 3 4 5 6 7

It's very gratifying	It's not at all gratifying

1 2 3 4 5 6 7

It's very exhilarating	It's not at all exhilarating

1 2 3 4 5 6 7

It's not at all stimulation	It's very stimulating

1 2 3 4 5 6 7

It gives me a strong sense of accomplishment	It does not give me any sense of accomplishment at all

1 2 3 4 5 6 7

It's very refreshing	It's not at all refreshing

1 2 3 4 5 6 7

I felt as though I would rather be something else	I felt as though there was nothing I would rather be doing

1 2 3 4 5 6 7

Item is reversed scored (i.e..1=7,2=6,. .. 6=2,7=1).