Risk Factors for Running-Related Pain After Childbirth

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A thesis submitted in fulfilment of the requirements for the degree of

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School of Health Sciences, College of Health, Medicine and Wellbeing

The University of Newcastle

This is to certify that the thesis entitled *Risk Factors for Runing-Related Pain After Childbirth*, submitted in fulfilment of the requirements for the degree Doctor of Philosophy (Physiotherapy), is in a form ready for examination.

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Statement of Originality

I hereby certify that the work embodied in the thesis is my own work, conducted under normal supervision. The thesis contains no material which has been accepted, or is being examined, for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made. I give consent to the final version of my thesis being made available worldwide when deposited in the University's Digital Repository, subject to the provisions of the Copyright Act 1968 and any approved embargo.

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Acknowledgement of Authorship

I hereby certify that the work embodied in this thesis contains published papers/scholarly work of which I am a joint author. I have included as part of the thesis a written declaration endorsed in writing by my supervisor, attesting to my contribution to the joint publication/scholarly work.

By signing below, I confirm that Shefali Christopher contributed to the concept and research design, acquisition of data, analysis and interpretation of data, as well as writing, reviewing and editing of the publications entitled:

- **Christopher S**, McCullough J, Snodgrass SJ, Cook C. Do alterations in muscle strength, flexibility, range of motion, and alignment predict lower extremity injury in runners: a systematic review. Archives of Physiotherapy. 2019;9(2):1-4
- **Christopher S**, McCullough J, Snodgrass SJ, Cook C. Predictive risk factors for first-onset lumbopelvic pain in postpartum women: a systematic review. Journal of Women's Health Physical Therapy. 2019 Jul 1;43(3):127-35.
- **Christopher S**, Garcia AN, Snodgrass SJ, Cook C. Common musculoskeletal impairments in postpartum runners: an international Delphi study. Archives of Physiotherapy. 2020 Oct;10(19)
- **Christopher SM**, Cook CE, Snodgrass SJ (2021) What are the biopsychosocial risk factors associated with pain in postpartum runners? Development of a clinical decision tool. PLoS ONE 16(8): e0255383. https://doi.org/10.1371/journal.pone.0255383

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Publications and Presentations Arising from this Thesis

Papers Published in Peer Reviewed Scientific Journals

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- **Christopher S**, Garcia AN, Snodgrass SJ, Cook C. Common musculoskeletal impairments in postpartum runners: an international Delphi study. Archives of Physiotherapy. 2020 Oct;10(19)
- **Christopher SM**, Cook CE, Snodgrass SJ (2021) What are the biopsychosocial risk factors associated with pain in postpartum runners? Development of a clinical decision tool. PLoS ONE 16(8): e0255383. https://doi.org/10.1371/journal.pone.0255383

Abstracts Presented at Peer Reviewed Scientific Conferences

- **Christopher S**, Trepte, A, Snodgrass, SJ, Cook, C. Common Musculoskeletal Impairments in Postpartum Runners with Pain: An International Delphi Study. Poster presentation. APTA Combined Sections Meeting, Denver CO, 2020
- **Christopher S**, McCoullough, J, Snodgrass, SJ, Cook, C. Objective clinical musculoskeletal assessments that predict injury in runners: A systematic review

and meta-analysis. Poster APTA Combined Sections Meeting, New Orleans, LA, 2018

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Abstract

Background

Women are initiating or returning to running for exercise after childbirth while also recovering from a myriad of perinatal changes to the body. For these women, integration into a high impact sport is not easy; up to 35% of postpartum runners report painful running. While there are established evidence-based rehabilitation protocols for returning to sport after a major injury, such evidence does not exist for the postpartum running population. This is likely due to a lack of evidence on possible musculoskeletal risk factors associated with running-related pain in postpartum women. A baseline understanding of potential risk factors for running-related pain in postpartum runners is needed to provide a starting point for future validation and interventional studies.

Purpose

The overall aim of this thesis is to identify possible risk factors for running-related pain in postpartum runners and determine their relationship to running, postpartum variables, and movement kinematics.

Methods

Because information on risk factors for running-related musculoskeletal injury in postpartum runners was non-existent, a systematic review was initially performed to understand the relationship between running injury and musculoskeletal strength, flexibility, range of motion and alignment alterations. A separate systematic review was also conducted to understand the risk factors associated with first-onset lumbopelvic pain (the most common type of pain) in postpartum women. A Delphi study was performed to gain expert consensus on musculoskeletal impairments and running-related risk factors

observed in postpartum runners. The information gathered from these studies was used to design and conduct a survey of postpartum runners with and without running-related pain to explore the relationship between demographic, postpartum and running-related risk factors, and pain. Since the effects of postpartum musculoskeletal changes on running are unknown, a laboratory study determined kinematic and musculoskeletal differences between postpartum runners and nulliparous controls.

Results

Both systematic reviews found low-quality evidence and bias within the studies reviewed. Seven studies found seven clinical assessments that predict running-related pain: hip strength, range of motion, flexibility, and alignment, and, knee strength and ankle alignment. Four studies identified five risk factors associated with first-onset postpartum lumbopelvic pain: C-section with epidural anesthesia, length of first stage labor, race, age and urinary tract infections. The 45 experts in the Delphi study reached consensus on the following risk factors observed in postpartum runners: abdominal, hip, and pelvic floor weakness, hip extension restriction, anterior pelvic tilt, general hypermobility, laxity in the abdominal wall, tightness in hip flexors, lumbar extensors, iliotibial band and hamstrings, a Trendelenburg sign, dynamic knee valgus, lumbar lordosis, over-pronation, and thoracic kyphosis. The survey of 538 postpartum runners found six variables that increased the odds of postpartum running-related pain: runner type-novice, postpartum accumulated fatigue scale score, previous running injury, most recent delivery-vaginal, incontinence, and amount of sleep. Using these variables, a clinical tool was created that indicated a 62% probability of having postpartum running-related pain if 4 of 6 variables were present. The laboratory study concluded that postpartum runners had 24.3% greater braking loading rate (mean difference (MD): 3.41 NBW/s; 95% CI 0.08, 6.74), 14% less hamstring flexibility (MD:10.98°; 0.97, 20.99), 25.9% less hip abduction (MD: 0.04

NBW, 95% CI 0.00, 0.08), and 51.6% less hip adduction strength (MD: 0.06 NBW; 0.02, 0.10) than controls.

Conclusions

This thesis established the first steps in identifying running-related risk factors in postpartum runners. This baseline understanding of potential risk factors for running-related pain provides a starting point for prospective studies to investigate risk factors for the onset of running-related pain in postpartum runners. It can also assist health care providers educate postpartum runners and develop interventions to assist postpartum women to stay injury free as they initiate or return to running.

CHAPTER 1. Introduction

1.1 Background

The number of women who run is increasing, particularly among women of childbearing age. In 2020, *USA Running* reported that 17.62 million people registered for running events ("Running USA Releases Latest U.S. Running Trends Report", 2020); 61% of those people were female, the majority of whom were between the ages of 25 and 45 years (mean 38 years) (Figure 1.1). In 2014, the mean age for first-time mothers reported by the Center of Disease Control was 26.3 years; it therefore follows that women of childbearing age are increasingly participating in running events around the United States of America (USA). In spite of such statistics, limited guidelines exist for initiating or running during pregnancy. Guidelines for returning to running postpartum are even sparser.

Table 1.1 USA Running Trends 2020 Report data, which summarizes everyone who registered for USA running-related races in 2019. (N= 17.62 million participants; 61% female)

Age	<18	18-24	25-34	35-44	45-54	55-64	65+
Participation	11%	8%	24%	25%	18%	10%	3%

One document that highlights the paucity of research and recommendations in the postpartum running population is the recently published American College of Obstetricians and Gynaecologists (ACOG) committee opinion on pregnancy and postpartum physical activity and exercise (Mota and Bø 2021). The fifteen-page document highlighted examples of safe exercise during pregnancy; specifically, anatomical and physiological aspects of exercise, benefits of exercise, recommendation of types of exercise programs, and work/ activity restrictions. Of the 3840 words, only 221 words (5.75% of all words)—less than one page of the document—had recommendations for the postpartum period. In the two paragraphs dedicated to postpartum exercise, ACOG recommended that healthcare providers “reinforce a healthy lifestyle” and help new mothers resume or start new exercise. They recommended resuming old exercise routines and adding pelvic floor exercises once medically safe; additionally, ACOG advises lactating mothers to feed their babies prior to engaging in activity. In the pregnancy and exercise sections, the guideline provided details about physiology and exercise during pregnancy, such as exercise duration, intensity, and environment. In the section regarding postpartum women, the advice was brief and lacked detail. Postpartum mothers are going through a major life event that can be compared to any other major surgical procedure, from which patients need to recover and rehabilitate appropriately. Without any guidelines, postpartum women may start or return to running with complications, like pain, that can possibly slow healing and recovery and have long-term implications on mental and physical health.

Studies report that postpartum women are running and experiencing complications such as pain with running (Blyholder et al., 2017; Tenforde et al., 2015). At two years postpartum, 35% of the postpartum runners surveyed reported musculoskeletal pain when running, with 91% of the pain complaints related to the lower back, pelvis, and/or hips (lumbopelvic) (Blyholder et al., 2017). Lumbopelvic pain is one of the most common and poorly understood health problems experienced during the perinatal period, reportedly affecting 50% of pregnant women regardless of running status (Aggeryd et al., 2021; Borg-Stein and Dugan, 2007; Thein-Nissenbaum et al., 2012). The pain generally dissipates one to three months postpartum (Albert et al., 2001; Ostgaard et al.,1996); however, it may persist in some women, leading to chronic postpartum lumbopelvic pain (Aggeryd et al., 2021). Many risk factors have been associated with the condition; to date, though, only a few systematic reviews exist that have investigated risk factors associated with lumbopelvic pain during the postpartum period (Aggeryd et al., 2021; Gutke et al., 2011). The lack of general postpartum care—much less postpartum care focused on integrating healthy exercise routines into postpartum life—may be one reason for the sparsity of research and rehabilitation (Deering et al., 2020).

In Westernized countries, maternal care is focused on the health of the pregnant female and her baby. During a healthy pregnancy, women are monitored closely up to childbirth, yet once the baby is born, regardless of mode of delivery, the mother typically has one visit at six weeks postpartum (Mottola, 2002). During this visit, physicians screen for postpartum depression, generalized pain, and discuss contraceptive use (Blenning and Paladine, 2005). Guidelines on exercise are inconsistently provided across practitioners (Mottola, 2002). Physical therapy evaluations for strengthening or formal rehabilitation to aid with recovery from childbirth are not typically prescribed. Because of body image, depression, a desire to lose weight (Silveira et al., 2015), and potentially because it is an individualized sport requiring no special equipment or modality, postpartum women turn to running as a form of exercise (Blyholder et al., 2017; Tenforde et al., 2015). Despite its prevalence, clinical providers do not have standardized guidelines to advise women on an appropriate (re)introduction to postpartum running.

1.1.1 Current Evidence

Research regarding musculoskeletal complaints in postpartum runners is non existent; as a result, we lack guidelines on starting or returning to running postpartum. At present, the postpartum literature consists of two case studies, two surveys (Blyholder et al., 2017; Tenforde et al., 2015), and one biomechanical kinematic and a kinetic analysis of postpartum runners (Blyholder et al., 2017; Brumitt, 2009; Provenzano et al., 2019; Tenforde et al., 2015; Thein-Nissenbaum et al., 2012). One of the case studies reported on a female (multiparous, 2 cesarean deliveries) with lumbopelvic pain, lumbar instability, and faulty movement at the trunk on evaluation (Thein-Nissenbaum et al., 2012). Another case study reported on a postpartum runner eager to return to running (multiparous, three children, 1 cesarean delivery), who had decreased core muscle endurance, impaired mobility, and decreased strength in one hip (Brumitt, 2009). In both cases, the women had pain when running (Brumitt, 2009; Thein-Nissenbaum et al., 2012).

When assessing the results of the surveys and kinematic studies in postpartum runners, the odds of pain in postpartum runners were related to and was increased with a previous injury (Blyholder et al., 2017). In order to help understand the habits of postpartum runners, data were collected on participation rates, breastfeeding and running, and postpartum depression in runners (Tenforde et al., 2015). The kinematic study investigating the biomechanics of running gait in women during early pregnancy and postpartum reported on restricted pelvic and trunk movement in postpartum runners (N=5) (Provenzano et al., 2019). The researchers hypothesized that this finding was a protective response to gain stability while running during the postpartum period (Provenzano et al., 2019). The three studies overviewed here—while representative of a growing interest in postpartum running—do not provide adequate evidence to gain a robust understanding of postpartum running nor postpartum running-related pain. This paucity of current evidence highlights one of the main reasons no specific postpartum running guidelines exist. Evidence-based information is desperately needed to guide runners and their health care providers.

1.2 Rationale for the Thesis

This thesis seeks to answer one primary question about postpartum running: What are the risk factors related to pain when initiating or returning to running after childbirth? The postpartum runner has significant musculoskeletal changes to recover from following childbirth. When initiating or resuming running, the new mother may discover barriers such as musculoskeletal pain and time constraints that prevent her from returning to exercise (Edie et al., 2021). Current initiation or return to running recommendations are hypothesized from postpartum cohorts who do not participate in running or cohorts of runners who are not postpartum. Detailed investigations of this specific cohort, postpartum runners, are limited. Each chapter and individual investigation involved a stepwise progression in the inquiry of postpartum pain with running. Due to a lack of literature on the postpartum runner, this thesis begins with a systematic review of musculoskeletal risk factors for running-related pain in the general population, followed by a systematic review of risk factors for first-onset lumbopelvic pain in the postpartum population. To supplement these reviews, the thesis then contains an expert consensus, Delphi study, on risk factors commonly observed in postpartum runners in pain. The results of the systematic reviews and Delphi study informed a survey of postpartum women with and without running-related pain that identified risk factors for running-related pain during the postpartum period. Alongside this, I performed one of the first biomechanical studies in a population of postpartum runners to identify running kinetics and musculoskeletal risk factors as compared to matched controls. These studies combined represent the first steps in identifying the common risk factors for pain in postpartum runners.

1.3 Aims and Hypothesis

1.3.1 Aims

The overall aim of this thesis is to identify possible risk factors for running-related pain in postpartum runners and determine their relationship to running, postpartum variables, and movement kinematics. This is achieved through five sub-aims, each corresponding to separate studies reported in Chapters 3 through 7.

1.3.2 Specific Aims of the Studies in this Thesis

The specific aims of the five studies comprising this thesis are:

1. To identify predictors of lower extremity injury—such as alterations in muscle strength, flexibility, joint range of motion, and alignment—in runners via a systematic review (Chapter 3).

2. To determine risk factors (modifiable and nonmodifiable) for first-onset lumbopelvic pain during the postpartum period via a systematic review (Chapter 4).

3. To assess expert consensus on musculoskeletal impairments in postpartum runners with pain, as well as generate expert ideas on common risk factors for pain in postpartum runners (Delphi study reported in Chapter 5)

4. To identify risk factors for pain in postpartum runners using a case control group of postpartum runners with and without a self-report of running-related pain. A sub aim was to explore a compounding effect of multiple associative variables and pain in postpartum runners, resulting in the development of a clinical decision tool (survey of postpartum runners reported in Chapter 6).

