LUMBOPELVIC CONTROL IN DYNAMIC TASKS – THE RELATIONSHIP BETWEEN THE ACTIVE HIP ABDUCTION TEST AND FRONTAL PLANE KINEMATICS

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ABSTRACT

This study investigated the relationship between Active Hip Abduction (AHAbd) test performance and lumbopelvic control (LPC) in the frontal plane during a dynamic stair circuit in physically active adults. Thirty-four participants (23 males, 11 females) completed the AHAbd and a 15-minute fatiguing stair circuit. While no significant effects of age, sex, or AHAbd score were observed on LPC during stair ascent, significant interactions were found during stair descent, particularly among younger adults and females with poor AHAbd scores. The AHAbd test did not effectively identify LPC deficits in this active older adult population, suggesting that further research is needed in less active populations. These findings highlight the importance of maintaining physical activity to mitigate age-related declines in LPC and suggest that diverse populations should be studied to optimize physical activity recommendations across age groups.

DEDICATION

To Richard, whose continued love and support has been invaluable. I could not have done this without you.

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CHAPTER 1.0 – INTRODUCTION

Lumbopelvic control (LPC) is suspected to be increasingly important as people age (Knox et al., 2022). LPC is defined as the ability to stabilize, coordinate, and/or actively mobilize the lumbar spine and pelvic regions and is required to complete everyday static and dynamic tasks, such as climbing stairs (Nadeau et al., 2003; Sahrmann et al., 2017). Physical activity and age are suspected to have opposing impacts on LPC, with activity having a positive effect and age having a negative effect on the level of control (Lazarus & Harridge, 2017; Pries et al., 2015; Ramsey et al., 2021; Skelton et al., 1994). Research on the level of LPC during dynamic tasks in adults over the age of 50 is scarce, but data from a predominantly 15-30y population has shown that having good LPC is necessary for reducing incidence of injury and remaining physically active (Cope et al., 2019; Dehcheshmeh & Gandomi, 2021; Fadaei Dehcheshmeh et al., 2021; Laudner et al., 2021; Perrott et al., 2013). This highlights the need for targeted research on LPC in older adults during dynamic tasks.

Research focusing on the frontal plane during stair ascending and descending tasks is limited, especially when looking at the lumbopelvic region. Due to the increased control required to actively mobilize and also prevent excessive side-to-side movement when performing stair tasks, analysis of frontal plane movements while on the stairs would be useful for assessing the effectiveness of dynamic task performance (Nadeau et al., 2003). Fatigue, which can significantly impair muscular endurance and coordination, further complicates LPC and its impact on functional tasks, particularly in older adults (Papa et al., 2015). Likewise, investigations into LPC during dynamic tasks needs to be completed in older aged participants where fatigue is monitored.

A sensitive measure of LPC (especially in the frontal plane) is the Active Hip Abduction test (AHAbd), where higher scores have been associated with decreased LPC and the development of clinically relevant levels of low back pain (LBP) during prolonged standing tasks (Nelson-Wong et al., 2009). Importantly, interventions targeting the increase of muscular endurance in lumbopelvic stabilizers have been shown to improve LPC and eliminate the associated clinical findings (Emeterio et al., 2022; Long, 2017; Mills et al., 2005; Nelson-Wong & Callaghan, 2010a) and the AHAbd was sensitive to the associated change in LPC. The relationship between AHAbd performance and the identification of at-risk participants during dynamic tasks has yet to be tested but may provide an earlier detection of issues with LPC before a decrease in physical activity and pain occur. Therefore, having a quick and straightforward test that can indicate an individual's level of LPC during short, functional dynamic tasks would be a useful assessment tool for populations, such as older adults, that are at a higher risk of LPC deficits (Pries et al., 2015) and for individuals who's preservation of physical activity ability is critical (Koltyn et al., 2019).

CHAPTER 2.0 – OBJECTIVES, RESEARCH QUESTIONS, & HYPOTHESES

The main objective of this study was to determine if AHAbd performance was related to frontal plane kinematics of the lumbopelvic region during a dynamic fatiguing stair climbing task in physically active adults. This can be especially important for identifying pre-clinical populations that are at risk for the development of clinically relevant levels of LBP in the future (e.g. helping active older adults reduce optimize their ability to stay active). Likewise, this study addressed the following research questions and hypotheses.

Research Questions:

1. Is the level of LPC identified by the AHAbd an indicator of the level of LPC quantified using frontal plane kinematics during a dynamic stair task?
2. Is there an impact of age on frontal plane kinematics when the level of LPC identified by AHAbd performance is controlled for?
3. Is the level of LPC identified by the AHAbd an indicator of the amount of change in frontal plane kinematics between the first round and the last round of a dynamic fatiguing stair circuit?

Hypotheses:

(1) It was hypothesized that poor LPC identified by scores of 2 or 3 on the AHAbd and increased age, would be related to significantly less frontal plane angular displacements in the lumbopelvic region during stair ascent and descent due to reduced ability to actively mobilize the pelvis.

(2) It was hypothesized that poor AHAbd scores and increased age, would be related to significantly greater change in lumbopelvic angle between the first and last round of the fatiguing stair circuit.

(3) It was hypothesized that participants would experience fatigue related changes identified by greater lumbopelvic angular displacements in the frontal plane during stair ascent and descent between the first and last round of the stair circuit.

CHAPTER 3.0 – KEY LITERATURE REVIEW

3.1 LUMBOPELVIC CONTROL

LPC can be defined as the ability to stabilize, coordinate, and/or actively mobilize the lumbar spine and pelvic regions and is a critical component of whole body postural control in everyday static and dynamic tasks (Babiolakis et al., 2015; Pool-Goudzwaard et al., 1998; Sahrmann et al., 2017). The ideal functioning and interaction of the lumbopelvic musculature is required for optimal coordination and control of the lumbar spine, pelvis, and hip (Henriksen et al., 2007; Sahrmann et al., 2017). Dysfunction of the lumbopelvic musculature or loss of control in the lumbopelvic area can impair the ability to perform activities of daily living, such as climbing the stairs (Namnik et al., 2018), and lead to clinically relevant levels of LBP development (Babiolakis et al., 2015; Nelson-Wong et al., 2008, 2009; Nelson-Wong & Callaghan, 2010b; Sahrmann et al., 2017). Babiolakis et al. (2015) examined physical fitness, physical activity, and biomechanical characteristics in nurses with and without recent back injuries, highlighting the impact of LPC on injury risk. Nelson-Wong et al. (2009) found that an assessment of LPC discriminated between pain-developer groups in the 40% of participants that developed low back pain. Poor LPC has also been shown to alter kinematics and muscle activity of the trunk and lower limbs, which may be a risk factor for lower limb injuries and increased fall risk in older adults (Dehcheshmeh & Gandomi, 2021; Emilio et al., 2014; Fadaei Dehcheshmeh et al., 2021). Emilio and colleagues (2014) conducted a controlled, longitudinal trial to determine the effects of a proprioceptive training program on older adults, finding significant improvements in flexibility, balance, and lumbar strength, which are associated with reduced risk of falls. The effects of LPC on landing mechanics and lower limb muscle activity in professional female athletes has also been studied, showing significant differences in landing

error scores, trunk and knee kinematics, and gluteus medius activity between those with proper and poor LPC (Fadaei Dehcheshmeh et al., 2021). LPC is essential for whole-body postural control and the performance of everyday tasks, with dysfunction in this area leading to impaired daily activities, increased risk of low back pain, and increased risk of lower limb injuries.

Kinematic measurements during stair climbing tasks have often had a focus on the sagittal plane, looking at flexion and extension movements at the hip, knee, and ankle (Laubenthal et al., 1972; Riener et al., 2002; Rowe et al., 2000), with the lumbopelvic joints overlooked. The sagittal plane has dominated the research due to the greater movement demands placed on the lower limb in that plane when climbing stairs. However, Nadeau et al. (2003) emphasized the significance of frontal plane measurements during stair climbing tasks. This research examining joint angular displacements, moments, and power at the hip knee and ankle highlighted the increased demands placed on the hip abductors to prevent excessive side-to-side movements and maintain pelvic control when climbing stairs, in contrast to level walking in healthy adults over the age of 40 (Nadeau et al., 2003). Therefore, examining the responses of the lumbopelvic region in the frontal plane may improve our understanding of effective stair climbing.

3.2 ACTIVE HIP ABDUCTION TEST

The AHAbd is a test developed by Nelson-Wong et al. in 2009 and was shown to be a sensitive measure of LPC. The AHAbd is an indicator of LPC in relatively static upright tasks and was able to identify individuals with clinically relevant levels of LBP and standing intolerance (Babiolakis et al., 2015; Nelson-Wong et al., 2009; Nelson-Wong & Callaghan,

2010b). When compared to 16 clinical measures associated with individuals with LBP, the AHAbd was the only measure able to distinguish LBP developers from non-LBP developers during a two hour standing protocol in an asymptomatic group of individuals (Nelson-Wong et al., 2009). Similarly, in a 2015 study by Babiolakis and colleagues, the AHAbd was the only test out of 22 fitness and biomechanical measures that was able to distinguish between nurses with and without recent history of back injury. All nurses in the study were currently working, engaged in patient handling, asymptomatic for back pain in the preceding month, and able to safely engage in physical activity. The correlation between the AHAbd and lumbopelvic instability in dynamic tasks has yet to be tested. The AHAbd has previously been studied in university aged populations meaning there is a lack of data involving the AHAbd and older adults (Babiolakis et al., 2015; Nelson-Wong et al., 2009; Nelson-Wong & Callaghan, 2010b). Because the AHAbd has been able to identify lumbopelvic deficits between asymptomatic high functioning individuals, exploring the AHAbd in an active older adult population (50y+) during a dynamic task could provide new insight into functional aging.

The AHAbd is scored from 0 to 3, with higher scores indicating a lower level of LPC during the test (*Table 4.3*). When identifying a negative or positive score on the AHAbd, grouping participants with a score of 0 or 1 (negative score) and grouping those with a score of 2 or 3 (positive score) makes it easier to identify individuals that are at risk of LBP development and differentiate between individuals with higher and lower levels of LPC (Davis et al., 2011; Nelson-Wong et al., 2009). The AHAbd is considered to be a reliable observation tool with good interrater and intrarater reliability, regardless of the experience level of the examiner scoring the test (Davis et al., 2011). More detail on the administration of the AHAbd is available in Methods

section 4.3.4. Briefly, assessors score the movement of the body during a side-lying leg raise against a set of established criteria.

3.3 AGE

During dynamic tasks, it has been shown that there are significant lumbopelvic kinematic differences between individuals above and below the age of 50y (Vazirian, 2017). Vazirian's study revealed that older adults exhibited a smaller lumbar contribution during forward bending and backward return tasks compared to younger individuals. Additionally, older adults demonstrated a more in-phase and stable lumbopelvic rhythm, potentially as a neuromuscular strategy to protect low back tissues from excessive strain (Vazirian, 2017). Other research has noted the age-related declines in spinal and lumbopelvic range of motion. Crawford et al. (2018) found that asymptomatic older adults used less spine, trunk and lower limb motion, except at the ankle during treadmill walking at various speeds and inclinations (Crawford et al., 2018). A review by Bryant and colleagues (2018) also suggests that older adults have less spinal range of motion when compared to younger adults (Bryant et al., 2018). Another study found that when comparing young adult women (23y ± 1.3) to older adult women (74y ± 6.8), the older adults produced significantly less hip abduction joint torques and suggest the need for frontal plane assessments in older adults to prevent the risk of falls (Johnson et al., 2004). In summary, aging negatively impacts lumbopelvic kinematics, movement, range of motion, and hip abduction strength, which underscores the importance of assessing these factors in older adults to mitigate fall risks and maintain functional abilities.

The age-related declines of muscle mass, strength, and power have been previously researched. It has been shown that adults lose 1% of their muscle mass, 2% of their strength, and 3.5% of their power every year after the age of 65 (Skelton et al., 1994). These age related loses in muscle mass, strength, and power are likely confounded by the effects of physical inactivity (Lazarus & Harridge, 2017). Age-related declines in muscle mass, strength, and power, which are compounded by physical inactivity, have been well-documented, highlighting the importance of addressing both aging and lifestyle factors in maintaining physical function in older adults (Ramsey et al., 2021), with the level of physical activity also being important for maintaining strength and power. A 2016 study found that competitive masters athletes had significantly greater peak power compared to recreational athletes and sedentary individuals in the same age group (Glenn et al., 2016). Masters athletes are individuals who engage in regular, competitive athletic training and events, specifically designed for older adults (Glenn et al., 2016). The positive effects of training programs on the level of flexibility, balance, and lumber strength in older adults have been shown in previous literature (Emilio et al., 2014), but this may not always be true for younger adults (Mills et al., 2005). The findings of Emilio et al., (2014) suggest that a 12-week proprioception training program significantly improves flexibility, balance, and lumbar strength in older adults (65y+; Emilio et al., 2014). The research done by Mills and colleagues (2005) found that female varsity volleyball and basketball players (18y-23y) that performed a 10-week training program did not have significant improvements in lumbopelvic stability when compared to a placebo and control group (Mills et al., 2005). Regular physical activity, especially at higher levels such as competitive sports, positively influences muscular power, strength, flexibility, balance, and lumbar strength in older adults, though these benefits may not

be as pronounced in younger populations. Presumably, the increased physical capacity of athletic older adults may translate into greater LPC as well.

While older adults benefit significantly from physical activity, aging also seems to negatively impact lumbopelvic kinematics and hip abduction strength, emphasizing the need for targeted assessments and interventions to reduce fall risk and preserve functional abilities in this population. In summary, age-related declines in muscle mass, strength, and power, exacerbated by physical inactivity, are well-documented, highlighting the critical role of regular physical activity in maintaining physical function.