5. To investigate musculoskeletal differences in overground running kinetics, strength, and flexibility between postpartum runners and age-matched nulliparous controls (biomechanical study reported in Chapter 7).

1.4 Overview of Thesis

This thesis is arranged into eight chapters. It consists of an introduction and literature review, followed by a series of five studies. Three of the manuscripts have been published in refereed journals and are presented in the format of each of the specific journals. The manuscripts in chapter 6 and 7 are under review. At the start of each chapter, a brief overview is presented to provide context of each paper as part of this overall thesis.

The introduction provides the background, the aims of the thesis, the rationale and the significance. Chapter 2 is a literature review that establishes why postpartum runners are a unique population in need of further study, identifies their potential risk factors for injury and pain, and highlights the lack of research in this field and a need for future studies. In order to collect risk factors for pain in postpartum running, two background systematic reviews were performed in postpartum and running populations respectively. Chapter 3 is a systematic review investigating musculoskeletal alterations in strength, flexibility, and range of motion that predict injury in runners. To understand risk factors for first time lumbopelvic pain after childbirth, another systematic review was conducted in Chapter 4, which investigates predictive risk factors for first-time lumbopelvic pain in postpartum women. To gather conceptual data involving postpartum women who are running, expert clinicians were asked to report on the most common musculoskeletal impairments and pain characteristics in postpartum runners and reach consensus as a group on the impairments. The results of this Delphi survey are presented in Chapter 5. In Chapter 6, a survey study is presented. The findings of the Delphi were used to design a survey to understand pain in postpartum runners. The risk factors proposed by the experts were validated in the postpartum running population and a clinical decision tool was created to understand the compounding effects of multiple associative variables and postpartum running-related pain. As the effect of pregnancy and postpartum-related musculoskeletal and physiologic changes on running gait are unknown, a cross sectional study investigating running-related variables was conducted in a biomechanics laboratory. This study is outlined in Chapter 7; the study investigates the kinematic and musculoskeletal differences between postpartum runners and nulliparous controls. The final chapter, Chapter 8, provides a summary of the key findings of this research and thesis with clinical recommendations for practice and future research.

1.5 Significance

Women are initiating or returning to running after having a baby. Of postpartum women surveyed, 35% complained of pain with running; of the women in pain, 91% experienced lumbopelvic pain upon returning to running (Blyholder et al., 2017). During the postpartum period, women are recovering from several pregnancy-related changes such as increased weight gain (National Research Council et al., 2010), hormonal changes such as joint and connective tissue laxity, postural changes such as increased lumbar lordosis, flattening of feet (Albright 2016), transient osteoporosis (Colleran et al., 2012; Krebs et al., 1997), and the after-effects of the birthing process, such as tearing of the pelvic floor muscles or recovering from c-section surgery (Hartmann and Sarton, 2014).

Despite these issues, studies have not investigated postpartum runners in detail. We are left with the following knowledge that initiated this line of inquiry:

1. Women are initiating or returning to running and experiencing pain.

2. There are fewer than ten studies investigating risk factors for injury in the postpartum running population.

3. There are no peer-reviewed published return-to-running guidelines for postpartum runners; the recommendations that do exist are mostly expert opinion hypothesized from other cohorts such as non-athlete postpartum women or other running cohorts.

This thesis consists of two systematic reviews, a Delphi consensus of experts, a survey of postpartum runners themselves, and a biomechanical analysis of postpartum runners that will provide the basis for future studies to evaluate risk factors for postpartum running-related pain in longitudinal studies and randomized control trials. Increased evidence-based research and validation of risk factors in postpartum running populations will help inform and improve guidelines for returning to running post-childbirth.

CHAPTER 2. Literature Review

2.1 Introduction

Running is a popular sport worldwide. According to the popular running app Strava, 36 million athletes from 195 countries logged 6.67 billion miles in 2017 (Dawson, 2018). Running's popularity may be due, in part, to its significant psychological and physiological health benefits. Runners have up to 40% reduced risk of premature mortality and live almost three years longer than non-runners (Lee et al., 2017). Running is beneficial for the whole body: it improves endurance, helps with weight loss, and decreases the risk of cardiovascular disease (Hespanhol Junior et al., 2015; Wewege et al., 2017). Although running is associated with a myriad of benefits, running-related injury (RRI) is one of the biggest reasons that runners limit or stop running (Juhler et al., 2020). While acute injuries are rare, the reported incidence of overuse injuries in runners is between 19.4% to 92.4%, with the most common sites in the lower extremity being the knee, lower leg, foot and upper leg (van Gent et al., 2007; Walther et al., 2005). Less commonly, injury in the ankle, hip, or pelvis are reported (van Gent et al., 2007). Injury rates largely correspond with the distances runners routinely run: short distance runners have injury rates up to 44.7%; long distance runners report as high as 79.3% (Van der Worp et al., 2015).

Several studies have attempted to understand the etiology of running injuries but have largely concluded that running injury is multifactorial (Vannatta et al., 2020). Some of the well-studied risk factors associated with running injury are personal factors (age, gender, body mass index, running experience, previous sports activity, level of competition, foot morphology), training factors (running frequency, volume, distance, terrain, shoe age, musculoskeletal impairments, intrinsic gait related factors, and peak force), and health related factors (previous injury) (Christopher et al., 2019; Vannatta et al., 2020; van Poppel et al., 2020). Less studied risk factors, such as sleep and fatigue, can also predict injury (Johnston et al., 2020).

Female runners may be more susceptible to running-related injuries than men; specifically, women appear more likely to suffer knee injuries than men (Francis et al. 2019). Data on risk factors is lacking despite increased female participation in the sport (Running USA Releases Latest U.S. Running Trends Report, 2020), and only a few studies have studied sex differences (Van der Worp et al., 2015). In 2020, USA running reported that 60% of the participants that attended running events were women. Of those women, almost half (49%) were between the ages of 25 and 40 years, which are typical childbearing years (Running USA Releases Latest U.S. Running Trends Report, 2020).

Despite the large number of female runners and runners of childbearing age (Running USA Releases Latest U.S. Running Trends Report, 2020), research on risk factors of RRI during childbearing years is sparse. Postpartum runners are returning to running, as indicated by one study that found that 48% of female runners returned to running less than 4 weeks after childbirth and 84% of participants returned to running by 12 weeks postpartum (Blyholder et al., 2017). Blyholder et al. (2017) reported that thirty-five percent of the women in their study, which included women up to two years postpartum, had musculoskeletal pain predominantly in the lumbar spine, hips and pelvis when they returned to running. Much like the sparsity of literature investigating running injuries in females, the factors resulting in or predicting pain in postpartum runners are poorly understood. In spite of the potential injury risks and pain present in postpartum runners, no high-quality peer review studies have investigated these factors in the postpartum running population.

This chapter reviews extant research related to (1) risk factors for running injuries in the general population, female runners, and postpartum runners; (2) postpartum changes in the musculoskeletal system that can complicate a return to running; and (3) risk factors for postpartum pain. Because this thesis aims to understand risk factors for running-related pain in postpartum runners, this review primarily focuses on synthesizing risk factors that have been studied for associations with RRI in the general population, female population, and postpartum population. Understanding the gaps in the literature will guide future studies in this thesis.

2.2 Risk Factors for Running Injuries and Pain in the General Population

Running injury is multifactorial. A deeper understanding of the factors can assist clinicians with injury prevention strategies. To understand the contributing factors for RRI, this chapter categorizes the risk variables into personal, training, biomechanical, and health (van Poppel et al., 2020). Running cohorts have also been categorized by short or long-distance runners to assist with a deeper understanding of the complexities of risk and injury as mileage increases or decreases (van Poppel et al., 2020). Short distance running was defined as ≤20km/week and ≤10km/session; long distance running was defined as >20km/week and >10km/session (van Poppel et al., 2020). Studies that did not report weekly mileage were included for completeness. Table 2.1 presents literature published on risk factors for RRI categorized by general population, female runners, and postpartum runners; for each category, literature is sub-divided into short and long distance running where known.

Table 2.1 Comprehensive summary of risk factors associated with running-related injury in the general, female and postpartum populations respectively

Risk Factors		**Type of runner (Weekly mileage)**	**General Population**	**Female Runners**	**Postpartum Runners**
Personal Factors	Sleep	Distance unknown	Associated (Johnston et al. 2020)	-	-
	Sex	Short distance	Associated (Buist et al. 2010) Not associated (Kluitenberg et al. 2015; Nielsen et al. 2013)	Not Associated (Buist et al. 2010; Buist et al. 2010)	-
		Long distance	Associated (Messier et al. 2018) Not associated(Dudley et al. 2017; Reinking et al. 2007)	NA	NA
		Distance unknown	Not associated (Ghani Zadeh Hesar et al. 2009; Kliethermes et al. 2021)	NA	NA
	Age	Short distance	Associated (Buist et al. 2010; Kluitenberg et al. 2015)	Associated (Taunton et al. 2003)	-

			Not associated (Nielsen et al. 2013; Taunton et al. 2003; Van derWorp et al. 2016)	Not associated (Buist et al. 2010; Buist et al. 2010)	
		Long distance	Not associated (Dudley et al. 2017; Messier et al. 2018)	Associated (Kelsey et al. 2007)	-
		Distance unknown	Not associated (Ghani Zadeh Hesar et al. 2009; Kliethermes et al. 2021; Thijs et al. 2011;Van Ginckel et al. 2009)	-	-
	Height	Short distance	-	-	-
		Long distance	Not associated (Dudley et al. 2017; Messier et al. 2018)	-	-
		Distance unknown	Not associated (Ghani Zadeh Hesar et al. 2009; Thijs et al. 2011; Van Ginckel et al. 2009)	-	-
	BMI	Short distance	Associated (Buist et al. 2010; Kluitenberg et al. 2015; Taunton et al. 2003)	Associated (Buist et al. 2010)	-

			Not Associated (Nielsen et al. 2013; Van der Worp et al. 2016)	Not associated (Buist et al. 2010; Taunton et al. 2003)	
		Long distance	Not associated (Messier et al. 2018)	-	-
		Distance unknown	Not associated (Kliethermes et al. 2021; Thijs et al. 2011; Van Ginckel et al. 2009)	-	-
	Weight	Short distance	-	-	-
		Long distance	Not Associated (Dudley et al., 2017; Messier et al., 2018)	-	-
		Distance unknown	Not associated (Ghani Zadeh Hesar et al. 2009; Thijs et al. 2011; Van Ginckel et al. 2009)	-	-
	Running experience	Short distance	Associated (Buist et al. 2010; Kluitenberg et al. 2015) Not associated (Nielsen et al. 2013; Van der Worp et al. 2016)	Associated (Buist et al. 2010)	-

		Long distance	Not associated (Hespanhol Junior et al. 2013; Messier et al. 2018)	-	-
	Previous sports activity	Short Distance	Associated (Buist et al. 2010) Not associated (Kluitenberg et al. 2015; Nielsen et al. 2013; Taunton et al. 2003; Van der Worp et al. 2016)	Associated(Buist et al. 2010) Not Associated (Buist et al. 2010; Taunton et al. 2003)	-
		Long distance	-	-	-
	Behavior (Competitive/hyperactive vs. relaxed/laid back, Type A, motivated)	Short distance	Associated (Nielsen et al. 2013) Not associated (Buist et al. 2010)	Not associated (Buist et al. 2010)	-
		Long distance	Not associated (Hespanhol Junior et al. 2013)	-	-
	Foot morphology (plantar arch index, navicular drop or foot pronation)	Short distance	Associated: Foot posture index (Nielsen et al. 2014) Not associated: Navicular drop (Buist et al. 2010; Taunton et	Associated: Navicular drop (Buist et al. 2010) Not associated (Taunton et al. 2003)	-

			al. 2003; Van der Worp et al. 2016)		
		Long distance	Not associated: Arch index (Hespanhol Junior et al. 2016; Messier et al. 2018) Navicular drop (Dudley et al. 2017)		-
	Strength	Short distance	Associated: Eccentric hip abduction (Ramskov et al. 2015)	-	-
		Long distance	Associated: Knee flexor (Hein et al. 2014) Not associated: Abdominal flexion, back extension, bilateral hip abduction, bilateral hip adduction, unilateral knee extension (Hein et al. 2014)	-	-

			Hip abductors, knee extensors, knee flexors, knee ratio, ankle plantar flexors (Messier et al. 2018)		
		Distance unknown	Not associated: Hip flexors, extensors, abductors, adductors, external and internal rotators (Thijs et al. 2011)	-	-
	Flexibility/Range of motion	Short distance	Not associated: MTP extension (Van der Worp et al. 2016) Hip internal and external rotation, ankle dorsiflexion and plantarflexion range of motion (Buist et al. 2010)	Not associated: Hip internal and external rotation, ankle dorsiflexion and plantarflexion range of motion (Buist et al. 2010)	-
		Long distance	Not Associated: Hip, knee, ankle (Hein et al. 2014) Flexibility of Quadricep, hamstring, plantar flexors,	-	-

			dorsiflexors (Messier et al. 2018)		
	Alignment	Short distance	Arch height not associated (Taunton et al. 2003)	Arch height not associated (Taunton et al. 2003)	-
		Long distance	Not associated Limb length discrepancy, Q-angle, subtalar angle (Hespanhol Junior et al. 2016) Q angle (Messier et al. 2018)	-	-
		Distance unknown	Q angle not associated (Thijs et al. 2011)		
Training Factors	Running frequency	Short distance	Associated (Malisoux et al. 2015) Not associated (Kluitenberg et al. 2016; Taunton et al. 2003)	Associated (Taunton et al. 2003)	-
		Long distance	Not associated (Hespanhol Junior et al. 2013)	-	-

	Training volume	Short distance	Associated (Kluitenberg et al. 2016; Malisoux et al. 2015) Time not associated (Van der Worp et al. 2016)	-	-
		Long distance	Preseason not associated (Dudley et al. 2017) In season not associated (Brund et al. 2017; Dudley et al. 2017; Hein et al. 2014)	Not associated (Kelsey et al. 2007)	-
	Weekly running distance /duration	Short distance	Associated (Van der Worp et al. 2016) not associated (R. Ø. Nielsen et al. 2014)	-	-
		Long distance	Associated Duration (Hespanhol Junior et al. 2013) Not associated Distance (Hein et al. 2014; Hespanhol Junior et al. 2013)	-	-
		Distance unknown		-	-
	Pace/speed/interval/intensity	Short distance	Previous session intensity associated	-	-

			(Kluitenberg et al. 2016)		
		Long distance	Speed and interval associated (Hespanhol Junior et al. 2013) Not associated (Dudley et al. 2017; Hein et al. 2014)	-	-
		Distance Uknown	Not associated (Kliethermes et al. 2021)	-	-
	Terrain/surface	Short distance	No association (Taunton et al. 2003; Van der Worp et al. 2016)	Not Associated (Taunton et al. 2003)	-
		Long distance	Not associated (Hein et al. 2014; Hespanhol Junior et al. 2013)	-	-
	Shoe age	Short distance	Associated (Taunton et al. 2003) Not associated (B. Kluitenberg et al. 2015; Van der Worp et al. 2016)	Associated (Taunton et al. 2003)	-
		Long distance	-	-	-
	Training shoes per week	Long distance	-	-	-

	Previous type of training shoe	Short distance	Not associated (Kluitenberg et al. 2015)	-	-
		Long distance	-	-	-
	Shoe heel drop	Long distance	Not associated (Dudley et al. 2017)	-	-
	Changed shoe classification	Long distance	Not associated (Messier et al. 2018)	-	-
	Cross training	Short distance	Not associated (Taunton et al. 2003)	Not associated (Taunton et al. 2003)	-
		Long distance	Not associated (Hein et al. 2014)	-	-
Biomechanics: Kinetics Factors (GRF variables)	Vertical impact peak	Short distance	-	-	-
		Long distance	Not associated (Messier et al. 2018)	Associated: Previous injury (Davis et al. 2016) Not Associated (Davis et al. 2016)	-
		Distance unknown	Associated (Kliethermes et al. 2021) Associated: Between limb asymmetry (Bredeweg et al. 2013) Not associated (Bredeweg et al. 2013)	Not associated (Bredeweg et al. 2013)	

	Time to impact peak	Short distance	-	Not Associated Vertical impact transient (Napier et al. 2018)	-
		Long distance	-	-	-
		Distance unknown	Not associated (Bredeweg et al. 2013; Kliethermes et al. 2021) Not associated with between limb asymmetry (Bredeweg et al. 2013)	Not associated (Bredeweg et al. 2013)	-
	Vertical loading rate	Short distance	-	-	-
		Long distance	-	-	-
		Distance unknown	Associated (Bredeweg et al. 2013) Not associated Peak (Kuhman et al. 2016) Limb asymmetry (Bredeweg et al. 2013)	-	-
	Average vertical loading rate	Short distance	-	Not Associated (Napier et al. 2018)	-
		Long distance	Not associated (Dudley et al. 2017)	Associated:	-

				Previous injured (Davis et al. 2016) Not Associated (Davis et al. 2016) Not associated (pooled analysis, both distances) (Vannatta et al. 2020)	
		Distance unknown	Not associated (Kliethermes et al. 2021)	-	-
	Instantaneous vertical loading rate	Short distance	-	Not Associated (Napier et al. 2018)	-
		Long distance	Not associated (Dudley et al. 2017)	Not Associated (Davis et al. 2016)) Associated: Previous injury (Davis et al. 2016)	-
		Distance unknown	-	-	-
	Vertical active peak	Short distance	-	Not Associated (Napier et al. 2018)	-
		Long distance	Not associated (Messier et al. 2018)	Not Associated (Davis et al. 2016)	-
		Distance unknown	Not associated (Bredeweg et al. 2013)	Not associated (Bredeweg et al. 2013)	

			Not associated Limb asymmetry (Bredeweg et al. 2013)		
	Time to active peak	Short distance	-	-	-
		Long distance	-	-	-
		Distance unknown	Not associated (Bredeweg et al. 2013) Not associated Limb asymmetry (Bredeweg et al. 2013)	Not associated (Bredeweg et al. 2013)	-
	Peak vertical force	Short distance	-	-	-
		Long distance	-	Not associated (Davis et al. 2016)	-
	Breaking force	Short distance	-	Associated (Napier et al. 2018)	-
		Long distance	Not associated (Messier et al. 2018)	-	-
	Breaking impulse	Distance unknown	Not associated (Kliethermes et al. 2021)	-	-
	Propulsive force	Short distance	-	-	-
		Long distance	Not associated (Messier, 2018)	-	-
	Vertical impulse	Short distance	-	Not associated (Napier et al. 2018)	-
		Long distance	-	-	-
		Distance unknown	Associated (Kliethermes et al. 2021)	-	-

Biomechanics: Kinetics Factors (other)	Peak hip abduction moment	Short distance	-	-	-
		Long distance	-	Associated (Eskofier et al. 2012) Not associated (Noehrenet al., 2007)	-
	Peak hip adduction moment	Short distance	-	-	-
		Long distance	Not associated (Dudley et al. 2017)	-	-
	IT band strain	Short distance	-	-	-
		Long distance	-	Associated (Hamill et al. 2008)	-
	IT band peak strain rate	Short distance	-	-	-
		Long distance	-	Not associated (Hamill et al. 2008)	-
	Peak knee flexion	Long distance	Not associated (Messier, 2018)	-	-
	Knee adduction moment	Long distance	Associated (Dudley et al. 2017)	-	-
	Knee abduction moment	Short distance	-	-	-
		Long distance	Associated (Stephanyshyn, 2006) Not associated (Messier et al. 2018)	-	-
	Knee extension moment	Short distance	-	-	-
		Long distance	Not associated (Messier et al. 2018)	-	-
	Knee stiffness	Short distance	-	-	-

		Long distance	Associated (Messier et al. 2018)	-	-
	Knee negative work	Short distance	-	-	-
		Long distance	Not associated (Messier et al. 2018)	-	-
	Knee power absorption	Short distance	-	-	-
		Long distance	Not associated (Messier et al. 2018)	-	-
	Patellofemoral compressive force	Short distance	-	-	-
		Long distance	Not associated (Messier et al. 2018)	Associated (Willson and Davis 2008)	-
	Knee external rotation moment	Short distance	-	-	-
		Long distance	-	Not associated (Noehren et al. 2007)	-
	Knee abduction impulse	Short distance	-	-	-
		Long distance	-	Associated (Stefanyshyn et al. 2006)	-
	Tibial compressive force	Short distance	-	-	-
		Long distance	Not associated (Messier et al. 2018)	-	-
	Rearfoot inversion moment	Short distance	-	-	
		Long distance	-	Not Associated (Noehrenet al., 2007)	-
	Vertical plantar peak forces	Short distance	-	-	-
		Long distance	-	-	-
		Distance unknown	Associated with PFPS (under MT II)(Thijs et al. 2008)	-	-

			Associated (Ghani Zadeh Hesar et al. 2009) Not associated with AT (under MT II) (Thijs et al. 2008)		
	Absolute force time integral	Short distance	-	-	
		Long distance	-	-	-
		Distance unknown	Associated (Ghani Zadeh Hesar et al. 2009)	-	-
	Anteroposterior displacement of the center of force	Short distance	-	-	-
		Long distance	-	-	
		Distance unknown	Associated Greater (Ghani Zadeh Hesar et al. 2009) Smaller (Van Ginckel et al. 2009)	-	-
	Velocity of anteroposterior displacement of center of force	Short distance	-	-	-
		Long distance	-	-	-
		Distance unknown	Associated with slower (Ghani Zadeh Hesar et al. 2009)	-	-
	Mediolateral plantar pressure distribution	Short distance	-	-	-
		Long distance	Higher medial shod pressure associated (Brund et al. 2017)	-	-

		Distance unknown	Associated (Ghani Zadeh Hesar et al. 2009) Laterally directed forced at first metatarsal contact and forefoot associated (Van Ginckel et al. 2009)	-	-
Biomechanics: Kinematic Factors	Peak hip adduction angle	Short distance	-	-	-
		Long distance	Not associated (Dudley et al. 2017)	Associated (Noehren et al. 2007; Noehren et al. 2013)	-
		Distance unknown	Not associated (Kliethermes et al. 2021)	-	-
	Peak hip internal rotation angle	Short distance	-	-	-
		Long distance	Not associated (Dudley et al. 2017)	Not associated (Noehren et al. 2013)	-
	Femur internal rotation	Long distance	-	Associated (Noehren et al. 2007)	
	Peak Knee abduction angle	Short distance	-	-	-
		Long distance	Not associated (Dudley et al. 2017)	-	-
	Peak knee flexion angle	Short distance	-	-	-
		Long distance	Associated (Hein et al. 2014)	-	-

			Not associated (Messier et al. 2018)		
	Time to peak flexion angle	Short distance	-	-	-
		Long distance	Not associated (Hein et al. 2014)	-	-
	Total Knee flexion range of motion	Short distance	-	-	-
		Long distance	Associated (Hein et al. 2014)	-	-
	Knee extension range of motion	Short distance	-	-	-
		Long distance	Associated (Hein et al. 2014)	-	-
	Peak knee internal rotation/femoral external rotation	Short distance	-	-	-
		Long distance	-	Associated (Noehren et al. 2007)	-
	Knee flexion at initial contact	Short distance	-	-	-
		Long distance	-	Not associated (Noehren et al. 2007)	
	Tibia rotation angle	Short distance	-	-	-
		Long distance	-	Not associated (Noehren et al. 2007)	-
	Peak ankle dorsiflexion (degrees)	Short distance	-	-	-
		Long distance	Associated (Hein et al. 2014)	-	-
		Distance unknown	-	-	-
	Ankle Dorsiflexion Range of Motion	Short distance	-	-	-
		Long distance	Associated (Hein et al. 2014)	-	-

		Distance unknown	Not associated (Kuhman et al. 2016)	-	-
	Time to peak ankle dorsiflexion	Short distance	-	-	-
		Long distance	Not associated (Hein et al. 2014)	-	-
	Peak plantarflexion	Short distance	-	-	-
		Long distance	Not associated (Hein et al. 2014)	-	-
	Peak rearfoot eversion(degrees)	Short distance	-	-	-
		Long distance	Associated (Hein et al. 2014) Not associated (Messier et al. 2018; Dudley et al. 2017)	Associated (Noehren, Davis, and Hamill 2007) Not associated (Noehren et al. 2013)	-
		Distance unknown	Associated (Kuhman et al. 2016)	-	-
	Peak rearfoot inversion	Short distance	-	-	-
		Long distance	Not associated (Hein et al. 2014)	-	-
	Rearfoot inversion range of motion	Short distance	-	-	-
		Long distance	Not associated (Hein et al. 2014)	-	-
	Ankle Eversion range of motion	Short distance	-	-	-
		Long distance	Associated (rearfoot) (Hein et al. 2014)	-	-

			Not associated (Dudley et al. 2017) Not associated (Messier et al. 2018)		
		Distance unknown	Associated (Kuhman et al. 2016)	-	-
	Peak ankle eversion velocity	Short distance	-	-	-
		Long distance	Associated (Dudley et al. 2017) Not associated (Messier et al. 2018)	-	-
		Distance unknown	Associated (Kuhman et al. 2016)	-	-
	Ankle eversion duration	Short distance	-	-	-
		Long distance	-	-	-
		Distance unknown	Not associated (Kuhman et al. 2016)	-	-
	Foot strike angle	Short distance	-	-	-
		Long distance	Not associated (Messier et al. 2018; Dudley et al. 2017)	-	-
		Distance unknown	Not associated (Kliethermes et al. 2021)	-	-

	Forefoot angle	Short distance	-	-	-
		Long distance	Not associated (Messier et al. 2018)	-	-
Biomechanics: Spatiotemporal Factors	Foot strike index	Short distance	-	-	-
		Long distance	Not associated (Messier et al. 2018)	-	-
		Distance unknown	Not associated (Kuhman et al. 2016)	-	-
	Step rate	Short distance	-	-	-
		Long distance	-	-	-
		Distance unknown	Associated (Kliethermes et al. 2021; Luedke et al. 2016) Not associated (Bredeweg et al. 2013)	Not associated (Bredeweg et al. 2013)	
	Stride length	Short distance	-	-	-
		Long distance	-	-	-
		Distance unknown	Not associated (Bredeweg et al. 2013) Not associated with asymmetry(Bredeweg et al. 2013)	Not associated (Bredeweg et al. 2013)	-
	Shorter ground contact time	Short distance	-	-	-
		Long distance	-	-	-
		Distance unknown	Associated (Bredeweg et al. 2013)	-	-

			Associated with asymmetry (Bredeweg et al. 2013)		
	Time to vertical plantar peak force	Short distance	-	-	-
		Long distance	-	-	-
		Distance unknown	Associated (Thijs et al. 2008)	-	-
	Step width	Short distance	-	-	-
		Distance unknown	Not associated(Kliethermes et al. 2021)	-	-
	Vertical excursion	Distance unknown	Associated (Kliethermes et al. 2021)	-	-
Health Factors	Previous injury	Short distance	Associated (Van der Worp et al. 2016; Buist et al. 2010) Not Associated (Kluitenberg et al. 2015; Nielsen et al. 2013)	Not associated (Buist et al. 2010)	
		Long distance	Associated (Hespanhol Junior et al. 2013; Hirschmüller et al. 2012; Reinking et al. 2007; Hespanhol Junior et al. 2016),	Associated(Kelsey et al. 2007)	

		Distance unknown	Associated (Kliethermes et al. 2021)	-	-
	Musculoskeletal non running injury	Short distance	Associated (Kluitenberg et al. 2015) Not associated (Nielsen et al. 2013)	-	Associated (Blyholder, 2016)
		Long distance	-	-	-
	Irregular or absent menstruation	Long distance	-	Irregular absent menstruation (Kelsey et al. 2007)	

2.2.1 Personal Factors

The most common personal risk factors investigated for RRI in the general population were gender differences, age, anthropometric measures, psychosocial factors, and clinical factors (Van der Worp et al., 2015). This section explores the relationship between RRI and personal risk factors such as age, height, weight, BMI, running or sports experience, sleep, fatigue, level of competition, foot morphology, strength, flexibility and alignment (Vannatta et al., 2020; van Poppel et al., 2020).

2.2.1.1 Short Distance Runners

When investigating runners that ran short distances, Buist et al (2010) found that being female was associated with RRI, though Neilson et al (2013) and Kluitenberg et al (2015) did not. Two studies (Buist et al., 2010; Kluitenberg et al., 2015) found higher age to be a risk factor, but multiple other studies found no association between age and RRI in the general short distance running population (Nielsen et al., 2013; Taunton et al., 2003; Van der Worp et al., 2016). Height and weight were not studied for an association with RRI in short distance runners; however, there was conflicting information identifying BMI as a risk factor for RRI (Buist et al., 2010; Kluitenberg et al., 2015; Nielsen et al., 2013; Taunton et al., 2003; Van der Worp et al., 2016). When investigating short-distance runners' running experience and RRI, there was conflicting evidence: two studies found a relationship (Buist et al., 2010; Kluitenberg et al., 2015) and two did not (Nielsen et al., 2013; Van der Worp et al., 2016). Runners' previous sporting experience was not associated with RRI in multiple studies (Kluitenberg et al., 2015; Nielsen et al., 2013; Taunton et al., 2003; Van der Worp et al., 2016); however, a runner's behavior—such as being too laid back—was correlated with RRI (Nielsen et al., 2013).

In addition to these behavioral risk factors, physiological and musculoskeletal risk factors emerged as important categories in short distance runners. One study (Nielsen et al., 2014) found that runners that pronate had significantly fewer RRI (per 1000km of running) when compared with normal foot morphology whereas three studies also studying foot morphology found no association with RRI (Buist et al., 2010; Taunton et al., 2003; Van der Worp et al., 2016). Only one study (Ramskov et al., 2015) investigated strength in short distance runners, and it identified a significant relationship between hip abduction and RRI. When investigating flexibility, one study (Van der Worp et al., 2016) did not find an association with first metatarsophalangeal range of motion and RRI. Of the alignment risk factors investigated, arch height was not associated with RRI (Taunton et al., 2003). In all, several personal factors were studied in short distance runners; however, there was either limited evidence or conflicting evidence in most of the categories of personal factors. Future clinical research should investigate musculoskeletal impairments (strength, flexibility, alignment), since physiotherapists commonly use those measures to evaluate and treat a patient after an injury.