3.4 FATIGUE

Muscular fatigue can be defined as a transient decrease in the capacity to perform physical actions (Enoka & Duchateau, 2008) and may affect the ability for the lumbopelvic region to be controlled at a high level. This decline in control can have significant implications for aging populations. A systematic review by Christie et al., (2011) examining 37 studies found that older adults (average age among studies: 61-84y) are less fatigable when compared to younger adults (average age among studies: 21-36y) under many of the methodological conditions examined, particularly isometric contractions. When dynamic contractions were used as an index of fatigue, older adults were more fatigable than younger adults, highlighting the importance of dynamic tasks when assessing fatigue in an older adult population (Christie et al., 2011).

The ability to perform activities of daily living, such as ascending or descending stairs independently, decreases with age (Hazell et al., 2007). In part, this is due to decreased capacity

of the musculoskeletal system. For example, it has also been shown that older adults (~74y) can use up to 78% of their maximal knee extensor moments when ascending stairs and 88% of their maximal knee extensor moment when descending the stairs (Hortobagyi et al., 2003), meaning they are performing the task at close to maximum effort. When compounded with fatigue, reduced musculoskeletal ability may inhibit an older adult population from performing stair tasks effectively. Therefore, an investigation of stair tasks in older adults may be revealing of fatigue related deficits in LPC.

3.5 PHYSICAL ACTIVITY

Physical activity plays an important role in maintaining health, well-being, physical function and quality of life (Canada, 2018). Global estimates show that up to 27.5% of adults and more than 81% of adolescents do not meet the aerobic exercises recommendations outlined by Global Recommendations on Physical Activity for Health in 2010 (World Health Organization, 2010). This points to the need for investment towards the promotion of physical activity in all age groups. The Canadian Physical Activity Guidelines and World Health Organization (WHO) physical activity guidelines outline the frequency, intensity, duration, and types of physical activity that mitigate health risk and offer significant health benefits and for all age groups (World Health Organization, 2022, Canada, 2018). The Canadian Physical Activity Guidelines suggest that adults over the age of 18y should perform at least 150min of moderate to vigorous aerobic physical activities per week. The WHO Guidelines state that adults over 18 years of age should do at least 150–300 minutes of moderate-intensity aerobic physical activity or at least 75–150 minutes of vigorous-intensity aerobic physical activity or an equivalent combination of moderate and vigorous intensity activity throughout the week. The wording of the WHO

guidelines can be beneficial when classifying individuals that do greater than 75min of vigorous physical activity but less than 150min of combined moderate and vigorous physical activity each week. The WHO guidelines recognize that vigorous physical activity is performed at a higher intensity than moderate physical activity and therefore requires less minutes per week to meet their recommendation. The Canadian and WHO Guidelines can be found in *Table 3.1* (Canada, 2018; World Health Organization, 2022).

While meeting general physical activity guidelines is crucial for overall health, not all types of physical activity are equally beneficial for specific aspects of physical function, such as LPC. Physical activities that target core strength, stability, and flexibility are more likely to enhance LPC. In contrast, activities like walking or cycling, while beneficial for cardiovascular health, may not significantly improve LPC if trunk and pelvis musculature is not engaged effectively. Therefore, individuals seeking to improve or maintain LPC should incorporate exercises specifically designed to enhance core stability and control into their physical activity routines (Nelson-Wong & Callaghan, 2010a; Perrott et al., 2013).

Table 3.1: Physical activity recommendations suggested by the Canadian Physical Activity Guidelines and World Health Organization Guidelines

	Canadian Physical Activity Guidelines (Canada, 2018)	WHO Physical Activity Guidelines (World Health Organization, 2022)
Age Group	Recommendation	
Adults (18y-64y)	• Moderate to vigorous aerobic physical activities such that there is an accumulation of at least 150 minutes per week • Muscle strengthening activities using major muscle groups at least twice a week • Several hours of light physical activities, including standing	• Should do at least 150–300 minutes of moderate-intensity aerobic physical activity; • or at least 75–150 minutes of vigorous-intensity aerobic physical activity; or an equivalent combination of moderate- and vigorous-intensity activity throughout the week • should also do muscle-strengthening activities at moderate or greater intensity that involve all major muscle groups on 2 or more days a week, as these provide additional health benefits. • may increase moderate-intensity aerobic physical activity to more than 300 minutes; or do more than 150 minutes of vigorous-intensity aerobic physical activity; or an equivalent combination of moderate- and vigorous-intensity activity throughout the week for additional health benefits.
Adults (65+; Additional recommendations)	• As for Adults • Plus, physical activities that challenge balance	• As part of their weekly physical activity, older adults should do varied multicomponent physical activity that emphasises functional balance and strength training at moderate or greater intensity on 3 or more days a week, to enhance functional capacity and to prevent falls

CHAPTER 4.0 – METHODS

4.1 OVERVIEW OF PROTOCOL

This study consists of two collections separated by two weeks. The first collection includes AHAbd measurements and a dynamic fatiguing stair circuit. The second collection consists of VO_2 max (maximal oxygen consumption) testing and a magnetic resonance imaging (MRI) protocol. AHAbd performance and frontal plane kinematics gathered during the first collection were used as the primary analyses to address the hypotheses in this study.

4.2 PARTICIPANTS

As part of a larger data collection, 62 adults (39M/23F, mean age 55.8y ± 19.2, mean height 1.70m ± 0.1, mean weight 72.8kg ± 14.5, mean BMI 25.0 ± 3.7) were recruited from the York University area. 34 of the recruited participants (23 Male: mean age 51.2y (±20.1), mean height 1.75m (±0.1), mean weight 75.9kg (±11.4); 11 Female: mean age 49.3y (±16.8), mean height 1.65m (±0.1), mean weight 63.92kg (±17.5)) were classified as being physically active at the level of the WHO guidelines (>150–300 minutes of moderate-intensity aerobic physical activity or >75–150 minutes of vigorous-intensity aerobic physical activity or an equivalent combination of moderate and vigorous intensity activity per week). These 23 male and 11 female physically active participants were used for the analysis in the current study.

Participants were grouped by age, sex at birth, and LPC. Participants between the ages of 18y and 50y (n=14) were classified as the Younger Adult group, while participants above the age of 50y (n=20) were classified as the Older Adult group. Vazirian (2017) found that grouping participants above and below the age of 50y helped identify age related differences between

younger adults and older adults between the ages of 20y and 70y when examining lumbopelvic kinematics during trunk motions (Vazirian, 2017). LPC was classified as high/low based on the AHAbd performance (scores of 0 or 1 and 2 or 3 respectively). This categorization of high and low AHAbd score has previously been shown to provide the best predictor of clinically relevant findings between high and low scores (Nelson-Wong et al., 2009). Again, to be included in this study, participants were required to be over the age of 18y and be physically active at a level equal to or greater than the (WHO) Physical Activity recommendations (*Table 3.1*). No participants presented with clinically relevant levels of LBP. Participant characteristics by group are summarized in *Table 4.1*.

Including only physically active participants, especially among the older adult population, enabled the attribution of observed differences between age groups to the effects of aging rather than the consequences of prolonged levels of low physical activity and/or sedentary behavior. By focusing on individuals who maintain a higher level of physical activity, this study aimed to focus on the impact of age on LPC, minimizing the confounding variable of inactivity. This approach provided a clearer understanding of how aging specifically affected physical function and control, independent of the detrimental effects associated with a physical inactivity.

Informed consent and a medical clearance form (Physical Activity Readiness Questionnaire; PARQ+) were filled out by each participant prior to completing the study. Any participants that did not pass the PARQ+ screen were required to get approval from a physician to perform the tasks in this study. Any individuals that were not medically cleared were excluded from participation, along with individuals that were unwilling or unable to perform the tasks required in the protocol for this study (e.g. stair climbing, AHAbd, etc.).

Table 4.1: Participant characteristics grouped by All participants combines, just Male or Female participants, and by the research groups of Younger, Middle, and Older Adult

	Group	N	Mean	SD
Age	All	34	50.6	18.9
	Male	23	51.2	20.1
	Female	11	49.3	16.8
	Younger Adult	14	31.0	7.4
	Older Adult	20	64.3	10.1
Height	All	34	1.72	0.1
	Male	23	1.75	0.1
	Female	11	1.65	0.1
	Younger Adult	14	1.74	0.1
	Older Adult	20	1.70	0.1
Weight	All	34	71.97	14.3
	Male	23	75.9	11.4
	Female	11	63.92	17.5
	Younger Adult	14	79.21	16.6
	Older Adult	20	67.29	10.0
BMI	All	34	24.29	3.6
	Male	23	24.80	3.1
	Female	11	23.24	4.6
	Younger Adult	14	25.99	4.1
	Older Adult	20	23.03	2.7
Self-reported Physical Activity level (HUNT1 score; HUNT1 (Trøndelag Health Study)	All	34	9.49	3.5
	Male	23	9.35	3.4
	Female	11	10	3.8
	Younger Adult	14	10.45	4.1
	Older Adult	20	8.82	3.4

4.3 EQUIPMENT AND MEASURES

4.3.1 Overview of Measures

Multiple approaches were used for the acquisition, processing, and analyses in this research project. This study was collected as part of a larger study, hence only the relevant equipment and measures are discussed in detail. Measures that were not of direct interest for the current study include the core strength assessments, balance tests, kinetics, MRI, anthropometrics, and various surveys but were collected as part of the larger data collection. The order of the protocol is outlined in section 4.4 below.

4.3.2 Kinetics

An instrumented three-step stair platform seen in *Figure 4.1* was used for completion of the dynamic fatiguing stair circuit. This platform holds three force plates (AMTI OR6-7, Advanced Mechanical Technology Inc., Watertown, MA, USA) for kinetic measurements during the circuit and to demark the segments of interest during the stair ascent and stair descent. A force plate positioned on the second step of the three-step stair platform, was used for kinetic measurements when ascending and descending the stairs. This stair force plate was used to identify the collection window of interest for the kinematic measures during the stair ascent and descent. This window was from the initial contact to terminal contact of the foot with the force plate during the step up and step down on the stairs. The two force plates located on the bottom level of the platform were used for kinetic measurements when completing the circuit, jumping task, chair rise task, and during 30s single-leg stance assessments. The force plates located on the bottom level of the platform were also used to identify the start and end of each round of the circuit. All kinetics were sampled at 1200Hz. Dimensions of the stair platform can be found in *Figure 4.2*.