2.2.1.2 Long Distance Runners

When investigating personal risk factors for RRI specifically in long-distance runners, age (Dudley et al., 2017; Messier et al., 2018), height (Dudley et al., 2017; Messier et al., 2018), BMI (Messier et al., 2018) and weight (Dudley et al., 2017; Messier et al., 2018) were not risk factors for RRI. There was conflicting evidence for sex, as one study (Messier et al., 2018) found being female was a risk factor for RRI and two did not (Dudley et al., 2017; Reinking et al., 2007). Experience, specifically being a novice runner, was not related to RRI (Hespanhol Junior et al., 2013; Messier et al., 2018). Hespanhol et al (2013) did not find a relationship with RRI and a runner's motivation.

Foot morphology was investigated in three studies, and neither study identified an association between arch index (Hespanhol Junior et al., 2016; Messier et al., 2018) or navicular drop and RRI (Dudley et al., 2017). Of the strength variables investigated, two studies found no association with hip, knee, or ankle strength and RRI, with the exception of hip flexor strength (Hein et al., 2014; Messier et al., 2018). Similarly, several studies investigating flexibility, motion, and alignment also reported no relationship between these clinical tests and RRI (Hein et al., 2014; Hespanhol Junior et al., 2016; Messier et al., 2018). As seen with short distance runners, studies investigating personal factors and long-distance runners had similar results, where there was either a lack of studies investigating each variable or conflicting evidence. More systematic reviews are needed to pool data, synthesize results and evaluate quality of the studies to improve the understanding of risk factors and RRI, specifically musculoskeletal risk factors and RRI.

2.2.1.3 Running Distance Not Reported

In studies that did not report weekly running mileage of the participants at baseline, multiple studies found no relationship between RRI and age (Hesar et al., 2009; Kliethermes et al., 2021; Thijs et al., 2011; Van Ginckel et al., 2009), height (Hesar et al., 2009; Thijs et al., 2011; Van Ginckel et al., 2009), BMI (Hesar et al., 2009; Thijs et al., 2011; Van Ginckel et al., 2009) and weight (Hesar et al., 2009; Thijs et al., 2011; Van Ginckel et al., 2009). When investigating musculoskeletal variables such as strength and alignment, Thijs et al (2011) did not find an association between strength of the hip (flexors, abductors, adductors, internal and external rotators) or Q angle alignment and RRI (Thijs et al., 2011). In summary, no risk factors were associated with RRI in studies that did not report average running mileage for the participants.

2.2.2 Training Factors

The most common training risk factors investigated for RRI were running frequency, volume, distance, and terrain. In this section, the relationship between these risk factors and RRI will be sub-divided by running distance and synthesized.

2.2.2.1 Short Distance Runners

When investigating short distance runners, there was conflicting evidence on running frequency and RRI: Masiloux et al (2015) found an association between running frequency and RRI, whereas Kluitenberg et al (2016) did not. Lower weekly volume was identified as a risk factor for RRI: one study (Kluitenberg et al., 2016) found running more than 60 minutes to be a protective factor, a finding consistent with another study's conclusion that running for less than 120 minutes was a risk factor (Malisoux et al., 2015). This information was contradicated by Van der Worp et al (2016), as they did not find an association between running time and RRI. Studies that assessed weekly running distance as opposed to weekly time spent running had conflicting evidence: Nielsen et al (2014) found no association between weekly distance running and injury, while Van der Worp et al (2016) found >30km/ week to be a risk factor for injury. In addition to running time and distance, researchers have examined a myriad of factors associated with training. Kluitenberg et al (2016) investigated running pace and did not find that increased intensity at a previous session and RRI had a relationship. Evidence suggested that terrain may not be a risk factor for RRI (Taunton et al., 2003; Van der Worp et al., 2016). Lastly, cross training did not have a relationship with RRI (Taunton et al., 2003).

Several studies (Kluitenberg et al., 2016; Taunton et al., 2003; Van derWorp et al., 2016) investigated the relationship between a short distance runner's feet and RRI, and only Taunton et al (2003) found a relationship between the ages of running shoes and RRI.

There was no relationship between the previous type of shoe and RRI in the general running population (Kluitenberg et al., 2016). In summary, no conclusions can be drawn about training-related risk factors in short distance runners and RRI because of conflicting data and the limited number of studies investigating these factors. More studies are needed to understand the relationship between training-related risk factors and RRI.

2.2.2.2 Long Distance Runners

Across studies, training-related factors were not identified as risk factors for long distance runners. This held true across running frequency (Hespanhol Junior et al., 2013), training volume (Brund et al., 2017; Dudley et al., 2017; Hein et al., 2014), running terrain (Hein et al., 2014; Hespanhol Junior et al., 2013), and shoe-related variables such as the number of training shoes per week, previous type of training shoe, and change in shoe classification (Dudley et al., 2017; Hein et al., 2014; Messier et al., 2018). Weekly running duration (minutes/ session) and the types of training (speed and interval) were the only training-related risk factors associated with RRI in long distance runners (Hespanhol, 2013).

2.2.2.3 Running Distance Not Reported

Among the studies that did not report weekly running mileage for participants, one study found that an increase in 30% of weekly mileage within a two-week period was related to running injury (Neilson, 2014), whereas runners' preferred running speed was not (Kliethermes et al., 2021).

2.2.3 Biomechanics Factors

Ground reaction forces, kinematics, and kinetics were investigated to understand the relationship between these biomechanical variables and RRI. In this section, the relationship between these biomechanical risk factors and RRI will be synthesized.

2.2.3.1 Short Distance Runners

There were no studies investigating biomechanical variables (ground reaction forces, kinetics and kinematics) and RRI in short distance runners.

2.2.3.2 Long Distance Runners

Only five studies have investigated the relationship between biomechanical variables and RRI in long distance runners (Brund et al., 2017; Dudley et al., 2017; Hein et al., 2014; Messier et al., 2018; Stefanyshyn et al., 2006). No relationship was found between ground reaction forces—specifically, vertical impact peak, average and instantaneous vertical loading rate, propulsive forces, vertical propulsive forces, braking force and vertical active peak—and RRI (Dudley et al., 2017; Messier et al., 2018). Of the kinetic variables investigated, peak hip adduction moment, peak knee flexion moment, knee extension moment, knee negative work, knee power absorption, patellofemoral compressive forces and tibial compressive force were not associated with RRI (Dudley et al., 2017; Messier et al., 2018). Messier et al (2018) did find a relation between one factor—knee stiffness—and injury prevalence. There was conflicting evidence when investigating internal knee abduction moment, as one study (Stephanyshyn, 2006) reported an association with RRI and another (Messier et al., 2018) did not. Dudley et al (2017) found that knee adduction moment was related to RRI. Brund et al. (2017) examined the foot and biomechanical factors related to RRI and found that runners who displayed more medial pressure during stance at a baseline test developed more RRIs compared to those with lateral shod pressure during stance.

Of the kinematic variables investigated as risk factors for RRI in long distance runners, peak hip adduction angle, peak hip internal rotation angle, peak knee abduction angle, time to peak knee flexion angle, ankle dorsiflexion range of motion, time to peak dorsiflexion, peak plantarflexion, peak rearfoot inversion, rearfoot inversion range of motion, ankle eversion duration, foot strike angle, foot strike index and forefoot angle were not associated with RRI (Dudley et al., 2017; Hein et al., 2014; Messier et al., 2018); however, total knee flexion range of motion, knee extension range of motion, peak ankle dorsiflexion and ankle dorsiflexion range of motion were (Hein, 2014). There was conflicting information on the relationship between RRI and peak knee flexion angle (Hein et al., 2014; Messier et al., 2018), peak rearfoot eversion (Dudley et al., 2017; Hein et al., 2014; Messier et al., 2018), ankle eversion range of motion (Dudley et al., 2017; Hein et al., 2014; Messier et al., 2018) and peak eversion velocity (Dudley et al., 2017; Messier et al., 2018). In summary, most biomechanical variables were not associated with RRI; however, one should use caution when interpreting the results, as many of the risk factors were measured in single studies or had conflicting results.

2.2.3.3 Running Distance Not Reported

Among the studies that did not report on weekly running mileage of their participants, most found no relationship between biomechanical risk factors and RRI (Bredeweg et al., 2013; Kliethermes et al., 2021; Kuhman et al., 2016). There was conflicting data on whether RRI are affected by vertical impact peak, vertical loading rate and vertical impulse (Bredeweg et al., 2013; Bredeweg et al., 2013; Kliethermes et al., 2021). Of the kinetic forces investigated, vertical plantar peak forces, absolute force time integral, medial lateral pressure distribution, and a slower velocity of anteroposterior displacement were associated with RRI (Hesar et al., 2009; Thijs et al., 2008; Van Ginckel et al., 2009). There was conflicting information regarding anteroposterior displacement of the center of forces: Hesar et al. (2009) found that a greater anteroposterior displacement of the center of force was related to running injury, whereas Van Ginkel et al. (2009) found a smaller displacement to be related to running injury. When investigating spatiotemporal variables, a decreased step rate was associated with injury in two studies (Kliethermes et al., 2021; Luedke et al., 2016); however, a different study found no association with RRI (Bredeweg et al., 2013). Stride length and symmetry between legs for stride length were both unrelated to RRI; however, shorter ground contact time and symmetry between legs for ground contact time were associated with RRI in two studies (Bredeweg et al., 2013; Bredeweg et al., 2013). Kliethermes et al. (2021) found that vertical excursion was related to RRI; however, step width was not. Lastly, time to peak vertical plantar force was related to injury in one study (Thijs et al., 2008). Therefore, in runners with unknown running mileage, a few kinetic factors and spatiotemporal variables were related to RRI. Because very few studies investigated each of these biomechanical risk factors, more research is needed.

2.2.4 Health Factors

The most common training health or lifestyle related factors investigated for RRI were previous injury and previous musculoskeletal injury (non-running-related). In this section, the relationship between these risk factors and RRI will be presented.

2.2.4.1 Short Distance Runners

Conflicting information exists regarding previous RRI as a risk factor for RRI in short distance runners. Two studies found an association with prior injury and RRI (Buist et al., 2010; Van der Worp et al., 2016), whereas two studies did not (Kluitenberg et al., 2015; Nielsen et al., 2013). When looking specifically at musculoskeletal injury, one study (Kluitenberg et al., 2015) concluded that a previous musculoskeletal complaint was a risk factor for new RRI, whereas one study (Nielsen et al., 2013) did not.

2.2.4.2 Long Distance Runners

Previous injury has been well established as a risk factor for injury in multiple sports and was also confirmed in long distance runners by several studies that found associations between previous RRI and new RRI (Hespanhol Junior et al., 2013, 2016; Hirschmüller et al., 2012; Reinking et al., 2007),

2.2.4.3 Running Distance Not Reported.

There were no studies in this section.

2.3 Risk Factors for Running Injuries and Pain in Female Runners

Studies exploring running risk factors in relation to sex differences are scarce (Van der Worp et al., 2015). It is important to note that only a few studies investigating risk factors have reported any sex differences. A systematic review from 2015 investigating risk factors and sex differences reported older age, running on concrete, running distance of greater than 48km but less than 63.8km, and wearing running shoes for 4-6months, and previous participation in non-axial sports, such as cycling and swimming, participating in a marathon in the last 12 months as risk factors that increased the risk of a running-related injury in women (Van der Worp et al., 2015). In individual studies, Macera et al. (1989) found that both men and women had similar rates of overuse running injury (50%) and Taunton et al. (2003) concluded that certain injuries were sex dependent. To understand risk factors in female runners, the next section identifies personal, training, biomechanical and health related risk factors that have been studied for their association with RRI in females.

2.3.1 Personal Factors

The most common personal risk factors investigated for RRI in the female running population were, age, anthropometric measures, and psychosocial factors (Vannatta et al., 2020). In this section, the relationship between these personal risk factors (age, BMI, foot morphology, and experience with running or other sports) and running-related injury will be synthesized.

2.3.1.1 Short Distance Runners

When investigating personal risk factors for RRI in short distance female runners, there was conflicting information about age and RRI: one study reported women >50 years were at higher risk for injury (Taunton et al., 2003), but two studies reported that age was not associated with RRI (Buist et al., 2010; Buist et al., 2010). Information on BMI and RRI in female runners that ran short distances was also conflicting, as one study (Buist et al., 2010) reported BMI to be a risk factor for RRI, whereas two studies did not (Buist et al., 2010; Taunton et al., 2003). Running experience and previous sports experience without axial load were both found to be risk factors for RRI in female runners in one study (Buist et al., 2010); however two studies did not find an association with previous sports experience and RRI (Buist et al., 2010; Taunton et al., 2003). Psychological variables, such as behavior (competitive vs. laid back) were not associated with RRI (Buist et al., 2010). There was conflicting information on musculoskeletal variables, specifically foot morphology and RRI, as a high amount of navicular drop was considered a risk factor for RRI in female runners in one study (Buist et al., 2010), but arch height was not found to be associated with injury in a different study (Taunton et al., 2003). No relationship was found between range of motion, and strength variables were not measured in female short distance runners (Buist et al., 2010). Overall, few studies have examined personal risk factors for RRI in female short distance runners, and evidence was inconclusive at best.

2.3.1.2 Long Distance Runners

One study (Kelsey et al., 2007) investigated personal risk factors for long distance female runners and found higher age to be a protective factor.

2.3.2 Training Factors

Researchers studied training-related risk factors and injury in female runners by assessing running frequency, training volume, terrain, and shoe age. The following section synthesizes the findings between these training-related risk factors and RRI.

2.3.2.1 Short Distance Runners

Of the research investigating training-related factors in short distance female runners, one study found that running less (1 day/week or less) was associated with RRI in females (Taunton et al., 2003). A running shoe of 4-6months (compared to 1-3months, 7-

12months or 1-2 years) was a risk factor for RRI in female runners (Taunton et al., 2003). Terrain was not associated with RRI (Taunton, 2003).

2.3.2.2 Long Distance Runners

Only one study investigated training related risk factors in long distance runners; it found no association between training volume and RRI in female runners (Kelsey et al., 2007).

2.3.3 Biomechanics Factors

Ground reaction forces, kinematics, and kinetics were investigated in female runners to understand the relationship between biomechanical risk factors and RRI specifically in females. This section explores the relationship between these biomechanical risk factors in female runners and RRI.

2.3.3.1 Short Distance Runners

In short distance runners, Napier et al. (2018) found no association between vertical impact transient, average vertical loading rate, vertical active peak, instantaneous loading rate, vertical impulse and running injury in females; however, they did find a relationship between peak braking force and RRI.

2.3.3.2 Long Distance Runners

When investigating ground reaction forces in female recreational runners that ran >20km/week, no difference in vertical impact peak was found between injured and uninjured runners (Davis et al., 2016). In female runners that sustained a previous RRI, vertical impact peak was associated with RRI (Davis et al., 2016). Average vertical loading rate and instantaneous loading rate were not associated with RRI; in runners that had a history of injury, though, these risk factors were associated with RRI (Davis et al., 2016). Davis et al. (2016) found no association when investigating vertical active peak and peak vertical force with RRI in female runners. There was conflicting information on hip kinetics and RRI. Noehren et al. (2007) found limited evidence that hip abduction moment is not an important risk factor for RRI, and Eskofier et al. (2012) found that increased hip abduction moment was the only variable that was different between female and male runners diagnosed with a RRI. Noehren at al. (2007) found that peak hip adduction moment was related to running injury. Studies investigating knee kinetics found that knee external rotation moment was not an important risk factors for RRI, whereas knee abduction impulse and patellofemoral joint compression were (Noehren et al., 2007; Stefanyshyn et al., 2006; Willson & Davis, 2008). Studies that examined the foot found rearfoot inversion moment was not an important risk factor for injury (Noehren et al., 2007). Finally, increased IT band strain rate was found to be a risk factor for injury; however, peak strain of the IT band was not (Hamill et al., 2008).