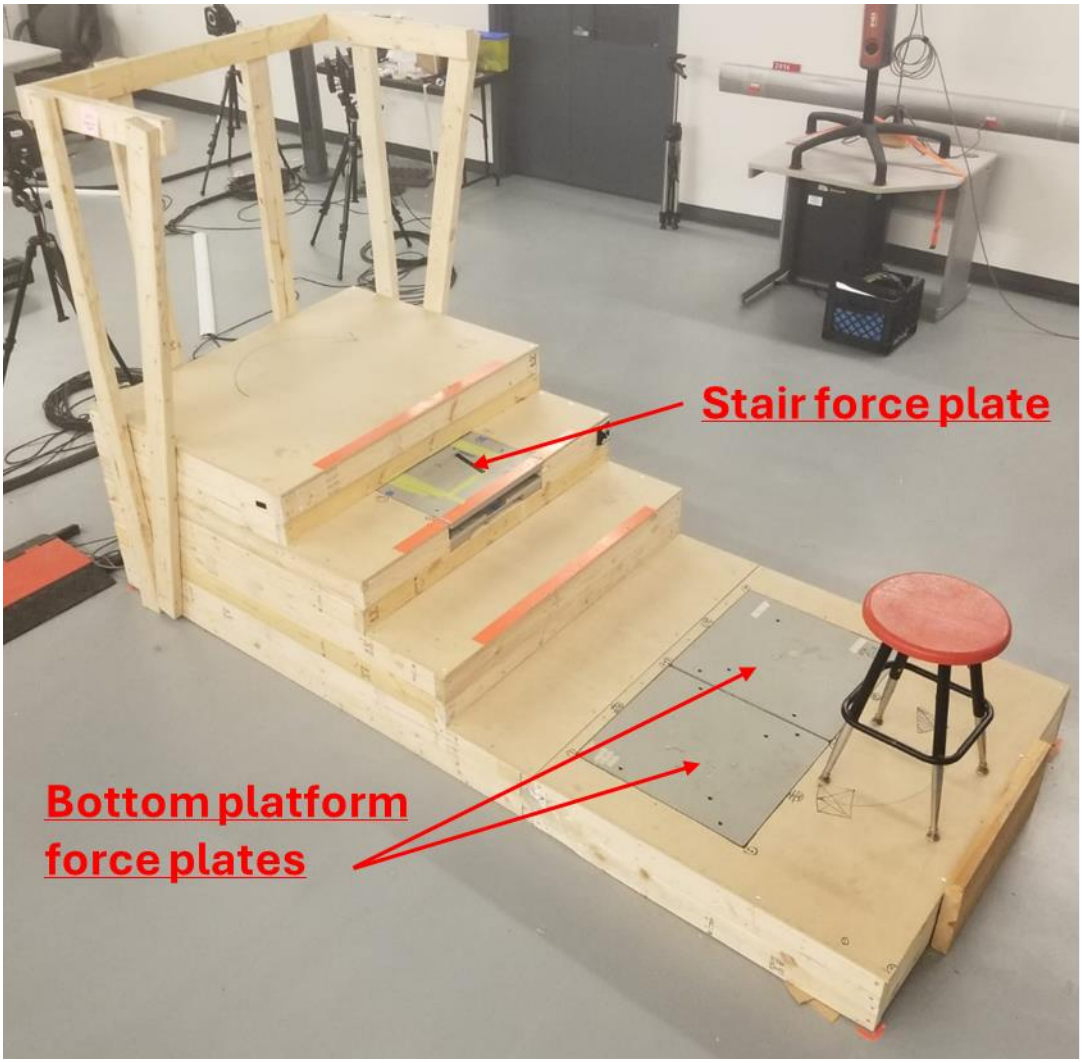

Figure 4.1: Image showing the three-step stair platform

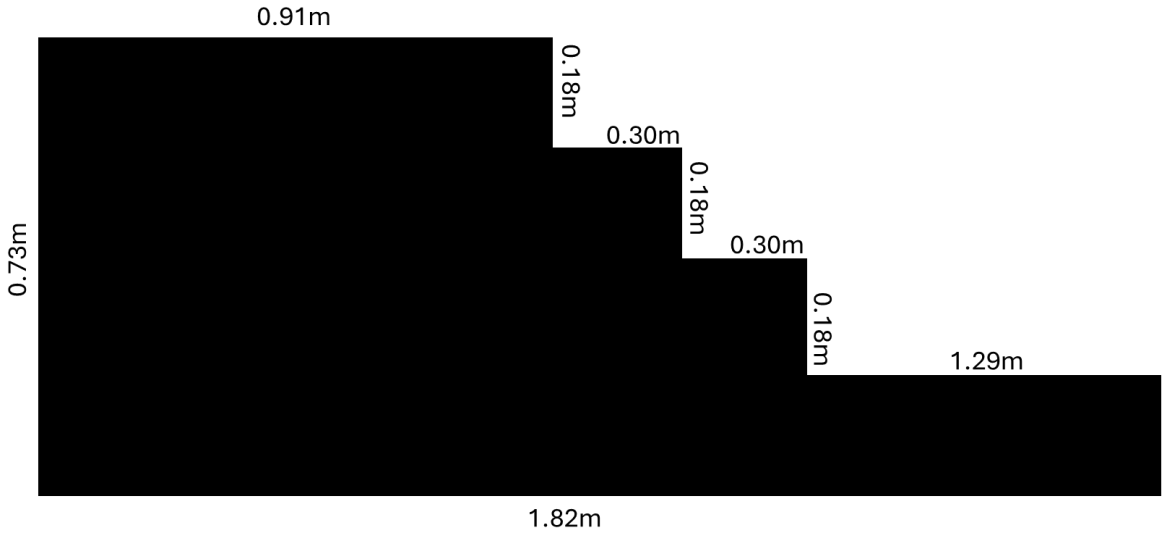

Figure 4.2: Dimensions of the stair platform used in the fatiguing stair circuit

4.3.3 Kinematics

3D kinematic data were collected using five optoelectronic sensors (3DInvestigator™, Northern Digital Inc. (NDI), Waterloo, ON, Canada). These sensors detected data at a sampling rate of 80Hz from 40 active infrared emitting diodes (IREDs) that were grouped into 8 clusters positioned on the body in different locations: trunk, pelvis, left and right thigh, left and right shank, and left and right foot. These clusters of IREDs were used as reference locations for the digitized anatomical locations listed in *Table 4.2* and/or tracking 3D movement of the participants. All landmark locations are in accordance with the IOR full body model.

The processed and modelled kinematic data were used to quantify LPC during the dynamic fatiguing stair circuit. 3D kinematics was quantified, while only the frontal plane kinematics was used in the primary analysis due to the increased demands in that plane while completing stair tasks (Nadeau et al., 2003). All post-processing and modelling of the kinetic and kinematic variables was done using Visual3D (v6.01.34, HAS-Motion Inc., Kingston, ON, CAN).

Table 4.2: Infrared marker cluster and digitized landmark locations for kinematic data collection

SEGMENT	ANATOMICAL LANDMARK
Pelvis	Posterior Superior Iliac Spine (Left & Right)
	Anterior Superior Iliac Spine (Left & Right)
Lumbar	Spinous Process of L1
	Spinous Process of L5
	Top of the lumbar cluster
Thigh	Greater Trochanter (Left & Right)
	Lateral Femoral Epicondyle (Left & Right)
	Medial Femoral Epicondyle (Left & Right)
Shank	Anterior Border of Tibial Tuberosity (Left & Right)
	Head of the Fibula (Left & Right)
	Medial Malleolus (Left & Right)
	Lateral Malleolus (Left & Right)
Foot	1st Metatarsal Head (Left & Right)
	2nd Metatarsal Head (Left & Right)
	5th Metatarsal Head (Left & Right)
	Calcaneus (Left & Right)
Force Platforms	Corners on Left floor force plate
	Corners on Right floor force plate
	Corners of stair force plate

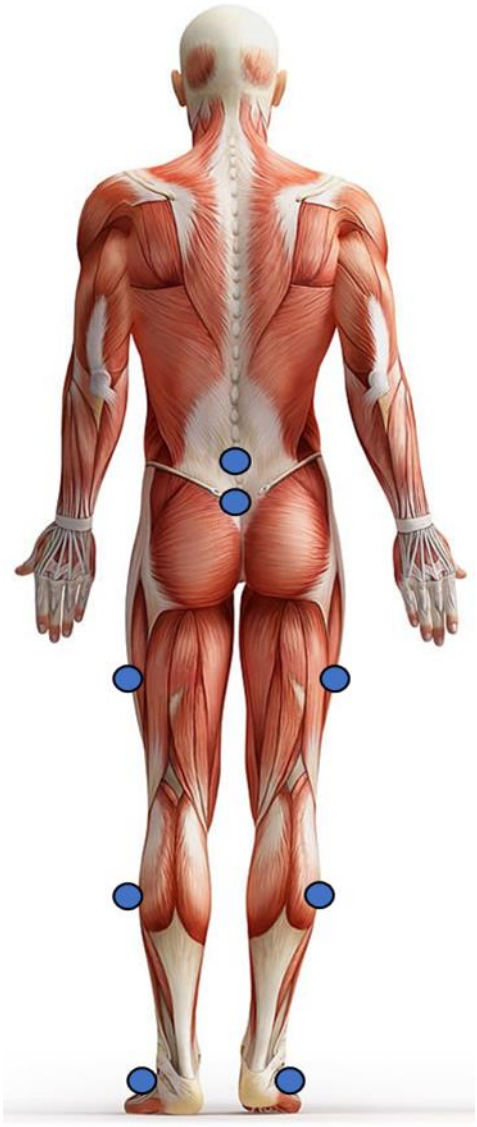

Figure 4.3: Anatomical figure with IRED cluster locations displayed as blue circles

4.3.4 Active Hip Abduction Test

The AHAbd was performed on a massage bed with the participant in a side lying position (*Figure 4.4*). Participants were instructed to keep both lower limbs fully extended with neutral hip rotation and relaxed ankle position. The top upper extremity was rested across the torso with the hand placed on the abdomen. Participants were not allowed to practice the movement prior to assessment. The AHAbd was administered by providing verbal instructions to the participants.

The same verbiage was read to every participant for consistency: *"Please keep your knee straight. Raise your top thigh towards the ceiling, keeping it in-line with the body. Try not to let the pelvis tip forwards or backwards."* The AHAbd was performed with the right and left leg and recorded via camera from the superior sagittal view. The videos were then sent to the AHAbd investigators for scoring (Davis et al., 2011; Nelson-Wong et al., 2009). Additional detail regarding the scoring of the AHAbd can be found in *Table 4.3.*

Figure 4.4: Participant performing the AHAbd test, demonstrating good control (score of 0) with the starting position (left), and top position (right) shown

Table 4.3: Scoring Criteria for the Active Hip Abduction Test as Provided to Raters (Nelson-Wong et al., 2009, *Table 1*)

Score	Cue for Examiner
0, Able to maintain position of pelvis in the frontal plane	Smoothly and easily performs movement; lower extremities, pelvis, trunk, and shoulders remain aligned in the frontal plane.
1, Minimal loss of pelvis position in the frontal plane	Slight wobble at initiation or throughout movement; may show noticeable effort or "ratcheting" of moving limb.
2, Moderate loss of pelvis position in the frontal plane	Has at least 2 of the following: noticeable wobble throughout movement; tipping of pelvis, trunk, or shoulder rotation; increase hip flexion and/or rotation of the moving limb; rapid or uncontrolled movement.
3, Severe loss of pelvis position in the frontal plane	Has more than 3 of the above characteristics and/or unable to regain control of movement once lost or may lose balance (has to place hand on table).

4.3.5 Activity Level

All participants completed the HUNT1 questionnaire (Trøndelag Health Study) as a self-reported indirect measure of physical activity. This survey asks questions regarding exercise duration and intensity and may provide a more accurate representation of an individuals yearly physical activity level when compared to directly measured physical activity devices such as the Actigraph device (Actigraph GTx9, Pensacola, FL, USA) being worn for seven consecutive days in this study. Although objective measures of physical activity are more accurate, they only collect data from the period when the device is being worn. Because many of the participants in this study were seasonal athletes, the HUNT1 was thought to provide a better representation of annual physical activity levels. The HUNT1 was used to quantify the level of physical activity using minutes of moderate or vigorous physical activity per week. This allowed for a comparison to the WHO physical activity guidelines that recommend adults over the age of 18y should do at least 150–300 minutes of moderate-intensity aerobic physical activity or at least 75–150 minutes

of vigorous-intensity aerobic physical activity or an equivalent combination of moderate and vigorous intensity activity each the week (World Health Organization, 2022).

The remaining collected measures, while not included in the current analysis, offer valuable insight for participant characterization and hold potential for future data exploration in subsequent research: additional objective and subjective measures of physical activity, aerobic capacity, core endurance, single-leg stance, imaging, and anthropometric measurements.

4.4 PROTOCOL

Visit 1:

Participants began visit one by signing consent and medical clearance forms (PARQ+), followed by a self-selected warm-up. Following the warm-up, participants performed the four core endurance assessments (front plank, left & right side plank, and Biering Sorenson test). The AHAbd was then performed and filmed for review by the investigators. For all the following tasks in Visit 1, a Full Body Harness (Petzl NEWTON) was offered to all participants.

The NDI infrared markers were then positioned on the body of the participant. Before beginning the fatiguing stair circuit, a 30s single-leg stance assessment was performed on both legs, along with baseline kinematic and kinetic measurements that included two sit-to-stands, two stair ascents, two stair descents, and three maximal vertical jumps. Prior to the maximal vertical jumps, submaximal practice jumps were performed with increasing intensity as a warm-up, continuing until they felt comfortable and ready to proceed.. The baseline measures and warm-up jumps likely reduced learning effects during the circuit. Once baseline kinetic and kinematic values were collected, participants began the dynamic fatiguing stair circuit. This

circuit consisted of three chair rises followed by a stair ascent and descent that were performed at a self-selected casual pace. The set of three chair rises and stair ascent/descent were repeated twice to complete one round of the circuit. Participants carried out continuous rounds of the circuit for 15 minutes, performing a maximal vertical jump between every round. The entire circuit was completed on the three-step stair platform show in *Figure 4.1*.

Following the termination of the circuit and a self-selected rest period, participants completed questionnaires. Between visits 1 and 2, participants wore the Actigraph activity monitor (Actigraph GTx9, Pensacola, FL, USA) for seven consecutive days as a direct measure of physical activity.

Visit 2:

Participants begin visit 2 by completing the MR imaging. The ~45-minute session consists of 4 images (trunk, pelvis, thigh, and shank). After completing the imaging, participants completed a direct assessment of their aerobic capacity via VO_2 max performed on a treadmill. The Petzl NEWTON Full Body Harness (Petzl) used in Visit 1 was also offered to all participants for this test. The VO_2 max protocol began with a 4-minute walking warm-up at one percent inclination. Following the warm-up, participants were brought to a comfortable jogging pace that they could sustain for roughly 20min. The inclination was then raised by two percent every 2min. The test was terminated when a participant could not complete a 2min stage or if the participant indicated that they would not be able to complete the following 2min stage. An outline of the protocol, including the fatiguing stair circuit can be found in *Figure 4.6*.

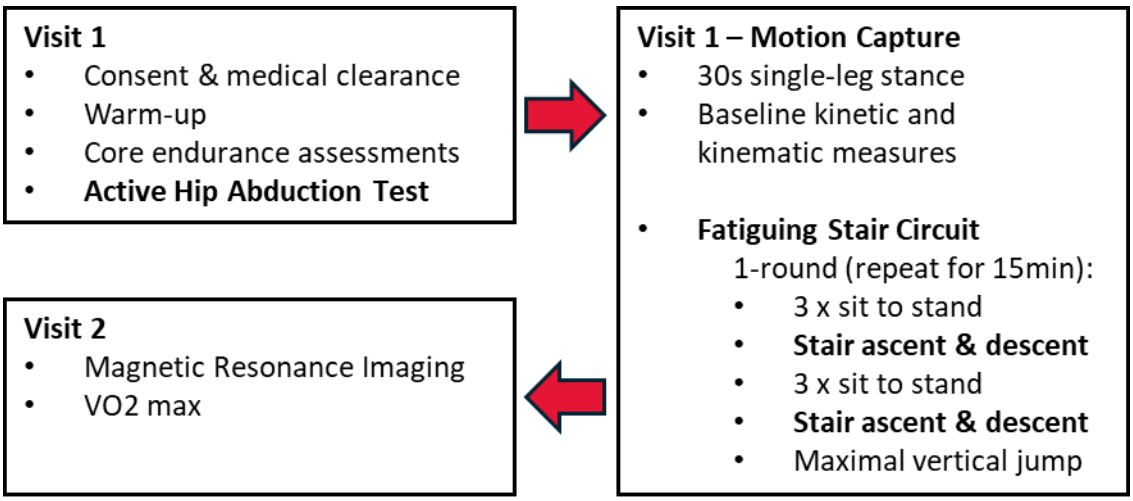

Figure 4.5: Outline of the protocol for Visits 1 and Visit 2 with important measures in bold (AHAbd, stair ascent, and stair descent)

4.5 PROCESSING & ANALYSIS

Each AHAbd video was scored twice by two investigators to examine interrater and intrarater reliability (Davis et al., 2011). The AHAbd test is scored on a scale from 0 to 3, with a higher score being worse and indicating lumbopelvic instability (*Table 1.0*; Davis et al., 2011; Nelson-Wong et al., 2009). For every participant, the score from the worse of the two sides was used for analysis. When there was a discrepancy between score in the first and second round of scoring, the examiner watched the video for a third time and assigned a consensus score. The two examiners compared their consensus scores to assess any discrepancies. When discrepancies were found, the video was watched again by both examiners and a new consensus score was assigned (Davis et al., 2011). Intrarater and interrater reliability was assessed for the scoring of the AHAbd tests by comparing the scores between the first and second round of scoring for each examiner and by comparing the consensus scores between examiners. Higher scores are

associated with negative health outcomes and so are considered a positive result (Davis et al., 2011). In the analysis for this study, individuals with scores of 0 and 1 are grouped (High LPC, negative result), and individuals with scores of 2 and 3 are grouped (Low LPC, positive result) to indicate a positive or negative result, respectively (Nelson-Wong et al., 2009).