Studies investigating joint kinematics found evidence that peak hip adduction was a risk factor for RRI (ITBS and PFP) (Noehren et al., 2007, Noehren et al., 2013). Peak hip internal rotation was not a risk factor for RRI (Noehren et al., 2013). Noehren et al (2007) reported that peak knee internal rotation and femoral external rotation (in relation to the global coordinate system) were risk factors for injury, particularly ITBS in female runners; knee flexion at initial contact and tibial orientation, however, were not (Noehren et al., 2007). Studies investigating kinematics of the ankle and foot in female long distance runners found mixed results: one discovered evidence that decreased peak eversion was a risk factor for injury (ITBS, PFPS) (Noehren et al., 2007); however one did not (Noehren et al., 2013). Overall, a very limited number of studies investigated female long-distance runners. Of the studies that did measure the same risk factor, there was conflicting information. Most studies investigated a variety of different biomechanical variables, making it difficult to draw conclusions about biomechanical risk factors for injury in female long-distance runners.

2.3.3.3 Running Distance Not Reported

Bredeweg et al (2010) investigated biomechanical variables in female runners but did not report average running mileage of the participants (Bredeweg et al., 2013). Ground reaction force variables—specifically, vertical impact peak, time to impact peak, vertical active peak, time to active peak—were not associated with RRI. Similarly, spatiotemporal variables such as step rate and stride length were not associated with RRI (Bredeweg et al., 2013).

2.3.4 Health Factors

In female short distance runners, Buist et al (2010) found no relationship between previous injury and RRI (Buist et al., 2010). In female long distance runners Kelsey et al (2007) found previous RRI to be a risk factor for RRI, specifically for stress fractures. The study also found an association with irregular or absent menstruation and RRI (Kelsey et al., 2007).

2.4 Risk Factors for Running Injuries and Pain in Postpartum Runners

A PubMed search for literature on postpartum runners resulted in 18 titles. After titles were reviewed, six studies were related to postpartum runners: none of the studies quantitatively measured risk factors for RRI when running after childbirth. The studies were either surveys (Blyholder et al., 2017; Christopher et al., 2020; Tenforde et al., 2015) or case studies (Brumitt, 2009; Lin & Lutz, 2004; J. M. Thein-Nissenbaum et al., 2012), leaving clinicians with low quality for providing evidence-based recommendations when treating a postpartum runner. The results from the case studies were not synthesized in this review because of the small subject size (N=1).

2.4.1 Personal Factors

There were no personal risk factors investigated in postpartum runners.

2.4.2 Training Factors

There were no training risk factors investigated in postpartum runners.

2.4.3 Biomechanics Factors

There were no biomechanical risk factors investigated in postpartum runners

2.4.4 Health Factors

One study investigated exercise behaviors after childbirth and found that women that had previous musculoskeletal injury were more likely to report running-related pain up to 2 years postpartum (Blyholder et al. 2017).

The information synthesized in this section on risk factors for RRI provides guidance for future studies. Even though there are several studies investigating risk factors in the general population, it is difficult to draw conclusions about risk factors and RRI due to conflicting information or the limited number of studies investigating a particular risk factor. It is clear that information on musculoskeletal risk factors such as strength, flexibility, range of motion and alignment is missing in the general population, in the female population, and in the postpartum population. Physiotherapists commonly evaluate runners for musculoskeletal impairments to guide rehabilitation back to running or to understand RRI; however, it is unknown if there is a relationship between these variables and RRI. Information on any running-related risk factors in postpartum runners was also missing. Future studies need to investigate these variables and synthesize the available information via systematic reviews and meta-analyses to guide physiotherapists working with injured runners in the general and postpartum populations.

2.5 Unique Considerations for the Postpartum Population

No evidence-based recommendations exist to guide the training or clinical treatment of postpartum runners beginning or returning to running, mostly because of the lack of research on running-related risk factors in the postpartum population. Although a few expert opinions derived from a non-athlete populations do exist (Donnelly et al., 2020; Edwards & Green, 2019), this research is insufficient to adequately meet the needs of postpartum female runners, no matter their level of competition (Deering et al., 2020). For example, the fascia from a cesarean section surgery scar has been seen to take up to 7 months to recover its pre-pregnancy strength (Miles et al., 2019). Return to running or initiating running may be considered akin to recovering from any major surgery. Consequently, to understand postpartum runners and their injury risk when initiating or returning to running, there need to be increased efforts in researching this unique athletic population. As seen in the overview sections above, only one study has investigated postpartum runners in pain (Blyholder et al. 2017). In light of this dearth of research, a recent viewpoint highlighted the need for increased research in postpartum runners (Deering et al., 2020). The following sections highlight changes to the musculoskeletal system through pregnancy and postpartum states, which will assist in understanding the depth and breadth of biomechanical, musculoskeletal and physiological changes that postpartum runners need to recover from to initiate or return to running and highlight the need for more research investigating running-related risk factors in this unique population.

2.5.1 Recovery from Pregnancy and Birthing Process

During the postpartum period, the body is returning to its pre-pregnancy state. Recovery from postural changes occurring during pregnancy takes place—such as lumbar lordosis and pelvic anterior tilt (Hartmann & Bung, 1999), gait changes—such as widening of step width, decreased single support time, and increase hip and knee flexion (Branco et al., 2013; Carpes et al., 2008; Forczek & Staszkiewicz, 2012; Gilleard, 2013; Hagan & Wong, 2010; Lymbery & Gilleard, 2005), and physiological changes—cardiovascular, thermoregulatory, etc. (Bø et al., 2016). The body is also recovering from injuries or surgeries that may have occurred during delivery. Recovery from vaginal delivery involves the Levator hiatus returning to its original size (as it has been widened during delivery and may contribute to incontinence and prolapse) as well as recovering from birth trauma such as perineal tearing and pain (Bø et al., 2017; Shek & Dietz, 2010; Stær-Jensen et al., 2015). Recovering from cesarean delivery most commonly involves recovery from the incision (for example, the Pfannenstiel incision is a 12–15 centimeter incision 3 centimeters above the pubic symphysis where the rectus abdominis is split midline and the transversalis fascia incised) (Bø et al., 2017). The fascia returns to up to 59% of its tensile strength by 6 weeks post-surgery and up to 93% of its original strength by 7 months (Ceydeli et al., 2005).

2.5.2 Neuromuscular Weakness and Structural Changes

Muscle weakness is common in postpartum women and more severe in women who have been prescribed bed rest during pregnancy or postpartum periods (Paddon-Jones et al., 2006). After 15 to 30 days of deconditioning, the postpartum mother usually needs significant conditioning to replace the muscle volume lost (Paddon-Jones et al., 2006). Abdominal muscle weakness has been the most commonly investigated muscle impairment in postpartum women and parous women have been observed to have significant weakness and persistent muscular fatigue when compared to nulliparous controls (Liaw et al., 2011; Deering et al., 2020). The growing uterus during pregnancy causes stretching of abdominal muscles and can result in a diastasis rectus or splitting of the rectus abdominis muscles (Sperstad et al., 2016). Diastasis recti has been frequently reported in the postpartum population, with a 60% prevalence at 6 weeks postpartum (Sperstad et al., 2016). Blyholder et al., (2017) reported a 37% prevalence in runners. In a study by Parker et al., (2009), women with diastasis recti reported more abdominal and pelvic pain at 3 months than women without the diastasis; however, conflicting information was presented by two studies that did not find an association between diastasis recti and pain (Fernandes da Mota et al., 2015; Sperstad et al., 2016).

2.5.3 Weight Gain

Average weight retention one year after pregnancy has been reported to be 0.5-4kgs (Lim & Mahmood, 2015; Linné et al., 2002; Olson et al., 2003). The strongest predictor of postpartum excess weight was the weight gained during pregnancy (Nehring et al., 2011; Rode et al., 2012). This weight retention is a risk factor for obesity, cardiovascular disease, Type II diabetes during midlife (Lim & Mahmood, 2015; Rooney et al., 2005), and low back pain (Shiri et al., 2010). A meta-analysis by Shiri et al. (2010) showed that women who are overweight or obese were more likely to seek care for low back pain and chronic back pain than overweight or obese men.

2.5.4 Biomechanical Considerations for Running

We identified a study investigating changes in running mechanics from pregnancy to postpartum by searching Google Scholar. This study (Provenzano et al., 2019) included five pregnant runners, and the journal in which it was published was not indexed in PubMed. The study recorded running kinematics at baseline (prior to conception or before the 14-week mark of the pregnancy), with a follow up at 6 weeks postpartum (Provenzano et al., 2019). Between the two data collection sessions, pain symptoms, training information, and injury risk were monitored via survey (Provenzano et al., 2019). The study found that postpartum women had less pelvic and trunk rotation, sagittal hip range of motion, and cadence from baseline (Provenzano et al., 2019). Sagittal knee range of motion, step width and stance time increased postpartum (Provenzano et al., 2019). The authors suggested that the decreased motion measured was a protective response to increase stability during running (Provenzano et al., 2019).

It is important to note that there are a plethora of pregnancy and postpartum-related changes that may need different levels of rehabilitation to meet the demands of high impact sports such as running. For example, despite this timeline for healing (up to 35weeks), most elite athletes return to some form of training at 4-6 weeks after cesarean section surgery (Bø et al., 2017). Small scale (N=5) biomechanical investigations are documenting changes in running gait through the perinatal period (Provenzano et al., 2019). More research is needed to determine if these physiological and biomechanical changes are associated with RRI, which is up to 35% in postpartum runners (Blyholder et al. 2017).

2.6 Postpartum Pain in Non-Running Populations

As risk factors for pain have not been studied in postpartum running populations, the following section synthesizes risk factors for pain in postpartum non-running populations. This information will guide future studies investigating the pain related risk factors explored in this thesis.

2.6.1 Risk Factors for Pain in Postpartum Non-Running Populations

Risk factors such as age (Blomquist et al., 2014; Chia et al., 2016; Loughnan et al., 2002; MacLeod et al., 1995; Mannion et al., 2015; Russell et al., 1993), ethnicity (Loughnan et al., 2002), marital status (Russell et al., 1993), medical issues (urinary tract infection, diabetes and hypertension in pregnancy) (Chia et al., 2016), multiparity (Chia et al., 2016; MacLeod et al., 1995; Mannion et al., 2015), complicated delivery (MacLeod et al., 1995; Mannion et al., 2015), mode of delivery (Bjelland et al., 2013; Blomquist et al., 2014; MacLeod et al., 1995; Mannion et al., 2015; Woolhouse et al., 2014), type of anesthesia (Chia et al., 2016; Russell et al., 1993), body mass index (Mannion et al., 2015), pregnancy complications (Mannion et al., 2015), length and duration of labor (Loughnan et al., 2002; MacLeod et al., 1995), muscle pain after delivery (MacLeod et al., 1995), child's birth weight (Mannion et al., 2015), and child's gestational (Mannion et al., 2015) age have been investigated as possible risk factors for lumbopelvic pain postpartum in individual studies. Insufficient support for any particular factor was found; therefore, no clear consensus has been established regarding whether any of these factors can predict if a woman will have postpartum lumbopelvic pain. For now, it is important to consider the individual factors as potential risk factors and, if possible, modify some of the risk factors to reduce the chance of future pain and injury.

2.6.2 Specific Causes of Pain in Postpartum Women

Musculoskeletal issues in postpartum females include pain from tendinopathies and stress fractures (Blyholder et al., 2017; Thein-Nissenbaum, 2016). Chronic symptoms can occur in 19% of postpartum women with pelvic girdle pain and in 29% of women with lower back pain (Bo & Backe-Hansen, 2007). Risk factors that predict chronic pain have been hypothesized to be modifiable and non-modifiable: abdominal muscle weakness (Benjamin et al., 2014), diastasis recti (Parker et al., 2009), mode of delivery (Benjamin et al., 2014), type of analgesia (epidural vs. none) (Chia et al., 2016; Russell et al., 1993), age (Blomquist et al., 2014; Chia et al., 2016; Loughnan et al., 2002; MacLeod et al., 1995; Mannion et al., 2015; Russell et al., 1993) and ethnicity (Loughnan, 2002).

Pain from sacral stress fractures has been reported in several case studies of postpartum women (Beltran & Bencardino, 2011; Celik et al., 2013; Karatas et al., 2008; Lin & Lutz, 2004; Oztürk et al., 2013; Speziali et al., 2015; Thein-Nissenbaum, 2016). Although causes for these fractures have not been identified, pregnancy-related osteoporosis may contribute to these injuries along with increased levels of Relaxin hormone, excessive weight gain, hyperlordosis, weakness of pelvic ligaments, high birth weight of infant, and Vitamin D deficiency, all of which have been identified as possible risk factors (Beltran & Bencardino, 2011; Hilal & Nassar, 2016).

Although no research exists on lower extremity tendinopathy in the postpartum population, upper extremity tendinopathies have been reported (Anderson et al., 2004; Thein-Nissenbaum, 2016). Tendinopathies have been hypothesized to be the result of fluid retention from endocrine changes (Anderson et al., 2004; J. Thein-Nissenbaum, 2016). The most commonly reported tendinopathies are of the hand and wrist, from possible repetitive overuse during new activities such as carrying, holding, changing and feeding an infant (Thein-Nissenbaum, 2016). Although no data exists on postpartum tendinopathies in the lower extremity, new mothers may be at risk for lower extremity tendinopathies as they return to running or begin running, since overuse running injuries are common in runners (Thein-Nissenbaum, 2016; van Gent et al., 2007). Tendinopathies such as Achilles tendinopathy are routinely reported in both genders in the running literature but more commonly for males (Kujala et al., 2005; Kvist, 1994; Lopes et al., 2012; Taunton et al., 2002; Willy et al., 2016). This could be due to the lack of studies in female and postpartum populations.

In conclusion, age and mode of delivery were established as risk factors in non-running populations in multiple studies (>2). Tendinopathy, a common running-related injury overuse injury was also found to be an important reason for pain in postpartum because of endocrine-related changes and overuse during child rearing activities. Finally, as bone stress injuries are high in female runners, postpartum runners need to be monitored for pregnancy related osteoporosis to ensure optimal bone health when initiating or returning to running.

2.7 Summary

In summary, although many personal, training, biomechanical and health related variables have been investigated as risk factors for running-related injury, information about risk factors in postpartum runners is sparse. A postpartum woman is going through a plethora of pregnancy and postpartum-related physiological changes that could potentially affect initiating or returning to running because of the demands of a high-impact sport such as running. From available literature, we know that 1) More women than men are running (Running USA Releases Latest U.S. Running Trends Report, 2020);

2) A majority of women runners are of childbearing age (Running USA Releases Latest U.S. Running Trends Report, 2020); 3) The postpartum runner needs to recover from a variety of perinatal musculoskeletal and physiological changes (Bø et al., 2017; Gilleard, 2013; Hagan & Wong, 2010; Hartmann & Bung, 1999); 4) Up to 35% of postpartum runners have pain with running (Blyholder et al., 2017); and 5) Running biomechanics of postpartum runners may be different when compared to pre-pregnancy (Provenzano et al., 2019). To truly understand running-related pain and changes to running biomechanics, more research is needed. Understanding risk factors will help runners and clinicians reduce pain in this population and assist with a successful entry or re-entry into high impact sports.

Since the literature review presented earlier in this chapter did not identify musculoskeletal tests and measures used by physiotherapists that evaluate runners in pain, the first study in this thesis will be a systematic review to determine what physical therapy-related tests and measures predict injury in runners. Because most studies examine pain in pregnancy or pregnancy-related pain in the postpartum state, a second systematic review will be conducted to determine risk factors for pain that started after childbirth (first-time lumbopelvic pain). The information collected from these reviews will inform the Delphi questionnaire. The Delphi will query expert physiotherapists who work with postpartum runners about common musculoskeletal impairments seen in postpartum runners with pain. The results of the Delphi will inform a survey given to postpartum women; the results of the survey will be used to develop a clinical decision tool as well as a comprehensive list of risk factors that are associated with pain when running after childbirth. Finally, a laboratory study will be performed to analyze the biomechanical factors that may be different in postpartum runners when compared to nulliparous controls to further understand perinatal changes to running gait that cannot be measured via survey.

CHAPTER 3. Do Alterations in Muscle Strength, Flexibility, Range of Motion, and Alignment Predict Lower Extremity Injury in Runners: A Systematic Review

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3.1 Overview

When an injured runner presents to a physiotherapy clinic with the goal of returning to running, physiotherapists commonly use musculoskeletal tests and measures to determine alterations (weakness, tightness, etc.) that may have led to injury. Physiotherapists then use this information to guide rehabilitation plans and build a progression to help the runner return to running. As noted in chapter 2, a synthesis of the evidence for musculoskeletal alterations in strength, flexibility, range of motion and alignment is missing. In the individual studies (Table 2.1), information between musculoskeletal tests and measures and running injury is conflicting or only supported by single studies. It is unknown if these alterations can predict injury. It is therefore important to determine if there are, in fact, musculoskeletal tests and measure that can predict injury in runners. The literature review (chapter two) highlighted three concepts missing from the current published literature: 1) A synthesis of these tests and measures, 2) an evaluation of the quality of the studies that have measured clinical musculoskeletal alterations in runners and 3) more clarity on whether the impairments were studied for a predictive association (i.e. if musculoskeletal impairments can result in future injury). Given these gaps, it was clear that a systematic review was needed to synthesize the musculoskeletal alterations in strength, flexibility, range of motion and alignment that might predict injury in runners.

Therefore, the first study of this thesis is a systematic review designed to understand musculoskeletal impairments in recreational runners that are associated with future injury. This review investigates common clinical tests of strength, flexibility, range of motion and alignment; these tests were measured in healthy runners at baseline, and the runners were followed for at least six months to see if they developed a running-related injury. Since physical therapists use a battery of tests to examine strength, flexibility, range of motion, and alignment to evaluate injured runners, more data on the predictive association between running-related injury and common musculoskeletal tests and measures is needed.

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REVIEW Open Access

Do alterations in muscle strength, flexibility, range of motion, and alignment predict lower extremity injury in runners: a systematic review

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Abstract

Background: Injury is common in running and seen to impact up to 94% of recreational runners. Clinicians often use alterations from normal musculoskeletal clinical assessments to assess for risk of injury, but it is unclear if these assessments are associated with future injury.

Objectives: To identify alterations in muscle strength, flexibility, range of motion, and alignment that may predict lower extremity injury in runners.

Methods: Articles were selected following a comprehensive search of PubMed, Embase, CINAHL, and SPORTDiscus from database inception to May 2018. Included articles were prospective cohort studies, which specifically analyzed musculoskeletal impairments associated with future running-related injury. Two authors extracted study data, assessed the methodological quality of each study using the Critical Appraisal Tool and assessed the overall quality using the GRADE approach.

Results: Seven articles met the inclusion criteria. There was very low quality of evidence for the 7 identified clinical assessment alteration categories. Strong hip abductors were significantly associated with running-related injury in one study. Increased hip external-to-internal rotation strength and decreased hip internal range of motion were protective for running injury, each in one study. Decreased navicular drop in females had a protective effect for running-related injury in one study.

Conclusions: Due to very low quality of evidence for each assessment, confounders present within the studies, a limited number of studies, different measurement methods among studies, measurement variability within clinical assessments, inconsistent definitions of injury and runner, different statistical modeling, and study bias, caution is suggested in interpreting these results.

Keywords: Running, Examination, Injury

Background

Injury in runners is common, affecting 19.4 to 94.4% of runners annually [1, 2]. A high incidence of lower extremity running injuries such as Achilles tendinopathy, anterior and/or lateral knee pain, hamstring injury, stress fractures, or medial tibial stress syndrome, is reported commonly in the scientific literature [1, 3]. Despite widespread research on running injuries and their treatment, there are few long-term strategies or guidelines for preventing injuries in runners [4]. Alterations in objective musculoskeletal clinical assessments that predict whether a runner is at risk of injury might potentially form the basis of long-term prevention strategies.

A method for identifying those at risk for future running-related injuries is necessary in clinical or community wellness settings. Recently, researchers have focused on developing models to predict running-related injury (RRI) by examining the interaction of factors such as training related characteristics (i.e. work load) [5] and acute to chronic workload ratios (i.e. changes in weekly running distance) [6, 7]. Several studies [8–15] have investigated running gait and formally evaluated kinematic and

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kinetic factors that may predict or differentiate an injured runner from an uninjured runner. However, kinematic measures used in laboratories are not readily transferable to clinical practice, as they require complex equipment such as force plates and motion analysis systems.

In practice, clinicians use objective assessments to determine alterations in muscle strength, muscle flexibility, joint range of motion, and alignment during evaluation of runners. Clinicians use results of these tests to explain RRI to patients [16] as these assessments have been hypothesized to be associated with running injuries [17–19]. They often rely on the results of single studies reporting individual tests as well as studies that use cross sectional designs. To our knowledge, alterations in objective musculoskeletal clinical assessments have not been formally investigated for their ability to predict injury in runners in a systematic review. Therefore, the objective of this review is to identify alterations in muscle strength, flexibility, joint range of motion, and alignment that may predict lower extremity injury in runners in order to improve future statistical modeling for injury risks in runners. Syntheses of clinical assessments' utility may assist clinicians who commonly use stand-alone findings from single cross-sectional studies to evaluate risk in athletes.

Methods

Study design

This study used the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA) statement during the search and reporting phase of this systematic review [20]. The systematic review was also registered with PROSPERO International prospective register of systematic reviews (CRD42016020087).

Search strategy

PubMed, Cumulative Index of Nursing and Allied Health Literature (CINAHL), Embase, and SPORTDiscus databases were searched in consultation with a biomedical librarian to identify studies reporting the use of objective musculoskeletal clinical assessments predicting lower extremity injury in runners from database inception to May 2018. Keywords and standardized vocabulary (e.g. medical subject headings (MeSH) for PubMed) were combined with Boolean operators to build the searches. The search terms for PubMed are included in Appendix 1. The searches for CINAHL, Embase, and SPORTDiscus were built from the PubMed search using controlled vocabulary for each database. A detailed hand search involving references from the selected articles and gray literature was conducted, as computerized searches can occasionally omit relevant articles. Searches were limited to humans.

Inclusion/exclusion criteria

We included only prospective cohort studies with longitudinal designs examining the relationship between musculoskeletal clinical assessments of the lower extremity assessed in a baseline cohort of runners who were uninjured and were followed over time to identify occurrence of an RRI. This inclusion criteria assisted our aim of predictive modeling, as the included studies "predict the output value for new observations given their input value" [21]. We only included studies that reported on strength of association (i.e., odds, hazard, or risks ratios in either bivariable or multivariable models) to assist predictive modelling. Odds ratio is used to compare the odds of an outcome when exposed to the variable of interest [22], hazard ratio measures the risk of complication given different event rates [23], and risk ratio measures risk of an event happening in one group compared to another group [24].

Running-related injury was operationally-defined in this review by at least one of the following: 1) diagnosed by a medical physician, athletic trainer or physical therapist, 2) presence of pain with duration of symptoms > 24 h, 3) decreased running mileage, or 4) missed workouts. Lower extremity was defined as any anatomic structure caudal to the lumbar spine. Included studies had to report on RRI. We excluded studies that did not mention clinical assessments, as well as studies using 3D analysis (camera/video) for interpretation. We excluded studies investigating 3D running kinematics (3D biomechanical risk factors) as this review focused on factors evaluated by clinicians. Due to time and expense, 3D is not regularly used by clinicians. We also excluded 2D video analysis as the validity and reliability of this evaluative method is still being established and the focus of this review was objective assessments that are frequently used by clinicians [25–27]. We also excluded military studies as the running conditions (e.g. footwear, carrying load, clothing) are usually different from recreational or competitive runners that would be seen in a community-based setting. Our inclusion criteria allowed for a variety of runner characteristics and follow-up points.

Study selection

Two authors (SC and JM) reviewed abstracts and selected full text articles independently. Disagreements on whether to include an article were resolved by consulting a third author (CC).

Data extraction

Data regarding study population (e.g., gender), definition of injury, clinical assessment measure investigated, strength of association statistics, methodological quality of studies and overall quality of the evidence were extracted from full text articles by one reviewer (SC), and confirmed by a second reviewer (JM). Included studies presented all needed data in the manuscript; therefore, no authors were contacted for further information.

Quality of studies

Included full text articles were each assessed independently by two authors (SC and JM) using the Critical Appraisal Tool (CAT), adapted form of the *Critical Appraisal Form for Quantitative Studies* to evaluate the methodological quality of the selected papers [28, 29]. This tool was chosen because a similar study investigating biomechanical risk factors in runners with defined injuries also used the adapted CAT [29]. The tool is designed to evaluate study quality based on the sample, measures, methods, and outcomes. Items that met criteria, '+,' were added to the total score, with the best quality score of 16. A CAT score of > 75% was deemed good quality, 50–75% moderate quality, and lower than 50% poor quality [29].

To evaluate the overall quality of evidence and strength of the findings for of the each clinical assessment alteration category, the GRADE approach (Grading of Recommendations Assessment, Development and Evaluation) [30] was used. The quality of each specific clinical assessment alteration category (Low or very low, as these were observational studies) was based on the performance of the studies against five domains: Risk of bias (methodological quality of each clinical assessment test alteration) [31], inconsistency (heterogeneity within assessment test categories) [32], indirectness (applicability of the findings in terms of population and outcomes) [33], imprecision (the number of participants and events and width of confidence level for each assessment) [34], and publication bias (the probability of selective publication) [35].

Results

Search results

Initially, before 189 duplicates were removed, the search yielded 916 results (PubMed 317, Embase 379, SPORTDiscus 33, CINAHL 179, and 8 via hand search)(Fig. 1). After the first screening, 50 full-text articles were retrieved. Following a consensus meeting, seven articles were included in this review. Reference checking did not find any additional studies.

A Patient, Exposure, Outcomes (PEO) table, which describes attributes of each study (author, population, exposure, and injury definition) is included in Appendix 2. Descriptions of the objective musculoskeletal clinical assessments identified in the included studies and their methods of measurement have been outlined in Appendix 2. The number of runners included in each study sample ranged from 59 to 532.

Quality of studies

The results of the assessment of quality of each study using the critical appraisal tool are reported in Table 1.

Among the seven studies included in this review, per the CAT, two were of good methodological quality (> 75%) [36, 37] and five were of moderate quality (50–75%) [16, 38–41]. The majority of methodological shortcomings were observed in the following items: sample bias (7/7 studies) [16, 36–41], reporting validity of measures (5/7 studies) [16, 38–41], justification of sample size (5/7 studies) [16, 38–41], and reporting reliability of measures (5/7 studies) [16, 38–41].

The included studies in this review were all observational design, and therefore per the GRADE approach were considered of low quality of evidence overall [31]. When evaluating each domain, the clinical assessment alterations categories were downgraded either for imprecision, indirectness, inconsistency or all three, resulting in very low quality evidence for each clinical assessment alteration investigated in this review [33, 34, 42]. Publication bias refers to the probability of selective publishing and due to the limited amount of studies for each the clinical assessment alterations(up to three) this item was not used to downgrade evidence in this review [35]. The results of GRADE are reported in Table 2.

Objective musculoskeletal clinical assessments (Table 2)

Hip strength

Evidence for hip strength was of very low quality (hip abduction strength downgraded due to indirectness, inconsistency, and imprecision whereas the rest were downgraded due to indirectness and imprecision). Of the two studies investigating hip abduction strength, one study [39] reported that stronger hip abduction strength was significantly associated with injured runners (OR = 5.35, 95% CI= 1.46, 19.53) whereas the other study [38] found no significant association. Finnoff et al. [39], also reported a significant protective association with increased hip external rotation to internal rotation strength ratio RRI (OR = 0.01, 95% CI= < 0.01, 0.44). There were no significant associations between hip adduction, abduction to adduction ratio, external rotation, internal rotation, flexion, extension, flexion-to-extension strength ratio and RRI [39].

Hip joint range of motion

Evidence for hip joint range of motion was of very low quality (downgraded due to indirectness and inconsistency). Two studies [36, 40] investigated hip internal and external range of motion, of which one study [40] found that increased hip internal rotation was protective against RRI in females that developed medial tibial stress syndrome (aOR = 0.91, 95% CI= 0.85, 0.99) [40].

Hip alignment

Evidence for hip alignment was of very low quality (Q angle downgraded for indirectness and inconsistency, and leg length downgraded for imprecision). Two studies [16, 40] investigated Q angle and one study [16] investigated leg length. The studies were unable to find significant relationships between hip alignment tests investigated and RRI.