Using Visual3D (v6.01.34, HAS-Motion Inc., Kingston, ON, CAN), maximum change in lumbopelvic angle was quantified for stair ascents and stair descent. This will be done for the first and last round of the circuit for each participant. After filtering the kinematic data using a 10Hz lowpass Butterworth filter and interpolating the data up to 8 frames, quantification of maximum lumbopelvic angle was done by finding the difference between the lowest and largest lumbopelvic angle experienced during a single step while performing the stair ascent and stair descent. The window for a single step was from the initial foot contact to terminal foot contact with the stair force plate. By gathering measures during the first and last round of the fatiguing circuit, it allowed for a comparison of lumbopelvic measures from fresh to fatigued (*Figure 4.7*).

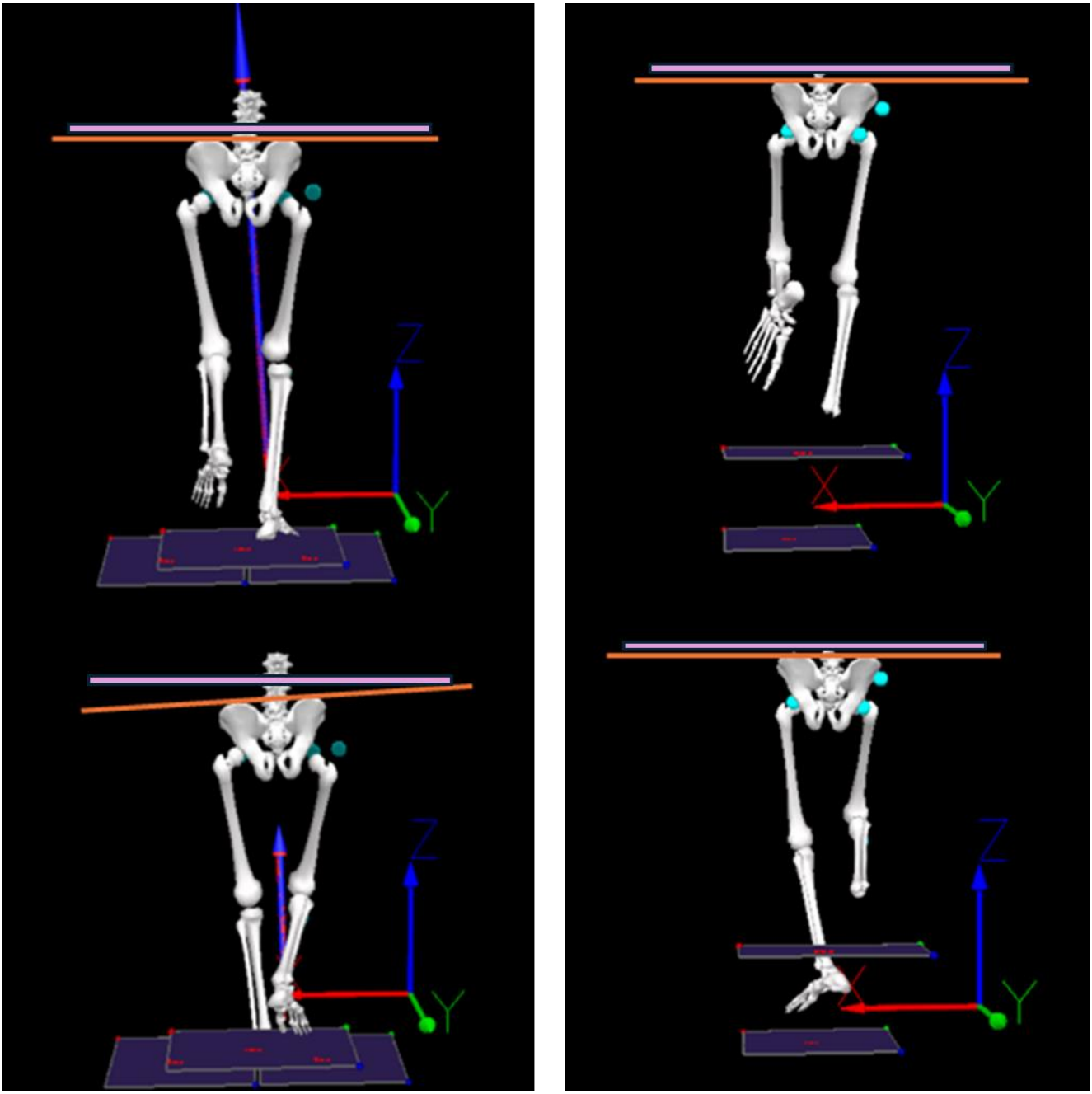

Figure 4.6: Visualization of participants performing stair descent, modeled in Visual3D. The pink lines represent horizontal alignment, while the orange lines depict pelvic angles in the frontal plane. The participant on the left exhibits a greater change in lumbopelvic angle compared to the minimal change observed in the participant on the right.

Enoka and Duchateau (2008) suggest that in research on task failure, rate-limiting adjustments can be detected by comparing two different groups performing the same task, as well as by analyzing one group performing the same task both before and after undergoing an intervention. The analysis in this study aimed to do that using the following statistical tests.

A 3-way analysis of variance (ANOVA) between Age Group (low: 18y-50y, high: 50y+), AHAbd Group (good: scores of 0 & 1, poor: scores of 2 & 3) and Sex (Male, Female) was used to see if these factors have an effect on maximum change in lumbopelvic angle. This analysis was completed six times to examine measures at different points in the stair circuit: Maximum change in lumbopelvic angle during the first stair ascent, maximum change in lumbopelvic angle during the first stair descent, maximum change in lumbopelvic angle during the last stair ascent, maximum change in lumbopelvic angle during the last stair descent, difference in maximum change of lumbopelvic angle between the first and last stair ascent, and difference in maximum change of lumbopelvic angle between the first and last stair descent.

No post-hoc tests were performed because each factor in the analysis (Age Group, AHAbd Group, and Sex) had only two levels. Post-hoc tests can be used to determine which specific groups differ from each other after a significant effect is found in factors containing more than two levels. In this case, with only two levels per factor, any significant effect can be interpreted without the need for examination of additional comparisons.

Effect sizes for each ANOVA were examined using Partial Eta Squared (η^2) values. Partial Eta Squared (η^2) were used to estimate effect sizes of small (0.01), medium (0.06), and large (0.14) using the ANOVA guidelines set by Cohen (Cohen, 1988). Cohen's (1998) guidelines for effect size interpretation was used in this study to ensure that magnitude of overserved effects was quantified using a widely recognized standardized framework. These

guidelines categorize effect size as small (η^2=.01), medium (η^2=.06), and large (η^2=.14), and provide comparability with existing biomechanics literature (Cohen, 1988; Sorensen et al., 2016). Sorensen and colleagues (2016) used the Cohen (1988) guidelines to categorize effect size for their study on asymmetry of lumbopelvic movement patterns during active hip abduction examining low back pain development during standing.

Paired T-tests examining the difference in maximum change in lumbopelvic angle between the first and last round of the fatiguing circuit was also completed for stair ascents and stair descents. This was to assess fatigue-related changes across all participants.

CHAPTER 5.0 – RESULTS

5.1 MAXIMUM CHANGE IN LUMBOPELVIC ANGLE DURING THE FIRST STAIR ASCENT

The 3-way ANOVA examining the maximum change in lumbopelvic angle during the first stair ascent found no significant effects across age, sex, and AHAbd score. The interaction effects between Age Group and Sex (F=.919, p=.347), Age Group and AHAbd Group (F=1.851, p=.185), and Sex and AHAbd Group (F=.000, p=.990) were all not significant. There were also no main effects of Age Group (F=3.078, p=.091), Sex (F=.051, p=.823), and AHAbd Group (F=.284, p=.599) on maximum change in lumbopelvic angle during the first stair ascent of the fatiguing stair circuit (*Table 5.1, Table 5.2*).

Table 5.1: Between Subject Factors (maximum change in lumbopelvic angle during the first stair ascent)

		N
Age Group	Old	20
	Young	14
AHAbd Group	Bad	17
	Good	17
Sex	Female	11
	Male	23

Table 5.2: Tests of Between-Subjects Effects (maximum change in lumbopelvic angle during the first stair ascent)

Factor	F	Sig.
Age Group	3.078	.091
AHAbd Group	.284	.599
Sex	.051	.823
Age Group * AHAbd Group	1.851	.185
Age Group * Sex	.919	.347
AHAbd Group * Sex	.000	.990
Age Group * AHAbd Group * Sex	.634	.433

Examining effect sizes using Cohen's guidelines (Cohen, 1988) revealed a small effect size for the interaction effect of Age Group and Sex (η^2=.034) and the main effect of AHAbd Group (η^2=.011). There is an estimated medium effect size for the interaction effect of Age Group and AHAbd Group (η^2=.066) and for the main effect of Age Group (η^2=.106; *Table 5.3*).

Table 5.3: Partial Eta Squared (η^2) values for Tests of Between-Subjects Effects (maximum change in lumbopelvic angle during the first stair ascent)

Factor	η^2
Age Group	.106
AHAbd Group	.011
Sex	.002
Age Group * AHAbd Group	.066
Age Group * Sex	.034
AHAbd Group * Sex	.000
Age Group * AHAbd Group * Sex	.024

5.2 MAXIMUM CHANGE IN LUMBOPELVIC ANGLE DURING THE FIRST STAIR DESCENT

When examining the first stair descent, there was a significant interaction effect between Age Group and AHAbd Group (F=9.869, p=.005; *Figure 5.1*). Younger adults with good AHAbd scores had significantly greater change in lumbopelvic angle during the first stair descent when compared to younger adults with poor AHAbd scores (This relationship was not significant among older adults). There were no significant interaction effects between Age Group & Sex (F=.060, p=.808), and Sex and AHAbd Group (F=2.042, p=.167). There were no significant main effects of Age Group (F=.031, p=.863), Sex (F=.121, p=.731), or AHAbd Group (F=1.954, p=.176) on maximum change in lumbopelvic angle during the first stair descent (*Table 5.4, Table 5.5*).

Table 5.4: Between Subject Factors (maximum change in lumbopelvic angle during the first stair decent)

Factor		N
Age Group	Old	19
	Young	11
AHAbd Group	Bad	16
	Good	14
Sex	Female	10
	Male	20

Table 5.5: Tests of Between-Subjects Effects (maximum change in lumbopelvic angle during the first stair descent)

Factor	F	Sig.
Age Group	.031	.863
AHAbd Group	1.954	.176
Sex	.121	.731
Age Group * AHAbd Group	9.869	.005
Age Group * Sex	.060	.808
AHAbd Group * Sex	2.042	.167
Age Group * AHAbd Group * Sex	2.220	.150

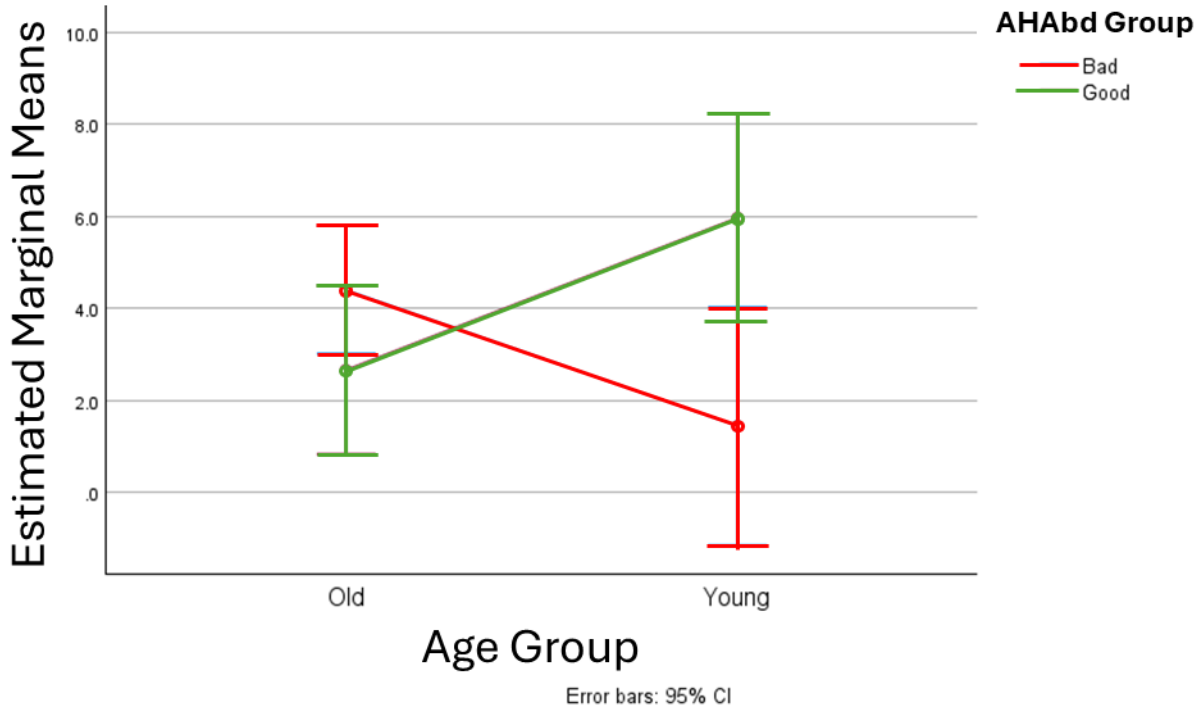

Figure 5.1: Younger adults with good AHAbd scores had significantly greater change in lumbopelvic angle during the first stair descent when compared to younger adults with poor AHAbd scores

There are estimated large effect sizes for the significant interaction effect of Age Group and AHAbd Group (η^2 =.310). An outline of all η^2 values for the factors examining maximum change in lumbopelvic angle during the first stair descent can be found in *Table 5.6.*

Table 5.6: Partial Eta Squared (η^2) values for Tests of Between-Subjects Effects (maximum change in lumbopelvic angle during the first stair descent)

Factor	η^2
Age Group	.001
AHAbd Group	.082
Sex	.005
Age Group * AHAbd Group	.310
Age Group * Sex	.003
AHAbd Group * Sex	.085
Age Group * AHAbd Group * Sex	.092

5.3 MAXIMUM CHANGE IN LUMBOPELVIC ANGLE DURING THE LAST STAIR ASCENT

No significant interaction effects were found between Age Group and Sex (F=.293, p=.593), Age Group and AHAbd Group (F=0.005, p=.945), and Sex and AHAbd Group (F=.236, p=.631) in the 3-way ANOVA examining the maximum change in lumbopelvic angle during the last stair ascent. The only significant main effect was Age Group (F=6.771, p=.015). The main effects for Sex (F=1.168, p=.290), and AHAbd Group (F=1.339, p=.258) were not significant. (*Table 5.7, Table 5.8*).