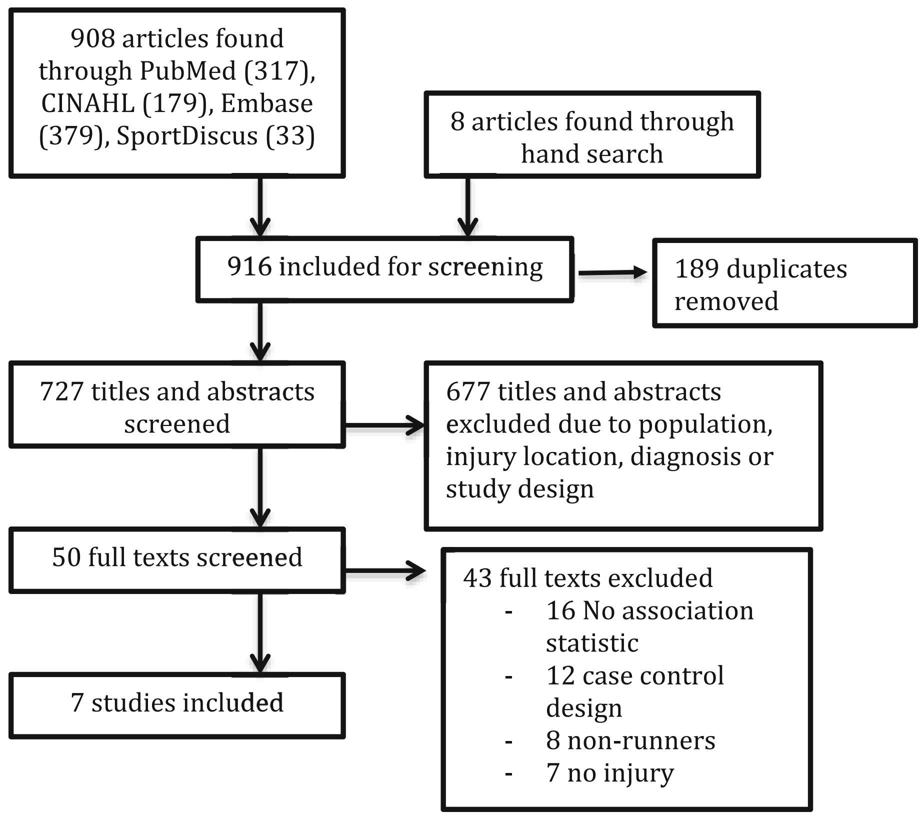

Fig. 1 PRISMA flow diagram of studies in systematic review

Hip flexibility

Evidence for hip flexibility was of very low quality (downgraded for indirectness and imprecision). One study [40] investigated straight leg raise and did not find significant association between straight leg raise test and RRI.

Knee strength

Evidence for knee strength was of very low quality (downgraded for indirectness and imprecision). One study [38] investigated knee strength using a HHD and did not find a significant association between quadriceps strength or hamstring strength and RRI.

Ankle alignment

Evidence for ankle alignment was of very low quality (navicular drop downgraded for indirectness and inconsistency, and foot posture index downgraded for indirectness and imprecision). Three studies [36, 37, 40] investigated navicular drop

Table 1 Quality assessment of included studies – adapted from the Critical Appraisal Form (CAT) for Quantitative Studies [28, 29]

Author	I-1	I- 2	I-3	I-4	I-5	I- 6	I- 7	I-8	I-9	I-10	I-11	I-12	I-13	I-14	I-15	I-16	T.S	T.%
Buist et al., 2010 [36]	+	+	−	+	+	+	−	+	+	−	+	+	+	+	+	+	13	81.25
Finnoff et al., 2011 [39]	+	+	−	+	+	+	−	+	+	−	−	+	+	+	+	+	12	75.0
Hespanhol Junior et al., 2016 [16]	+	+	−	+	+	+	−	+	+	−	−	+	+	+	+	+	12	75.0
Luedke et al., 2015 [38]	+	+	−	+	+	−	+	+	+	+	−	+	−	+	−	+	11	68.75
Plisky et al., 2007 [37]	+	+	−	+	+	+	+	+	+	+	+	+	+	+	+	+	15	93.75
Ramskov et al., 2013 [41]	+	+	−	−	+	+	−	+	+	−	−	+	+	+	+	+	11	68.75
Yagi et al., 2013 [40]	+	+	−	+	+	+	−	+	+	−	−	+	+	+	+	+	12	75.0

Note. Item 1: Purpose of the study was clearly stated, Item 2: Study design was appropriate, Item 3: Study detected sample bias, Item 4: Measurement biases were detected in the study, Item 5: Sample size was stated, Item 6: The sample was described in detail, Item 7: Sample size was justified, Item 8: Outcomes were clearly stated and relevant, Item 9: Method of measurement was described sufficiently, Item 10: The measures used were reliable, Item 11: The measures used were valid, Item 12: The results were reported in terms of statistical significance, Item 13: The analysis methods used were appropriate, Item 14: Clinical importance was reported, Item 15: Missing data were reported when appropriate, Item 16: Conclusions were relevant and appropriate given methods and results of the study
Abbreviations I- Item, T.S- total score, T%- total CAT %, meets criteria '+', does not meet criteria '-'

Table 2 Clinical measures and the reported predictive statistics in the 7 studies investigated in this review

Author, year	Statistical Analysis	Assessment Method	Values (uninjured)	Values (injured)	Association Statistic, 95% Confidence Interval; *p*-value
Hip Strength					
Hip abduction (GRADE- Very low +++O) [b,c,d]					
Finnoff et al., 2011 [39]	Bivariable logistic regression	(%BWxheight) = Torque(Nxm)× 100/[BW(N)x height(m)]	2.57(0.53)%	3.14(0.63)%	**OR:5.35, 95% CI= 1.46, 19.53; *p*:<.01**
Luedke et al., 2015 [38]	Bivariable logistic regression	Force (N)x resistance moment arm (m)/body mass (kg).	Boys: R = 0.25(0.07) Nm/Kg L = 0.25(0.08) Nm/Kg Girls: R = 0.25(0.08) Nm/Kg L = 0.26(0.07) Nm/Kg	NR	Boys: Shin pain tertiles Weakest:OR:1.25, 95% C=I 0.2, 9.9. Middle: OR 1.00, NA Girls: Shin pain tertiles Weakest OR:1.23, 95% CI= 0.7, 21.6, Middle: OR 2.28, 95% CI= 0.2, 28.0
Hip adduction (GRADE- Very low ++OO)[c,d]					
Finnoff et al., 2011 [39]	Bivariable logistic regression	(%BWxheight) = Torque(Nxm)× 100/[BW(N)x height(m)]	2.79 (0.61)%	2.87 (0.45)%	OR: 1.23, 95% CI= 0.48, 3.17
Hip abduction to adduction ratio (GRADE- Very low ++O)[c,d]					
Finnoff et al., 2011 [39]	Bivariable logistic regression	NR	1.12 (0.28)%	1.06 (0.25)%	OR: 14.14, 95% CI= 0.90, 221.06
Hip internal rotation (GRADE- Very low ++OO)[c,d]					
Finnoff et al., 2011 [39]	Bivariable logistic regression	(%BWxheight) = Torque(Nxm)× 100/[BW(N)x height(m)]	1.68 (0.40)%	1.88 (0.68)%	OR: 2.75, 95% CI= 0.33, 23.17
Hip external rotation (GRADE- Very low ++OO)[c,d]					
Finnoff et al., 2011 [39]	Bivariable logistic regression	(%BWxheight) = Torque(Nxm)× 100/[BW(N)x height(m)]	1.44 (0.31)%	1.34 (0.26)%	OR: 0.35, 95% CI= 0.03, 4.48
Hip external to internal rotation strength (GRADE- Very low ++OO)[c,d]					
Finnoff et al., 2011 [39]	Bivariable logistic regression	NR	0.87 (0.17)%	0.74 (0.13)%	**OR: 0.01, 95% CI= < 0.01, 0.44;p:0.02**
Hip flexion (GRADE- Very low ++OO)[c,d]					
Finnoff et al., 2011 [39]	Bivariable logistic regression	(%BWxheight) = Torque(Nxm)× 100/[BW(N)x height(m)]	2.84 (0.61)%	2.49 (0.92)%	OR: 0.40, 95% CI= 0.05, 3.09
Hip extension (GRADE- Very low ++OO)[c,d]					
Finnoff et al., 2011 [39]	Bivariable logistic regression	(%BWxheight) = Torque(Nxm)× 100/[BW(N)x height(m)]	3.15 (0.79)%	2.87 (0.79)%	OR: 0.64, 95% CI= 0.21, 1.90
Hip flexion to extension strength (GRADE- Very low ++OO)[c,d]					
Finnoff et al., 2011 [39]	Bivariable logistic regression	NR	0.86 (0.15)%	0.96 (0.13)%	OR: 0.17, 95% CI= 0.021, 5.61
Hip Range of Motion					
Hip IR ROM (GRADE- Very low ++OO)[b,c]					
Buist et al., 2010 [36]	Multivariable logistic regression	Goniometer	Male L = 30.6(8.1)° R = 31.1(8.8)° Female L = 35.9(9.5)° R = 37.7(8.3)°	NR	Male: HR: 1.00 **Female HR 0.98** **aHR: 0.99, 95% CI= 0.97, 1.01; P:0.08**
Yagi et al., 2013 [40]	Multivariable logistic regression	Goniometer	Male: 12.4 (8.7)° Female: 25.5 (9.5)°	Male: MTSS:12.9(5.8)° SF: 7.5 (3.5)° Female: MTSS: 31.1 (9.9)° SF: 20.7(7.6)°	Male MTSS: aOR: 0.99, 95% CI 0.91, 1.08 SF: aOR: 1.26, 95% CI 0.81, 1.96 Female MTSS: **aOR 0.91, 95% CI 0.85, 0.99; p:0.02** SF: aOR:1.00, 95% CI 0.88, 1.12

Table 2 Clinical measures and the reported predictive statistics in the 7 studies investigated in this review *(Continued)*

Author, year	Statistical Analysis	Assessment Method	Values (uninjured)	Values (injured)	Association Statistic, 95% Confidence Interval; *p*-value
Hip ER ROM (GRADE- Very low ++OO)[b,c]					
Buist et al., 2010 [36]	Multivariable logistic regression	Goniometer	Male: L = 39.7(11.6)° R = 40.2(12.9)° Female L = 45.7(14.3)° R = 45.8(13.9)°	NR	Male: HR: 1.01 Female: HR:1.00
Yagi et al., 2013 [40]	Multivariable logistic regression	Goniometer	Male: 39.7(8.8)° Female: 35.1 (9.0)°	Male: MTSS: 44.5(8.9)° SF: 40.0(14.1)° Female: MTSS: 37.4 (8.5)° SF: 43.3 (2.9)°	Male: MTSS: aOR: 0.96, 95% CI 0.88, 1.03 SF: aOR: 0.76, 95% CI 0.56, 1.03 Female MTSS: aOR:1.0, 95% CI 0.93, 1.08 SF: aOR:1.0, 95% CI 0.90, 1.11
Hip Alignment					
Q angle (GRADE- Very low ++OO)[b,c]					
Hespanhol junior et al., 2016 [16]	Multivariable logistic regression	Goniometer	10.1(5.1)°	11.8(5.0)°	OR:0.9, 95% CI= 0.8, 1.0
Ramskov et al., 2013 [41]	Bivariable logistic regression	Goniometer	L = 11.1(4.4)° R = 11.1(5.0)°	L = 8.2(4.5)° R = 9.1(4.5)°	cRR: 1.26, 95% CI= 0.49, 3.23
Leg length (GRADE- Very low +OOO)[d]					
Hespanhol junior et al., 2016 [16]	Multivariable logistic regression	Measuring Tape	0.5(0.6)cm	0.4(0.6)cm	OR: 1.3, 95% CI= 0.6, 2.7
Hip Flexibility					
Straight leg raise (GRADE- Very low ++OO)[c,d]					
Yagi et al., 2013 [40]	Multivariable logistic regression	Goniometer	Male:74.3(10.4)° Female:76.1 (12.5)°	Male: MTSS:77.6(8.5)° SF:60.0 (14.1)° Female: MTSS:77.7(11.0)° SF:78.3 (7.6)°	Male MTSS: aOR: 0.99, 95% CI= 0.60, 1.29 SF: aOR: 1.38, 95% CI= 1.04, 1.83 Female MTSS: aOR: 0.98, 95% CI= 0.92, 1.05 SF: aOR:1.00, 95% CI= 0.90, 1.11
Knee Strength					
Quadriceps strength (GRADE- Very low ++OO)[c,d]					
Luedke et al., 2015 [38]	Bivariable logistic regression	Force (N)x resistance moment arm (m)/body mass (kg).	Boys: R = 0.31(0.06)Nm/kg L = 0.30(0.05)Nm/kg Girls: R = 0.28(0.04)Nm/kg L = 0.28(0.05)Nm/kg	NR	Boys: Shin pain Tertiles Weakest OR:0.83, 95% CI= 0.1, 6.1 Middle: No injured Girls: NR

Table 2 Clinical measures and the reported predictive statistics in the 7 studies investigated in this review *(Continued)*

Author, year	Statistical Analysis	Assessment Method	Values (uninjured)	Values (injured)	Association Statistic, 95% Confidence Interval; *p*-value
Hamstring strength (GRADE- Very low ++OO)[c,d]					
Luedke et al., 2015 [38]	Bivariable logistic regression	Force (N)x resistance moment arm (m)/body mass (kg).	Boys: R = 0.22(0.06) Nm/kg L = 0.21(0.06) Nm/kg	NR	Boys: Shin pain Tertiles Weakest OR:1.20, 95% CI= 0.2, 8.8, Middle: OR: 0.40, 95% CI= 0.1, 5.2
			Girls: R = 0.20(0.03) Nm/kg L = 0.20(0.04) Nm/kg		Girls: Shin pain Tertiles Weakest: OR: 1.33, 95% CI= 0.2,16.7 Middle: OR: 0.55, 95% CI= 0.1, 9.9
Ankle Alignment					
Navicular drop (GRADE- Very low ++OO)[b,c]					
Buist et al., 2010 [36]	Multivariable logistic regression	NR	Male: L = 6.6(3.5)mm R = 6.7(3.5)mm	NR	Male HR 1.02
			Female: L = 6.0(3.1)mm R = 6.2(2.8)mm		**Female HR 0.92** **aHR- 0.87, 95% CI= 0.77, 0.98; p:0.01**
Plisky et al., 2007 [37]	Bivariable logistic regression	Ruler perpendicular to the floor	> 10 mm N Boys: 20(43.5) N Girls:24(40.7)	N 15.8	OR: 1.0
			< 10 mm N Boys:26(56.5) N Girls:25(59.3)	N 14.9	OR: 0.9, 95% CI= 0.3, 2.8
Yagi et al., 2013 [40]	Multivariable logistic regression	Goniometer	Male: 4.5(3.4)mm	Male MTSS:4.9(3.0) mm SF: 2.4(3.1)mm	Male MTSS: aOR:0.93, 95% CI= 0.75, 1.14 SF: aOR: 1.00, 95% CI= 0.71, 1.42
			Female:4.2(2.4)mm	Female MTSS:4.9(3.0)mm SF: 3.4(2.9)mm	Female MTSS: aOR: 0.90, 95% CI= 0.70, 1.19 SF: aOR: 1.5, 95% CI= 0.95, 2.51
Foot posture index (GRADE- Very low ++OO)[c,d]					
Ramskov et al., 2013 [41]	Bivariable logistic regression	Method by Redmond et al	N: Very pronated:1 Pronated: 14 Neutral: 79 Supinated: 0 Very supinated: 0	N: Very pronated:3 Pronated: 4 Neutral: 14 Supinated: 0 Very supinated: 0	cRR: 1.65, 95% CI= 0.65, 4.17

Table 2 Clinical measures and the reported predictive statistics in the 7 studies investigated in this review *(Continued)*

Author, year	Statistical Analysis	Assessment Method	Values (uninjured)	Values (injured)	Association Statistic, 95% Confidence Interval; *p*-value
Ankle Range of Motion					
Ankle dorsiflexion (GRADE- Very low +OOO)[c]					
Buist et al., 2010 [36]	Multivariable logistic regression	Goniometer	Male: L= KB- 104.7(7.8)° KS-99.2(8.2)° R= KB-104.6(7.5)° KS-99.2(7.8)° Female: L= KB-103.6(11.5)° KS-99.0(10.9)° R= KB-103.8(8.7)° KS- 99.1(9.2)°	NR	Male HR: 1.01(KB) HR: 1.01 (KS) Female HR: 1.00(KB) HR: 1.00 (KS)

OR odds ratio, *aOR* adjusted odds ratio, *HR* Hazard ration, *aHR* adjusted hazard ratio, *RR* risk ratio, *cRR* cumulative relative risk, *SF* stress fracture, *MTSS* medial tibial stress syndrome, *KB* knee bent, *KS* knee straight
GRADE working group grades of evidence: (bolded? heading for below items)
Low quality: Further research is likely to have an important impact on our findings
Very low quality: We are uncertain about the findings
a. Item was downgraded due to risk of bias in methods, recruitment, follow up or selective reporting
b. Item was downgrade due to inconsistency such as difference in measurement method, population, injury definition within the studies included in the outcome
c. Item was downgraded due to indirectness and therefore applicability of findings regarding population or outcomes
d. Item was downgraded due to imprecision (i.e. small sample size < 300)

and the development of running injuries. One study [36] found a significant protective relationship between decreased navicular drop amount in females and injury (HR = 0.92); two studies did not find a significant relationship between navicular drop and injured runners. One study [41] investigated the Foot Posture Index [43] and did not find a significant relationship between foot posture and injured runners.