Table 5.7: Between Subject Factors (maximum change in lumbopelvic angle during the last stair ascent)

Factor		N
Age Group	Old	20
	Young	14
AHAbd Group	Bad	11
	Good	23
Sex	Female	17
	Male	17

Table 5.8: Tests of Between-Subjects Effects (maximum change in lumbopelvic angle during the last stair ascent)

Factor	F	Sig.
Age Group	6.771	.015
AHAbd Group	1.168	.290
Sex	1.339	.258
Age Group * AHAbd Group	.293	.593
Age Group * Sex	.005	.945
AHAbd Group * Sex	.236	.631
Age Group * AHAbd Group * Sex	.694	.421

When examining maximum change in lumbopelvic angle during the last stair descent, an estimated small effect size was found for the interaction effect of Sex and Age Group (η^2=.11) and the main effects of Sex (η^2=.043) and AHAbd Group (η^2=0.049). A large effect size is estimated for the main effect of Age Group (*Table 5.9*).

Table 5.9: Partial Eta Squared (η^2) values for Tests of Between-Subjects Effects (maximum change in lumbopelvic angle during the last stair ascent)

Factor	η^2
Age Group	.207
AHAbd Group	.049
Sex	.043
Age Group * AHAbd Group	.000
Age Group * Sex	.011
AHAbd Group * Sex	.009
Age Group * AHAbd Group * Sex	.026

5.4 MAXIMUM CHANGE IN LUMBOPELVIC ANGLE DURING THE LAST STAIR DESCENT

The 3-way ANOVA examining the maximum change in lumbopelvic angle during the last stair descent found no significant interaction effects between Age Group and Sex (F=.153, p=.700), Age Group and AHAbd Group (F=.012, p=.914), and Sex and AHAbd Group (F=1.599, p=.219). There were also no main effects of Age Group (F=.009, p=.925), Sex (F=1.232, p=.279), and AHAbd Group (F=.472, p=.499) on maximum change in lumbopelvic angle during the last stair descent of the fatiguing stair circuit (*Table 5.10, Table 5.11*).

Table 5.10: Between Subject Factors (maximum change in lumbopelvic angle during the last stair descent)

Factor		N
Age Group	Old	19
	Young	11
AHAbd Group	Bad	10
	Good	20
Sex	Female	16
	Male	14

Table 5.11: Tests of Between-Subjects Effects (maximum change in lumbopelvic angle during the last stair descent)

Factor	F	Sig.
Age Group	.009	.925
AHAbd Group	1.232	.279
Sex	.472	.499
Age Group * AHAbd Group	.153	.700
Age Group * Sex	.012	.914
AHAbd Group * Sex	1.599	.219
Age Group * AHAbd Group * Sex	.154	.699

The interaction effect between Sex and AHAbd Group has an estimated medium effect size (η^2=.068). The effect size for the main effects of Sex (η^2=.053) and AHAbd Group (η^2=.021) was small (*Table 5.12*).

Table 5.12: Partial Eta Squared (η^2) values for Tests of Between-Subjects Effects (maximum change in lumbopelvic angle during the last stair descent)

Factor	η^2
Age Group	.000
AHAbd Group	.021
Sex	.053
Age Group * AHAbd Group	.001
Age Group * Sex	.007
AHAbd Group * Sex	.068
Age Group * AHAbd Group * Sex	.007

5.5 DIFFERENCE IN MAXIMUM CHANGE IN LUMBOPELVIC ANGLE FROM THE FIRST STAIR ASCENT TO LAST STAIR ASCENT

The analysis of the difference in maximum change in lumbopelvic angle during stair ascent between the first and last round of the fatiguing stair circuit using a 3-way ANOVA found no significant findings when in the interaction effects between Age Group and AHAbd Group (F=.2.248, p=.146), Age Group and Sex (F=2.742, p=.110), and Sex and AHAbd Group (F=.365, p=.551). Main effects of Age Group (F=1.799, p=.191), Sex (F=2.400, p=.133), and AHAbd Group (F=3.850, p=.061) were not significant (*Table 5.13*, *Table 5.14*).

Table 5.13: Between Subject Factors (difference in maximum change in lumbopelvic angle from the first stair ascent to the last stair ascent)

Factor		N
Age Group	Old	20
	Young	14
AHAbd Group	Bad	17
	Good	17
Sex	Female	11
	Male	23

Table 5.14: Tests of Between-Subjects Effects (difference in maximum change in lumbopelvic angle from the first stair ascent to the last stair ascent)

Factor	F	Sig.
Age Group	1.799	.191
AHAbd Group	3.850	.061
Sex	2.400	.133
Age Group * AHAbd Group	2.248	.146
Age Group * Sex	2.742	.110
AHAbd Group * Sex	.365	.551
Age Group * AHAbd Group * Sex	3.392	.077

Partial Eta Squared values outlined in *Table 5.15* revealed low estimated effect size for the interaction effect of AHAbd Group and Sex (η^2=.014. A medium effect size was found for the interaction effects of Age Group and Sex (η^2=.095) and Age Group and AHAbd Group (η^2=.080), and for the main effects of Sex (η^2=.084, Age Group (η^2=.065), and AHAbd Group (η^2=.129).

Table 5.15: Partial Eta Squared (η^2) values for Tests of Between-Subjects Effects (difference in maximum change in lumbopelvic angle from the first stair ascent to the last stair ascent)

Factor	η^2
Age Group	.065
AHAbd Group	.129
Sex	.084
Age Group * AHAbd Group	.080
Age Group * Sex	.095
AHAbd Group * Sex	.014
Age Group * AHAbd Group * Sex	.115

A paired T-test examining the difference in maximum change in lumbopelvic angle between the first and last round of the fatiguing circuit was completed for stair ascents (p=.087) examining the entire participant pool and was found to be insignificant, meaning there was not a significant amount of change in lumbopelvic angle throughout the circuit.

5.6 DIFFERENCE IN MAXIMUM CHANGE IN LUMBOPELVIC ANGLE FROM THE FIRST STAIR DESCENT TO LAST STAIR DESCENT

There was a significant interaction effect between Age Group and AHAbd Group (F=13.919, p=.001; *Figure 5.2*), and Sex and AHAbd Group (F=8.441, p=.008; *Figure 5.3*) when examining the difference in maximum change in lumbopelvic angle between the first and last

stair descent as the dependent variable. Younger adults with poor AHAbd scores had significantly greater change in lumbopelvic angle from the first to last stair descent when compared to younger adults with good AHAbd scores (this was not significant in older adults). Females with poor AHAbd scores also had a greater change in lumbopelvic angle from the first to last stair descent when compared to Females with good AHAbd scores (this relationship was not significant when examining Males). There was no interaction effect between Age Group and Sex (F=.434, p=.517). AHAbd Group was the only main effect (F=5.458, p=.029), with no significant main effects seen when examining Sex (F=.355, p=.557), or AHAbd Group (F=5.458, p=.029; (*Table 5.16, Table 5.17*).

Table 5.16: Between Subject Factors (difference in maximum change in lumbopelvic angle from the first stair descent to the last stair descent)

Factor		N
Age Group	Old	19
	Young	11
AHAbd Group	Bad	16
	Good	14
Sex	Female	10
	Male	20

Table 5.17: Tests of Between-Subjects Effects (difference in maximum change in lumbopelvic angle from the first stair descent to the last stair descent)

Factor	F	Sig.
Age Group	.016	.901
AHAbd Group	5.458	.029
Sex	.355	.557
Age Group * AHAbd Group	13.919	.001
Age Group * Sex	.434	.517
AHAbd Group * Sex	8.441	.008
Age Group * AHAbd Group * Sex	2.121	.159

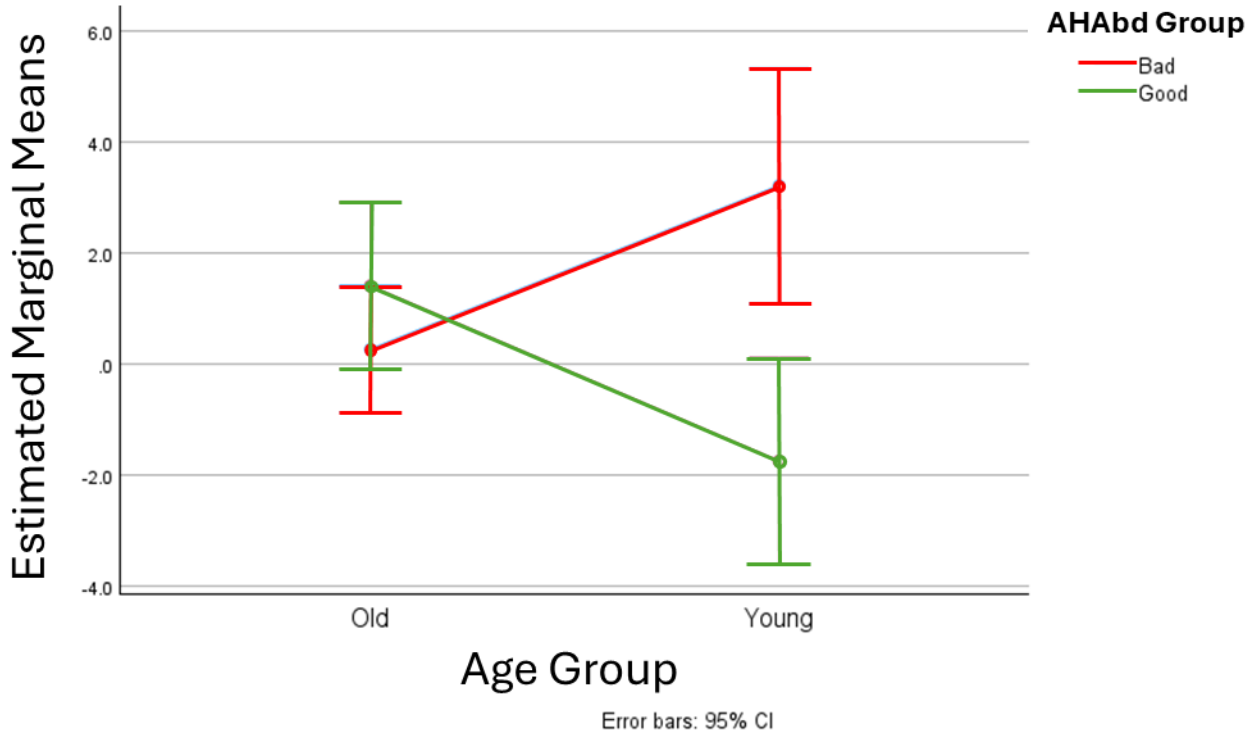

Figure 5.2: Younger adults with poor AHAbd scores had significantly greater change in lumbopelvic angle from the first to last stair descent when compared to younger adults with good AHAbd scores

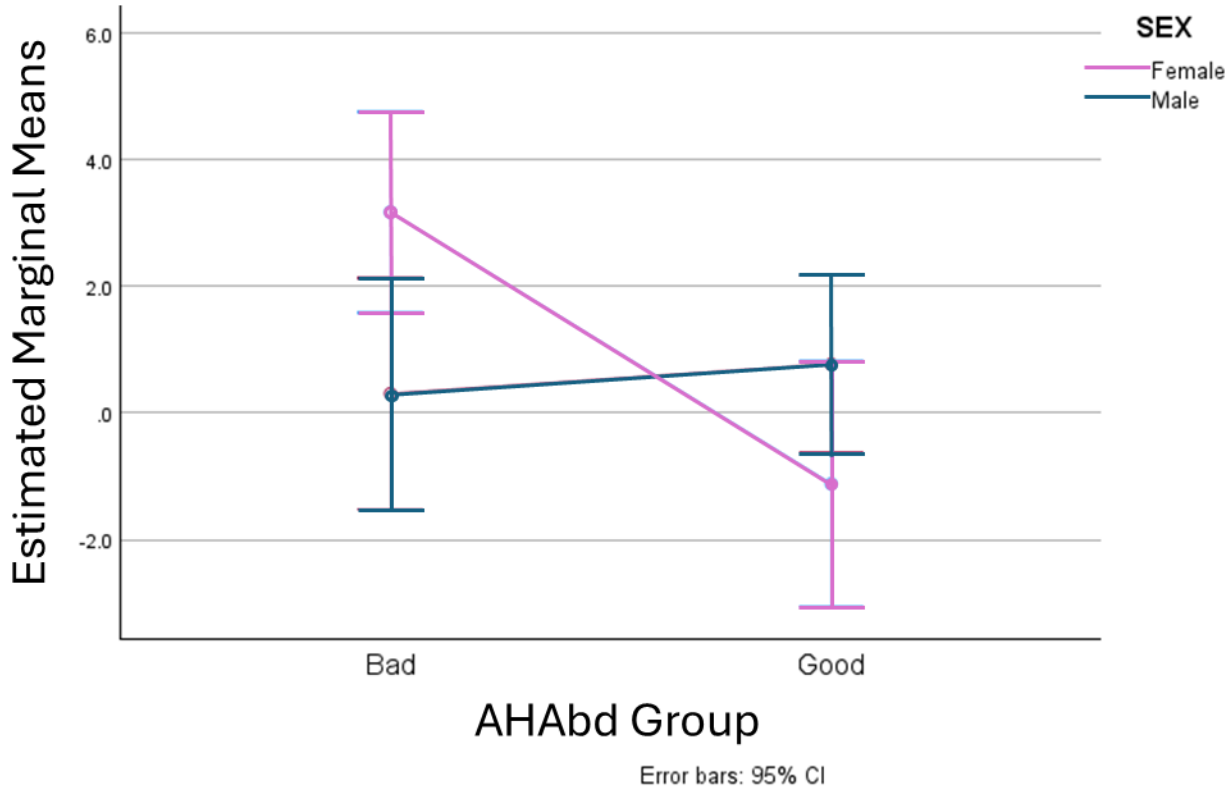

Figure 5.3: Females with poor AHAbd scores had a greater change in lumbopelvic angle from the first to last stair descent when compared to Males with poor AHAbd scores

An examination of estimated effect sizes provides more insight into the significant interaction effects between Age Group and AHAbd Group (η^2=.387), and AHAbd Group and Sex (η^2=.277). These large effect sizes suggest that the interactions have substantial practical significance, highlighting the importance of these variables in the analysis. An outline of the η^2 values can be found in *Table 5.18*.

Table 5.18: Partial Eta Squared (η^2) values for Tests of Between-Subjects Effects (difference in maximum change in lumbopelvic angle from the first stair descent to the last stair descent)

Factor	η^2
Age Group	.001
AHAbd Group	.199
Sex	.016
Age Group * AHAbd Group	.387
Age Group * Sex	.019
AHAbd Group * Sex	.227
Age Group * AHAbd Group * Sex	.088

A paired T-test examining the difference in maximum change in lumbopelvic angle between the first and last round of the fatiguing circuit was also completed for stair descents (p=.321). Similar to stair ascending, this T-test revealed no significant findings, indicating that fatigue-related changes in angular displacements of the lumbopelvic region in the frontal plane were not evident.

5.7 ACTIVE HIP ABDUCTION TEST SCORING

Of the 33 participants that completed the AHAbd, four (12%) were given a score of 0, twelve (36%) presented as scores of 1, thirteen (39%) achieved a score of 2, and the remaining four (12%) scored a 3 on the test. Among the 33 participants, fourteen (42%) had an asymmetry between sides identified by different scores for the right and left leg on the AHAbd. Eight (24%) of these individuals had an asymmetry with a different grouping (good, bad) for each leg (i.e. one leg was scored 0 or 1 and the other leg was scored 2 or 3).

There was a total of four discrepancies in AHAbd score between the two examiners across the 66 tests that were scored (6%; 33 participants, left and right leg). These videos were

watched again by the two examiners with a third-party present and assigned a consensus scores. None of the assigned consensus scores resulted in a change in AHAbd grouping.

CHAPTER 6.0 – DISCUSSION

The primary objective of this study was to investigate the relationship between LPC and the ability to perform dynamic tasks in young and older adults. Specifically, we aimed to determine whether the AHAbd test could effectively predict LPC levels during a fatiguing stair circuit and to examine how LPC varies with age, fatigue, and sex. Validating the use of the AHAbd as an assessment of dynamic tasks may be useful for identifying pre-clinical populations that may be at risk for the development of clinically relevant findings such as LBP. Identifying pre-clinical individuals, especially among an older population can be highly important for injury prevention and the prolonged maintenance of functional abilities. This study aimed to answer the following questions:

Research Questions:

1. Is the level of LPC identified by the AHAbd an indicator of the level of LPC quantified using frontal plane kinematics during a dynamic stair task?
2. Is there an impact of age on frontal plane kinematics when the level of LPC identified by AHAbd performance is controlled for?
3. Is the level of LPC identified by the AHAbd an indicator of the amount of change in frontal plane kinematics between the first round and the last round of a dynamic fatiguing stair circuit?

6.1 LUMBOPELVIC CONTROL AND AGE

Contrary to other studies looking at the effect of age on LPC, the analysis in this study found that age did not have many significant interaction effects when examining lumbopelvic angles under different conditions. (Bryant et al., 2018; Crawford et al., 2018; Vazirian, 2017). While younger adults did see significant differences in lumbopelvic angles during stair descents between participants with high and low AHAbd scores, these relationships were not significant among the older adults and suggest that performance on a clinical test of LPC (AHAbd) may not have a strong relationship with LPC during dynamic tasks in aging populations.

The effect of age on lumbopelvic angle may have been diminished in this study due to the participants being physically active. In older adults, general physical activity has a positive impact on strength and power (Ramsey et al., 2021) which are especially important for completing stair tasks. Previous research has found differences in lumbopelvic range of motion and mobility between younger adults and adults over the age of 50y (Bryant et al., 2018; Crawford et al., 2018; Pries et al., 2015; Vazirian, 2017). These findings underscore the importance of maintaining physical activity to preserve lumbopelvic function and mobility in older adults.

The young adults and older adults in this study do a similar amount of weekly physical activity when measured by HUNT1 score. Because there was a lack of significant findings between the younger and older adults it points to the importance of physical activity in maintaining functional ability and reduce age-related declines in the lumbopelvic region.

6.2 LUMBOPELVIC CONTROL AND ACTIVE HIP ABDUCTION

The AHAbd has already been shown to identify clinical and pre-clinical populations (Nelson-Wong et al., 2009; Nelson-Wong & Callaghan, 2010b), but the results of this study may help identify pre-clinical populations based on LPC loss during a dynamic task. Individuals lacking dynamic LPC may be at risk for future development of clinically relevant findings, such as LBP and standing intolerance. Examining the relationship between AHAbd score and a fatiguing circuit may indicate the ability of the AHAbd to identify fatigue related changes in LPC. The association between the AHAbd and dynamic tasks in older adults builds on the body of knowledge already established on the AHAbd (Babiolakis et al., 2015; Davis et al., 2011; Nelson-Wong et al., 2009; Nelson-Wong & Callaghan, 2010b).

The AHAbd did not seem to be a significant predictor of LPC during the stair tasks performed in this study for the older adult population. In the younger population it was found that younger adults with good AHAbd scores had significantly greater change in lumbopelvic angle during the first stair descent when compared to younger adults with poor AHAbd scores. It was also found that younger adults with poor AHAbd scores had significantly greater change in lumbopelvic angle from the first to last stair descent when compared to younger adults with good AHAbd scores. Both of these significant findings had estimated large effect sizes (0.310 and 0.387, respectively) meaning that the differences observed were substantial and meaningful within the context of this study. Both of these significant findings were not significant in the older adult population. This suggests that the relationship between the AHAbd and frontal plane lumbopelvic kinematics may be diminished with increased age.

The relationship between poor AHAbd scores and dynamic LPC may be stronger among females. Females with poor AHAbd scores had a greater change in lumbopelvic angle from the

first to last stair descent when compared to Males with poor AHAbd scores. This was the only significant difference found between sexes but did have a large estimated effect size (0.277) meaning that the observed difference between females and males with poor AHAbd scores during the stair descents was substantial and likely to be meaningful in understanding sex-specific differences in LPC.

The lack of significant relationships between increased age and AHAbd performance may be because the participants recruited for this study perform enough weekly physical activity to avoid significant compensatory lumbopelvic movements in the frontal plane during relatively low intensity stair tasks, even if their ability to maintain control during the AHAbd was not at a high level. In a less active population, a stronger relationship between stair measures in the frontal plane and the AHAbd may be present. The participants in this study are familiar and proficient at performing dynamic unilateral tasks using various amounts of lower limb power which may aid in their ability to perform stair tasks without presenting significant compensation in the lumbopelvic region.

The fatiguing stair circuit used in this study may also have been too short in duration for any changes in lumbopelvic angle to occur between older adults with good AHAbd scores (0, 1) and older adults with poor AHAbd scores (2, 3; Davis et al., 2011). The AHAbd was shown to be an indicator of LPC in prolonged relatively static upright tasks and was proficient at identifying individuals that experience clinically relevant levels of LBP and standing intolerance (Nelson-Wong et al., 2009). If a longer fatiguing protocol was used in this study, it way have uncovered stronger relationships between AHAbd performance and LPC.

This was the first study that examined the use of the AHAbd to compare young adults to older adults. This was also the first study to examine the use of the AHAbd as a predictor of

control during a dynamic task. While the AHAbd test has been useful in identifying clinical and pre-clinical populations with lumbopelvic instability (Nelson-Wong et al., 2009; Nelson-Wong & Callaghan, 2010b), its applicability in predicting LPC under dynamic and fatigued conditions may be limited and requires further investigation.

6.3 LUMBOPELVIC CONTROL AND FATIGUE

This study only found significant interaction effect for Age Group and AHAbd Group, and AHAbd Group and Sex when examining the change between the first and last rounds of the stair circuit. These relationships were also only found for stair descent. This suggests that fatigue may not have as profound an impact on LPC as hypothesized, or that the fatigue protocol being used was insufficient to elicit noticeable changes in LPC. Contrary to the findings of this study, Papa and colleagues found that fatigue caused significant detrimental effects on lower extremity joint kinematics during simulated falls (Papa et al., 2015). Another study found that older adults (~74y) use up to 78% of their maximal knee extensor moments when ascending stairs and 88% of their maximal knee extensor moment when descending the stairs (Hortobagyi et al., 2003). These findings suggests that the combination of fatigue and the age-related declines in gait parameters may increase the risk of falls in older adults. This highlights the importance of older adults maintaining their aerobic and muscular endurance to help prevent fatigue related increases in fall risk.

The protocol used in this study was designed to be completed by individuals of all activity levels including individuals that are physically inactive. This circuit was likely performed at a relatively low effort level for the physically active participants analyzed in this

study, possibly resulting in an inadequate level of fatigue to induce fatigue related changes in the lumbopelvic region. It is likely that some level of muscular and cardiovascular fatigue did occur, but not at a level that was significantly detectable by kinematics during the stair task.

Quantifying fatigue can be a challenging and complicated task when assessing older adults. Under many methodological conditions, older adults are less fatigable than their younger counterparts. When muscular power measures or dynamic contractions are used to quantify fatigue, older adults seem to be more fatigable (as expected; Christie et al., 2011). The current study sought to quantify fatigue by monitoring the changes in the lumbopelvic region during a dynamic stair task.

6.4 SUMMARY OF FINDINGS

With all outcomes considered, this study found that while the AHAbd was an effective predictor of frontal plane LPC during stair descending in younger adults, its predictive capability diminished in the older population. The predictive value was also higher in Females during stair descent when compared to males. The impact of fatigue on LPC was less significant than expected, suggesting that the fatiguing protocol may not have been sufficient to induce detectable changes in the lumbopelvic region. Overall, these findings highlight the importance of physical activity in maintaining LPC and mitigating age-related declines.

6.5 IMPLICATIONS FOR CLINICAL PRACTICE AND ATHLETIC TRAINING

6.5.1 Preventive Measures and Interventions

The findings of this study may support the need for endurance improvements in the lumbopelvic stabilizers, especially in an active older population, to aid in injury prevention and maintenance of physical activity level. Exercise interventions have been shown to increase LPC and reduce the incidence on clinical findings in athletic and physically inactive populations (Emeterio et al., 2022; Long, 2017; Mills et al., 2005; Nelson-Wong & Callaghan, 2010a).

The current study points to the effectiveness of following the Canadian Physical Activity Guidelines and the WHO physical activity guidelines. Results of this study suggest that performing physical activity at or above the level of the Canadian and/or WHO guidelines allows older adults to perform unilateral functional dynamic tasks without significant frontal plane movement deficits in the lumbopelvic region regardless of the level of control established by the AHAbd. Previous research on general physical activity has found a positive effect on muscular power, strength, flexibility, and balance in older adults (Emilio et al., 2014; Ramsey et al., 2021). The significant age-related declines in muscle mass, strength, and power are compounded by the effects of physical inactivity (Lazarus & Harridge, 2017; Skelton et al., 1994).

Specific exercise interventions may also offer additional benefits to the level of LPC. Hazell and colleagues found that while general resistance training increases muscular strength in older adults, power training is more effective for maintaining the ability to perform daily activities (Hazell et al., 2007). Another study demonstrated that a 12-week proprioceptive training intervention significantly improved flexibility, balance, and lumbar strength in older adults (Emilio et al., 2014). Similarly, Emeterio and colleagues reported that an 8-session lumbopelvic stability training intervention enhanced muscular endurance and core stability

(Emeterio et al., 2022). A 2013 review found that performing lumbopelvic exercises reduced the risk of lower limb muscle strain injuries when compared to other interventions or usual training in recreational athletes (Perrott et al., 2013). Nelson-Wong and Callaghan (2010a) found that a prescribed exercise program emphasizing the strengthening of trunk musculature performed four times per week for four weeks had beneficial effects on lumbopelvic measures such as LBP when compared to a control group that performed usual activity (Nelson-Wong & Callaghan, 2010a). These findings collectively suggest that incorporating diverse exercise interventions, beyond traditional training, can provide substantial benefits. Programs focusing on power training, proprioceptive training, and lumbopelvic stability can enhance overall physical function, reduce injury risk, and maintain the quality of life for older adults.

6.5.2 Injury Prevention and Functional Maintenance

Multiple studies have shown that increased LPC can aid in the prevention of musculoskeletal injuries of the upper and lower body in athletic populations (Cope et al., 2019; Dehcheshmeh & Gandomi, 2021; Fadaei Dehcheshmeh et al., 2021; Laudner et al., 2021; Perrott et al., 2013). Maintaining or increasing the level of LPC is suspected to not only prevent injury and maintain athletic performance in an older adult population but can aid in maintaining functional abilities (Perrott et al., 2013). Research has shown that maintaining a competitively active lifestyle results in greater lower-body functional power in older adults and may support prolonged functionality (Glenn et al., 2016).

The importance of good LPC extends to the prevention of upper limb injuries as well. Research on baseball pitchers has shown that players with lower levels of LPC in both the sagittal (Chaudhari et al., 2014; Laudner et al., 2021) and frontal planes (Laudner et al., 2021) are more likely to experience injuries.

6.6 HYPOTHESES REVISITED

The proposed research questions were analysed and tested with the goal of either rejecting or accepting the hypotheses listed below:

(1) It was hypothesized that poor LPC identified by scores of 2 or 3 on the AHAbd and increased age, would be related to significantly less frontal plane angular displacements in the lumbopelvic region during stair ascent and descent due to reduced ability to actively mobilize the pelvis.

- Accepted: This hypothesis is accepted when young adults were examined during stair descents (Section 5.2, *Table 5.5*, *Figure 5.1*).
- Rejected: This hypothesis is rejected when older adults were examined, or when stair ascents were used as the dependent variable

(2) It was hypothesized that poor AHAbd scores and increased age, would be related to significantly greater change in lumbopelvic angle between the first and last round of the fatiguing stair circuit.

- Rejected: Poor AHAbd score was significantly related to greater change in lumbopelvic angle between the first and last round of the fatiguing stair circuit but only when the interaction effect between AHAbd and Age was analysed for the change between the first last stair descent. In this interaction, young adults and poor score were related to greater change in angle, which is contrary to the stated hypothesis (Section 5.6, *Table 5.17*, Figure 5.2).

(3) It was hypothesized that participants will experience fatigue related changes identified by greater lumbopelvic angular displacements in the frontal plane during stair ascent and descent between the first and last round of the stair circuit.

- Rejected: T-tests examining the change in lumbopelvic angle from the first round to last round of the circuit did not find significance. This was true for stair ascents and descents; therefore, this hypothesis is rejected.

6.7 METHODOLOGICAL CONSIDERATIONS

6.7.1 Strengths

A strength of this study is the number of measures that were collected for each participant. This study included a test of lumbar pelvic control (AHAbd), frontal plane kinematics measured during a fatiguing stair circuit (lumbopelvic angle), a direct objective measure of physical activity (Actigraph), and an indirect subjective measure of physical activity (HUNT1). By making comparisons between dynamic tasks, age, physical activity, and LPC it allows us to analyze LPC in numerous ways.

The estimated large effect size that was found for the significant interaction effects provides a higher level of confidence when interpreting the findings in this study. The significant effects are more likely to reflect true differences rather than random variation, thereby enhancing the credibility of the study's conclusions.

The high levels of intrarater and interrater reliability established in previous research were also observed in this study. This indicates that the scoring of the AHAbd was likely accurate and reliable.

6.7.2 Limitations

There are limitations that come with using self reported subjective measures of physical activity such as the HUNT1. Individuals may overestimate or underestimate the level of easy moderate and vigorous physical activity that they do on an average week. To account for this, we also measured physical activity using Actigraph activity monitors. These do provide an objective direct measure of physical activity but if an individual that is active most weeks of the year wears the Actigraph device on a week when they are inactive, they can be categorized as lower than their true physical activity level. Many of the participants in this study play seasonal sports and may have been at a time of the year when they are performing lower than normal amounts of physical activity.

Another limitation was the exclusion of less active individuals. The inclusion of these individuals may have provided additional insight into the changes in LPC that occur with increased age and under fatigued conditions. The inclusion of only physically active individuals made a comparison between physical activity level difficult. This homogeneity in physical activity levels limited our ability to differentiate the effects of activity level on LPC, as the participants were too similar to reveal any significant differences. Therefore, the variations between varying degrees of physical activity could not be adequately explored.

We did not collect electromyography (EMG) data, which could have provided detailed information on muscle activation patterns during the tasks. While this limits our ability to analyze the specific muscle activity involved in LPC, our primary focus was on kinematic and dynamic outcomes, which can be reliably assessed without EMG data. The absence of EMG did not affect our primary results, as our kinematic analysis was comprehensive enough to meet the study's objectives.

No participants reached exhaustion or relatively high levels of fatigue during the stair circuit, limiting our understanding of LPC under highly fatigued conditions. However, stair tasks are usually performed under typical conditions rather than extreme fatigue scenarios. The controlled fatigue levels ensured that participants could perform the tasks consistently, allowing us to collect high-quality data for our intended analysis without the confounding effects of severe fatigue.

The capture volume of the 3D motion capture system was limited, potentially restricting the range of movement analysis. Although this limitation exists, our study's tasks were designed to fit within the capture volume's constraints. As a result, the limited capture volume did not adversely affect the quality of the data collected for our specific research objectives. There are inherent limitations in using surface-mounted markers, including potential inaccuracies due to marker movement on the skin. Despite this, our use of a standardized protocol for marker placement and movement tracking helped mitigate these issues.

Heart rate was not tracked during the stair circuit, which could have offered valuable data on physiological responses. Continuous rating of perceived exertion (RPE) measures during the circuit would also have been beneficial to provide more insight into effort level and fatigue. However, our study was designed to focus on biomechanical outcomes rather than physiological responses. The lack of heart rate data did not compromise our findings related to LPC and kinematic analysis, which were the main focus of the research.

A further limitation of this study was the lack of control over the participants' warm-up routines. The warm-up was self-selected, meaning participants could have varied significantly in the type, intensity, and duration of their warm-up activities. This variability could have influenced their performance during the stair tasks. A standardized warm-up protocol might have

helped to minimize these differences, ensuring that all participants were equally prepared for the physical demands of the tasks. However, given the physically active nature of the participants, it is reasonable to assume that they were capable of preparing themselves for the relatively low-intensity tasks involved in this study, even without specific warm-up guidance.

It is likely that not all participants reached a state of muscular fatigue during the stair circuit. Some participants may have exhibited kinematic changes over time due to learning effects, but these were likely minimized by the progressive warm-up in this study. However, these factors could have influenced their movement patterns, making it difficult to distinguish between fatigue related changes and those resulting from increased task familiarity or the effects of gradually warming up. This adds complexity to the interpretation of kinematic data, as the observed changes may not solely reflect the impact of fatigue.

6.7.3 Future Research Directions

Having a longitudinal or follow-up visits would be a useful addition to this body of research, especially in an older adult population. By tracking physical activity and LPC over a longer period of time, it may point to the effect physical activity level has on the age-related declines in the lumbopelvic region.

Intervention studies are also necessary to test specific exercise programs aimed at improving LPC, especially in higher risk populations such as older adults. Studies designed at finding the ideal ways to keep adults (especially older populations) active and pain free are essential for optimizing physical activity recommendations for younger and older adults.

In this study, back pain was only assessed using one questionnaire. A more comprehensive back pain questionnaire and/or a back pain questionnaire that would be

completed during the fatiguing stair circuit may have provided more insight into the relationship between LPC, dynamic tasks, and LBP. A longer dynamic fatiguing protocol or a prolonged standing protocol may have revealed significant levels of LBP in the participants with lower levels of LPC (Nelson-Wong et al., 2008; Nelson-Wong & Callaghan, 2010b, 2010a).

Future research should also consider the type of physical activity participants engage in, not just activity level. Different types of activities may have varying impacts on LPC during dynamic tasks and effect related outcomes. This may offer a deeper insight into which exercises are most beneficial for maintaining LPC. Additionally, the participant characterization measures collected but not analyzed in this study, such as objective and subjective measures of physical activity, VO_2max, core endurance assessments, and MRI could provide valuable information. By exploring this data in future research, we can gain a better understanding of the similarities and differences between groups, potentially revealing key factors that contribute to effective LPC and prevention of LBP. This may suggest the need for more targeted and effective intervention strategies for maintaining physical activity and preventing pain, particularly in older adults.

6.8 CONCLUSION

While this study did not find significant differences across many of the analysed lumbopelvic variables, it did reveal notable significant interaction effect for AHAbd performance and age, and AHAbd performance and sex when examining stair descents. More significant interaction effects may become more apparent under different conditions or when examining a different population. The results of the current study underscore the importance of maintaining adequate levels of physical activity to reduce age-related declines in LPC. The lack of

significance related to fatigue points to the importance of maintaining high levels of physical activity to effectively perform dynamic tasks. It would be useful to examine the declines in LPC in a less active older population to gain a more in depth understanding of the increased age when compounded with low levels of physical activity or sedentary behaviour.

The protocol and analysis in this study did not find significant findings when examining the potential for the AHAbd to identify LPC deficits in and active older population during a fatiguing stair circuit. The AHAbd still holds promise for identifying LPC deficits in a less active population or under conditions where the level of fatigue is higher. In conclusion, this study contributes to the body of knowledge on the effects of age, physical activity, and fatigue on LPC. The findings on this study highlight the need for future research aimed at more diverse populations to optimize physical activity recommendations for both younger and older adults to preserve LPC, maintain functional abilities, prevent injuries, and improve quality of life.

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APPENDIX A – INTAKE FORMS

Power of Exercise - Intake Form

Today's Date:	mmm/dd/yyyy	Time of Collection:	hh:mm am/pm
Participant Code:			

Participant Information

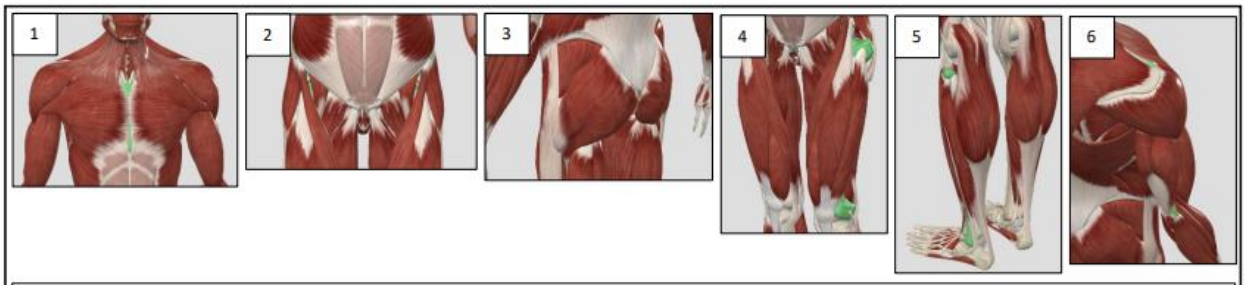
Name:			
DOB:	mmm/dd/yyyy		
Sex (at birth):		Gender:	
Masters Athlete*:	☐ Yes ☐ No	Athlete**:	☐ Yes ☐ No
Primary Sport:			

* Masters athletes are defined as "individuals who systematically train for, and compete in, organized forms of competitive sport specifically designed for older adults" (Geard et al., 2017).

** Athletes are defined as individuals "who participate in an organized team or individual sport that requires regular competition against others as a central component, places a high premium on excellence and achievement, and requires some form of systematic (and usually intense) training" (Maron et al., 2015).

Anthropometrics

Height (m):			Weight (kg):		
Body Fat (%):			Handgrip Strength	Left:	Right:
Chest @ nipple (cm):			Waist @ naval (cm):		
Hips @ widest (cm):			Thigh @ 50% from GT to lat condyle (cm):	Left:	Right:
Shank @ 50% from fib head to lat mall (cm):	Left:	Right:	Arm (cm):	Left:	Right:



1) Chest circumference @ nipple line
2) Waist circumference @ naval
3) Hip circumference @ largest girth
4) Thigh circumference @ 70% of distance moving proximally between greater trochanter and lateral epicondyle of femur
5) Shank circumference @ 66% of distance moving proximally between lateral malleolus and fibular head
6) Arm circumference @ 50% of distance between a/c joint and lateral epicondyle of humerus

Date:

VISIT 1

- ☐ 1 Participant completes consent, PARQ+, intake and MRI screen
- ☐ 2 Warm-up
  - 2.1.1 Run or walk on treadmill for 5 minutes
  - 2.1.2 Leg swings fore/aft/side x 10/10/10/10
  - 2.1.3 Walking lunges x 10/10
  - 2.1.4 Bird dog x 5/5/5/5
  - 2.1.5 Burpees x 5
- ☐ 3 Core endurance and control assessment
  - 3.1 AHABD "Please keep your knee straight and raise your top thigh towards the ceiling, keeping them in line with your body, and try not to let your pelvis tip forwards or backwards."
  - 3.2 Front plank for time
  - 3.3 Side plank for time (L)
  - 3.4 Side plank for time (R)
  - 3.5 Biering sorenson for time
- ☐ 4 Mocap cofiguration
  - 2.1 Register and align cameras
  - 2.2 Place rigs on participant and digitize
  - 2.3 Perform static trial ----------
  - 2.4 Perform left single support trial (30s) ----------
  - 2.5 Perform right single support trial (30s) ----------
- ☐ 5 Vertical jump assessment
  - 5.1 Vertical jump
    - 5.1.1 Familiarization - instruct hands on hips, standing centered on plate trying to jump as high as possible
    - 5.1.2 Complete 3 repetitions of max vertical jump with hands on hips ----------
- ☐ 6 Surveys
  - 6.1 Within 30 minute window, participant completes RAPA, RAND 36 and Custom Survey
- ☐ 7 Functional task circuit
  - 7.1 Familiarization - instruct to limit hand rail usage, keep same footing up stairs, face same direction for movements
  - 7.2 Perform each movement separately (baseline). Rest 1 min between movements.
    - 7.2.1 Chair rise ----------
    - 7.2.2 Stair climb
    - 7.2.3 Stair descent
  - 7.3 Circuit, AMRAP 15 min
    - 7.3.1 chair rise x 3, stair climb, stair descent
    - 7.3.2 chair rise x 3, stair climb, stair descent
    - 7.3.3 Max vertical jump

Date:

VISIT 2

- ☐ 1 Participant completes MRI screening
- ☐ 2 Participant attends MRI theatre for imaging
  - 2.1 DIXON Imaging of hip / lumbar ----------
  - 2.2 DTI Imaging of hip / lumbar ----------
  - 2.3 DIXON Imaging of thigh ----------
  - 2.4 DTI Imaging of thigh ----------
  - 2.5 DIXON Imaging of shank ----------
  - 2.6 DTI Imaging of shank ----------
- ☐ 3 VO2max assessment
  - 3.1 Warm-up
    - 3.1.1 Run or walk on treadmill for 5 minutes
    - 3.1.2 Leg swings fore/aft/side x 10/10/10/10
    - 3.1.3 Walking lunges x 10/10
    - 3.1.4 Bird dog x 5/5/5/5
    - 3.1.5 Burpees x 5
  - 3.2 VO2max test with verification ----------

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PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

Regular physical activity is fun and healthy, and more people should become more physically active every day of the week. Being more physically active is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

SECTION 1 - GENERAL HEALTH

	Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1.	Has your doctor ever said that you have a heart condition OR high blood pressure?	○	○
2.	Do you feel pain in your chest at rest, during your daily activities of living, OR when you do physical activity?	○	○
3.	Do you lose balance because of dizziness OR have you lost consciousness in the last 12 months? Please answer NO if your dizziness was associated with over-breathing (including during vigorous exercise).	○	○
4.	Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)?	○	○
5.	Are you currently taking prescribed medications for a chronic medical condition?	○	○
6.	Do you have a bone or joint problem that could be made worse by becoming more physically active? Please answer NO if you had a joint problem in the past, but it does not limit your current ability to be physically active. For example, knee, ankle, shoulder or other.	○	○
7.	Has your doctor ever said that you should only do medically supervised physical activity?	○	○

If you answered NO to all of the questions above, you are cleared for physical activity.

Go to Section 3 to sign the form. You do not need to complete Section 2.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow the Canadian Physical Activity Guidelines for your age (www.csep.ca/guidelines).
- You may take part in a health and fitness appraisal.
- If you have any further questions, contact a qualified exercise professional such as a CSEP Certified Exercise Physiologist® (CSEP-CEP) or CSEP Certified Personal Trainer® (CSEP-CPT).
- If you are over the age of 45 yrs. and NOT accustomed to regular vigorous physical activity, please consult a qualified exercise professional (CSEP-CEP) before engaging in maximal effort exercise.

If you answered YES to one or more of the questions above, please GO TO SECTION 2.

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better
- You are pregnant – talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the PARmed-X for Pregnancy before becoming more physically active OR
- Your health changes – please answer the questions on Section 2 of this document and/or talk to your doctor or qualified exercise professional (CSEP-CEP or CSEP-CPT) before continuing with any physical activity programme.

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SECTION 2 - CHRONIC MEDICAL CONDITIONS

Please read the questions below carefully and answer each one honestly: check YES or NO.			YES	NO
1.	Do you have Arthritis, Osteoporosis, or Back Problems?		○ If yes, answer questions 1a-1c	○ If no, go to question 2
	1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	○	○
	1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/ or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	○	○
	1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	○	○
2.	Do you have Cancer of any kind?		○ If yes, answer questions 2a-2b	○ If no, go to question 3
	2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and neck?	○	○
	2b.	Are you currently receiving cancer therapy (such as chemotherapy or radiotherapy)?	○	○
3.	Do you have Heart Disease or Cardiovascular Disease? This includes Coronary Artery Disease, High Blood Pressure, Heart Failure, Diagnosed Abnormality of Heart Rhythm		○ If yes, answer questions 3a-3e	○ If no, go to question 4
	3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	○	○
	3b.	Do you have an irregular heart beat that requires medical management? (e.g. atrial fibrillation, premature ventricular contraction)	○	○
	3c.	Do you have chronic heart failure?	○	○
	3d.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer YES if you do not know your resting blood pressure)	○	○
	3e.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	○	○
4.	Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes		○ If yes, answer questions 4a-4c	○ If no, go to question 5
	4a.	Is your blood sugar often above 13.0 mmol/L? (Answer YES if you are not sure)	○	○
	4b.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, and the sensation in your toes and feet?	○	○
	4c.	Do you have other metabolic conditions (such as thyroid disorders, pregnancy-related diabetes, chronic kidney disease, liver problems)?	○	○
5.	Do you have any Mental Health Problems or Learning Difficulties? This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome)		○ If yes, answer questions 5a-5b	○ If no, go to question 6
	5a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	○	○
	5b.	Do you also have back problems affecting nerves or muscles?	○	○

Please read the questions below carefully and answer each one honestly: check YES or NO.			YES	NO
6.	Do you have a Respiratory Disease? This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure		○ If yes, answer questions 6a-6d	○ If no, go to question 7
	6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	○	○
	6b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	○	○
	6c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	○	○
	6d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	○	○
7.	Do you have a Spinal Cord Injury? This includes Tetraplegia and Paraplegia		○ If yes, answer questions 7a-7c	○ If no, go to question 8
	7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	○	○
	7b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	○	○
	7c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	○	○
8.	Have you had a Stroke? This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event		○ If yes, answer questions 8a-c	○ If no, go to question 9
	8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer NO if you are not currently taking medications or other treatments)	○	○
	8b.	Do you have any impairment in walking or mobility?	○	○
	8c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	○	○
9.	Do you have any other medical condition not listed above or do you live with two chronic conditions?		○ If yes, answer questions 9a-c	○ If no, read the advice on page 4
	9a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months OR have you had a diagnosed concussion within the last 12 months?	○	○
	9b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	○	○
	9c.	Do you currently live with two chronic conditions?	○	○

Please proceed to Page 4 for recommendations for your current medical condition and sign this document.

PAR-Q+

If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active:

- It is advised that you consult a qualified exercise professional (e.g., a CSEP-CEP or CSEP-CPT) to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually – 20-60 min. of low- to moderate-intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate-intensity physical activity per week.
- If you are over the age of 45 yrs. and NOT accustomed to regular vigorous physical activity, please consult a qualified exercise professional (CSEP-CEP) before engaging in maximal effort exercise.

If you answered YES to one or more of the follow-up questions about your medical condition:

- You should seek further information from a licensed health care professional before becoming more physically active or engaging in a fitness appraisal and/or visit a or qualified exercise professional (CSEP-CEP) for further information.

Delay becoming more active if:

- You are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise profesional, and/or complete the PARmed-X for Pregnancy before becoming more physically active OR
- Your health changes - please talk to your doctor or qualified exercise professional (CSEP-CEP) before continuing with any physical activity programme.

SECTION 3 - DECLARATION

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The Canadian Society for Exercise Physiology, the PAR-Q+ Collaboration, and their agents assume no liability for persons who undertake physical activity. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.
- Please read and sign the declaration below:

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that they maintain the privacy of the information and do not misuse or wrongfully disclose such information.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

For more information, please contact:
Canadian Society for Exercise Physiology
www.csep.ca

KEY REFERENCES
1. Jamnik VJ, Warburton DER, Makarski J, McKenzie DC, Shephard RJ, Stone J, and Gledhill N. Enhancing the eectiveness of clearance for physical activity participation; background and overall process. APNM 36(S1):S3-S13, 2011.
2. Warburton DER, Gledhill N, Jamnik VK, Bredin SSD, McKenzie DC, Stone J, Charlesworth S, and Shephard RJ. Evidence-based risk assessment and recommendations for physical activity clearance; Consensus Document. APNM 36(S1):S266-s298, 2011.

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or BC Ministry of Health Services.

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APPENDIX B – QUESTIONNAIRES AND SURVEYS

Section 1. This section deals with **repetitive strain injuries**. By this we mean injuries caused by overuse or by repeating the same movement frequently. For example, carpal tunnel syndrome, tennis elbow or tendonitis.

1. In the past 12 months, did you experience any injuries due to repetitive strain which were serious enough to limit your normal activities?
   a) Yes
   b) No (skip to Section 2)
2. Thinking about the most serious repetitive strain, what part of the body was affected?
   a) Head
   b) Neck
   c) Shoulder, upper arm
   d) Elbow, lower arm
   e) Wrist
   f) Hand
   g) Hip
   h) Thigh
   i) Knee, lower leg
   j) Ankle, foot
   k) Upper back or upper spine (excluding neck)
   l) Lower back or lower spine
   m) Chest (excluding back and spine)
   n) Abdomen or pelvis (excluding back and spine)

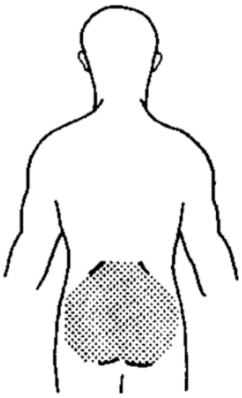
Section 2. Now some questions about **acute injuries** which occurred in the past 12 months, and were serious enough to limit your normal activities. For example, a broken bone, a bad cut or burn, a sprain, or a poisoning.

3. Not counting repetitive strain injuries, were you injured in the past 12 months?
   a) Yes
   b) No (skip to Section 3)
4. How many times were you injured?

_____

5. Thinking about the most serious injury, what type of injury did you have?
   a) Multiple injuries
   b) Broken or fractured bones
   c) Burn, scald, chemical burn
   d) Dislocation
   e) Sprain or strain
   f) Cut, puncture, animal or human bite (open wound)
   g) Scrape, bruise, blister
   h) Concussion or other brain injury
   i) Poisoning
   j) Injury to internal organs
6. Thinking of this same injury, what part of the body was injured?
   a) Head
   b) Neck
   c) Shoulder, upper arm
   d) Elbow, lower arm
   e) Wrist
   f) Hand
   g) Hip
   h) Thigh
   i) Knee, lower leg
   j) Ankle, foot
   k) Upper back or upper spine (excluding neck)
   l) Lower back or lower spine
   m) Chest (excluding back and spine)
   n) Abdomen or pelvis (excluding back and spine)

Section 3. Complete the following *only if* you indicated overuse or acute **injury of the low back** (question 2 L or 6 L). Adapted from Bahr et al., 2004, Fett et al., 2017, and Kuorinka & Andersson 1987.



LOW BACK

How to answer the questionnaire: In this picture you can see the approximate position of the part of the body referred to in the questionnaire. By low back trouble is meant ache, pain or discomfort in the shaded area whether or not it extends from there to one or both legs (sciatica).

Please answer by putting a cross in the appropriate box — one cross for each question. You may be in doubt as to how to answer, but please do your best anyway.

7. Have you been examined or treated for LBP by a physician, physical therapist, chiropractor, or other health personnel as an outpatient during the previous 12 months?
   a) Yes
   b) No
8. Have you ever been admitted to hospital because of LBP?
   a) Yes
   b) No
9. Have you ever had surgery because of LBP?
   a) Yes
   b) No
10. Have you ever had to change your occupation or working assignments because of LBP?
    a) Yes
    b) No
11. Have you experienced LBP during the previous 7 days?
    a) Yes
    b) No
12. Have you ever had radiating LBP?
    a) Yes
    b) No
13. How many days during the past 12 months have you had LBP?

    _____ days

Section 4. Please describe your **physical activity history**. Some examples include casual weight-training, recreational soccer, or varsity basketball. An example is provided in the first row. You may add additional details as you see fit.

Activity	Competitive Level*	Duration (h) per session	Sessions per week	Weeks per year	Started (Year)	Ended (Year)
Volleyball	*High school*	*2*	*3*	*16*	*1982*	*1984*

* List the competitive level if applicable – recreational / non-competitive, varsity, national, international

Section 5. This section collects additional information regarding your occupation (or past occupation) and any related physical activity.

14. What is/was your occupation? _____
15. Does your work involve **vigorous-intensity activity** that causes **large increases in breathing or heart rate** like carrying/lifting heavy loads, digging, or construction work for at least 10 minutes continuously?
    a) Yes
    b) No (skip to Question 18)
16. In a typical week, how many days do you do vigorous-intensity activities as part of your work?
    _____ days
17. How much time do you spend doing vigorous-intensity activities at work on a typical day?
    _____ hours _____ minutes
18. Does your work involve **moderate intensity activity** that causes **small increases in breathing or heart rate** such as brisk walking or carrying light loads for at least 10 minutes continuously?
    a) Yes
    b) No (skip to Question 21)
19. In a typical week, how many days do you do moderate-intensity activities as part of your work?
    _____ days
20. How much time do you spend doing moderate-intensity activities at work on a typical day?
    _____ hours _____ minutes
21. What is your income bracket?
    a) 0-50k
    b) 51-100k
    c) 101-155k
    d) 156-221k
    e) 222k+

Section 6. This section asks about miscellaneous factors that may affect your physical performance.

22. Are you taking any medications that may affect your physical performance? Examples would include lipid lowering drugs (i.e., Lipitor), androgens (i.e., testosterone), ADHD medication (i.e., methylphenidate).
23. What is the date of your last menstrual cycle (if applicable)? _____
24. Have you had any surgeries? If so, please list them below with the approximate date.

1. _____ Date: mmm/dd/yyyy
2. _____ Date: mmm/dd/yyyy
3. _____ Date: mmm/dd/yyyy
4. _____ Date: mmm/dd/yyyy
5. _____ Date: mmm/dd/yyyy

25. Have you ever been diagnosed with osteoarthritis? If yes, please list the joint(s).

_____

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0

Exercise: going for walks, skiing, swimming or training / sport

1 How frequently do you exercise? (on average)

- ☐ Never
- ☐ Less than once a week
- ☐ Once a week
- ☐ 2-3 times per week
- ☐ Almost every day

2 If you do exercise as frequently as once or more per week, how hard do you push yourself?

- ☐ I take it easy without breaking into a sweat or losing my breath
- ☐ I push myself so hard that I lost my breath and break into a sweat
- ☐ I push myself to near-exhaustion

3 How long does each session last? (on average)

- ☐ Less than 15 minutes
- ☐ 16-30 minutes
- ☐ 30 minutes to 1 hour
- ☐ More than 1 hour

Power of Exercise - Initial Exit Survey

1. How did you find the tasks in today's session?

_____
_____
_____

2. Would you recommend participating in this study to your friends?

_____
_____
_____

3. Do you have any questions for us?

_____
_____
_____

4. Is there any information, anecdotes, and/or concerns you would like to share?

_____
_____
_____