Ankle joint range of motion
Evidence for ankle range of motion was of very low quality (downgraded for indirectness). One study [36] investigated ankle dorsiflexion range of motion and did not report a significant association between ankle dorsiflexion (in knee straight and bent) and RRI.

Discussion
Findings within the studies
The goal of this study was to summarize the results of stand-alone studies that have investigated clinical assessment and risk of injury. Synthesizing the work should improve an understanding of which factors may be transferable to a clinical environment. Stand-alone findings such as increased hip external to internal rotation strength ratio and decreased navicular drop were protective of injury, but only in a few studies. We also found that increased hip abduction strength was predictive of injury and decreased hip internal rotation was protective of injury in runners, largely contradicting clinical thought and results from non-longitudinal studies of association [44]. In no cases did we find compelling evidence from multiple studies of common predictors of injury risk in running. Also, all clinical assessment alteration categories had very low quality of evidence; therefore, clinicians should be very cautious interpreting the results below.

As stated, increased hip external to internal strength ratio was seen to be protective for injury in runners that developed patella femoral pain syndrome. This finding was reported in one study by Finnoff et al. [39] Although the authors did not operationally define this ratio, it is assumed that an increase in hip external rotator strength when compared to internal rotator strength would be protective for runners. The hip external rotators muscles control femoral internal rotation and a lack of control may be linked with running injury [45, 46]. It is important to note there were several confounders in this study. The study did not report running distance per week (mileage) nor did it report any injury history, both of which have been associated as risk factors for injury. Because these athletes were high school runners, these factors could have significantly influenced results [1].

Decreased navicular drop was seen to be protective of injury in this review. This finding was reported in one study [36]; however, it was not significant among the two other studies [25, 28] that did investigate this measure. Excessive pronation of the foot causes tibial rotation and has been seen to be related to medial stress syndrome in runners [47]. This finding was investigated in novice runners participating in a 13-week training program for a 4-mile running event and therefore cannot be applied to all running populations in general.

Increased hip abduction strength was found to be predictive of injury in one cohort study. The finding that runners with stronger hip abductors were more associated with RRI may have been due to a number of confounders. The participants included in the study were high school athletes, possibly novice runners. As mentioned before, weekly training mileage and injury history were not reported. Finnoff et al. [39], theorized that the injured subjects in the group had higher body mass index (BMI), which could have led to higher hip abduction moments. To compensate for these larger moments, the runners may have developed increased hip abductor (eccentric) strength over time [39]. This finding shows that some injured runners may have increased strength, specifically if they are younger or novice runners with a higher BMI. Caution should be used when interpreting this result with all running populations.

Decreased hip internal rotation was found to be protective in one cohort study [40]. Excessive hip internal rotation has been associated with injury during jump landing tasks and lack of control of the lower extremity in the frontal and transverse planes has also been hypothesized as a cause for injury in runners [48, 49]. Decreased mobility could therefore be beneficial and protective for runners, as it would require less neuromuscular control. This finding shows that stiffness in runners may not be an impairment as previously thought [50, 51], specifically if they are young and may not have developed the neuromuscular control needed to stabilize the limb. Caution should be used while interpreting the findings of this study as participants were high school runners. Shin pain was the only injury reported. Mileage of the runners was not reported; however, frequency of training was. Experience was noted as national, state, or entry level, however no history of running injury or amount of running miles was reported.

Findings between the studies
The GRADE level of evidence quality was very low for all objective assessment alteration categories included in this review. Studies were downgraded for either indirectness, inconsistency, imprecision or all three. There were no common predictors across a number of studies in this review. There may be several reasons for the lack of commonality or the occasional findings that are contradictory to clinical thought, such as differences in subject demographics, different measurement methods, measurement variability within clinical assessments, inconsistent definitions of injury and runner, different statistical models, and study bias. These issues have been further addressed below.

There were a wide range of different assessments used to compare clinical assessment alterations and future injury within the seven prospective studies, and studies used different methods when measuring the same construct. For example, ankle alignment was measured with navicular drop [36, 37, 40] or Foot Posture Index [41]. This lack of homogeneity between studies resulted in difficulties comparing clinical assessments between studies, even when studies focused on a similar construct (e.g., alignment).

A variety of methods was used to define and report the clinical assessments, even when the same testing device was used. For instance, weakness in hip HHD assessment was often reported by asymmetry between left and right sides [39, 40]. However, another study [38] divided strength into three tertiles (weakest, middle and strong) across participants and used the strongest strength values as the comparator. One study [38] multiplied the HHD reading by the moment arm and then normalized it to the participant's body mass. The other studies normalized HHD values to body mass and height [39]. This variability in the reporting of muscle strength assessments made it difficult to compare studies, perform meta-analyses, or identify common patterns of muscle strength in included prospective studies.

Population and injury definitions were also heterogeneous among studies. Running populations in studies varied from novice to recreational, with more males than females in the Q angle studies [13, 29]. Running related injury has been defined many ways in the literature, as evidenced by the wide variability of injury incidence rates reported in various studies [1, 2, 52]. When defining an injury, studies used: 1) evaluation by a medical physician, athletic trainer or physical therapist [39], 2) presence of pain with duration of symptoms > 24 h [37], 3) decrease in running mileage, 4) missed workouts [16] or, 5) a combination of the variables listed [36, 38, 40, 41] all which were included in our study. Consistent reporting about injury severity, the course of treatment, previous injury, or whether the runner had sought assistance from a health care provider was lacking. Difference in levels of injury severity would likely alter associational modeling and influence the statistical significance of the findings.

Lastly, statistical modeling was different among studies. Three studies used a multivariable model, whereas four studies used a bivariable model. Among the three studies that used a multivariable model, measures of independent variables such as age [36], other clinical tests [16] and BMI [40] were also included in the regression analysis model. This could have influenced the relationship between singular clinical test (such as navicular drop) [36] and RRI.

Previous reviews investigating the risk of RRI have also reported similar criticisms [53, 54]. Winter et al. [53] investigated fatigue and RRI, and were unable to find conclusive patterns of associations due to a lack of homogeneity of the runners, small sample sizes, and the distances that were run to determine fatigue. A systematic review studying vertical ground reaction force and injury was also unable to make recommendations due to a lack of prospective studies investigating this variable and its association with injury [54]. When reviewing biomechanical risk factors, Aderem and colleagues [29] concluded that shod female runners with iliotibial band syndrome (ITBS) may have associated increased peak knee internal rotation and peak hip adduction during stance (based on one prospective cohort study), but because of limitations in effect size and the number of studies and methods, the authors did not make any additional recommendations. In the one review that investigated alterations to the musculoskeletal system, similar to the current study, i.e., plantar pressures, the authors concluded there was inconsistency among studies and suggested improved methodology for future research [55].

Limitations

There are several limitations to this review. Studies with post-operative populations were excluded from the study, so it is possible the runners included in the selected studies had less severe injuries, which potentially influenced the clinical assessment alterations between baseline and future injury. This was performed to better generalize the results to the population of runners commonly seen in outpatient community-based clinics, who often present without having seen a surgeon [56].

Conclusion

This review suggests that objective assessments that measure alterations in muscle strength, flexibility, alignment, and range of motion of the lower extremity had very low quality of evidence. Within the studies there were several confounders such as participant's experience, unknown injury history, and unknown weekly running mileage, all of which have been seen to be associated with RRI [1]. Among the studies, there were a limited number of studies investigating each assessment, inconsistent results, different measurement methods among studies, measurement variability within clinical assessments, inconsistent definitions of injury and runner, different statistical modeling, and study bias. Future studies should aim to improve the quality of the studies as well as use standardized assessments and minimize confounders when conducting clinical research to predict injury in runners.

Appendix 1

Search terms used in PubMed database

Injury[tiab] OR Injuries[tiab] OR "physiopathology" [Subheading] OR "injuries" [Subheading] OR "Wounds and Injuries"[Mesh]) AND (Runner[tiab] OR Runners[tiab] OR Running) AND (Muscle Strength OR Muscle Weakness OR Strength[tiab] OR Weakness[tiab]) AND (sensitive[tiab] OR sensitivity[tiab] OR specificity[tiab] OR sensitivity and specificity[MeSH] OR diagnosis[tiab] OR diagnostic[tiab] OR diagnosed[tiab] OR diagnosis[MeSH] OR diagnosis[sh] OR cross-sectional studies[Mesh] OR cross-sectional[tiab]) NOT (review[ptyp] OR Editorial[ptyp] OR Letter[ptyp] OR Case Reports[ptyp] OR Comment[ptyp]) NOT (animals[mh] NOT humans[mh]

Appendix 2

Table 3 PEO (Population, Exposure, Observation) Table; description of included articles

Author, Year of publication	Population N (gender) Follow up	Exposure (Clinical Measure)	Observation (Injury Definition)
Buist et al., 2010 [36]	532 novice runners (226 male, 306 female); 8 or 13-week program	Range of motion with universal goniometer: Internal and external ROM of the hip: assessed in supine and the tested hip and knee flexed to 90° Ankle dorsal flexion- measured both with the knee fully extended and flexed to 90° passively, in supine position. Alignment: Navicular drop- assessed by measuring the change in the height of the navicular tuberosity between sitting with the subtalar joint in neutral position and standing, weight-bearing with the subtalar joint in relaxed stance, measurements were made twice for each foot, results were averaged	Self-reported musculoskeletal pain of the lower extremity or back causing a restriction of running for at least 1 week, i.e. 3 scheduled consecutive training sessions.
Finnoff et al., 2011 [39]	98 high school cross country and track athletes (53 male and 45 female); Cross country and/or track season	Leg Length- measuring from anterior superior iliac spine (ASIS) to a point 2 cm proximal to the apex of medial malleolus Muscle strength with HHD for break test: Hip flexion- seated hip flexion to 120° with HHD on distal aspect of thigh Hip Extension- extend test hip to a neutral position with the knee extended while maintaining neutral hip rotation with HHD against the subject's posterior calcaneus Hip External Rotation- seated knees were also flexed 90° with the hip in neutral rotation with HHD positioned 2 cm proximal to the apex of the medial malleolus Hip Internal rotation- position identical to the one used for hip external rotation strength testing with HHD positioned 2 cm proximal to the apex of the lateral malleolus Hip Abduction- 30° abduction with neutral hip flexion, extension, rotation) HHD positioned 2 cm proximal to the apex of lateral malleolus Hip Adduction- neutral flexion, extension, rotation (subject allowed to grasp table for trunk stability). Strength test was performed with the HHD placed 2 cm proximal to the medial malleolus Pain- Visual Analogue Scale (10 cm)	ATC monitored and evaluated by physician investigators: ITBS suspected with lateral knee pain, local tenderness over lateral knee where ITB crosses over condyle, exacerbated by flexion and extension while applying pressure PFP suspected with anterior knee pain, exacerbated by deep knee flexion and/or climbing stairs, and by reproduction of pain with at least one of following: 1) pressure over distal quadriceps with active contraction and 2) direct palpation of medial and lateral patellar facets
Hespanhol Junior et al., 2016 [16]	89 recreational runners (68 male/21 female); 12 weeks	Leg Length: in a supine position, lower limbs relaxed. Measuring tape was used to determine the real length of the lower limbs i.e., the length between the ASIS of the hemipelvis to the center of the ipsilateral medial malleolus of both lower limbs. The lower limb length discrepancy was considered normal when lower than 1.0 cm Q-angle: In sports clothes and standing barefoot in an orthostatic position. A straight line was traced using a ruler from the ASIS to the center of the patella, and a second line was traced from the center of the patella to the tibial tuberosity. The angle formed by the intersection of these two lines constitutes the Q-angle, which was measured by a universal goniometer. Values between 10° and 15° were considered normal for both genders	Missed at least one training session due to musculoskeletal pain (Biweekly questionnaire reporting musculoskeletal pain, number of training sessions missed, pain intensity (10 point numerical pain rating scale), description (type and anatomical location) of new injury)
Luedke et al., 2015 [38]	68 High school runners (16 male, 47 female); Interscholastic cross-country season	Muscle strength with HHD for bilateral peak isometric strength (2 trials): Hip abduction- sidelying, non-test limb was positioned in 30–45° of hip flexion and 90° of knee flexion, pelvis was stabilized to the table using a strap, test hip was in 0° of extension and abducted to parallel with the table and HHD was placed just proximal to the lateral malleolus on the test limb	Injury- required athlete to be removed from practice or competitive event, or miss a subsequent practice/ competitive event PT or LAT determine injury: Knee pain 1. Pain around ant aspect of knee 2) insidious

Table 3 PEO (Population, Exposure, Observation) Table; description of included articles *(Continued)*

Author, Year of publication	Population N (gender) Follow up	Exposure (Clinical Measure)	Observation (Injury Definition)
		Knee Extension: seated at the end of a table with the test knee at 45° of flexion, stabilizing strap was placed around the thighs and table, resistance applied to the anterior aspect of the tibia 5 cm proximal to the ankle joint Knee Flexion - prone and the test knee flexed to 45°, stabilizing strap was placed around the pelvis and table with resistance applied to the posterior aspect of the tibia 5 cm proximal to the ankle joint	onset 3) no incidence of trauma Shin injury 1) continuous or intermittent shin pain 2) exacerbated by weight bearing activities 3) local pain with palpation along tibia
Plisky et al., 2007 [37]	105 high school cross country runners (59 male, 46 female); 13 week cross country season	Alignment: Navicular drop (normalized to full foot length and truncated foot length) - in unilateral standing position, the runner's foot placed subtalar neutral, ruler was placed next to the medial foot perpendicular to the floor and was read (mm) at the height of the navicular tubercle, 2 measurements were recorded, relaxing in between, and the difference value was documented as navicular drop (Runners were allowed to maintain their balance by placing a hand on a handrail during unilateral stance)	PT and ATC examined runner for MTSS criteria 1) continuous or intermittent pain in the tibial region, exacerbated by weight bearing activities 2) local pain with palpation along distal 2/3 of posterior medial tibia
Ramskov et al., 2013 [41]	59 novice runners (31 male, 28 female); 10 weeks	Alignment: Foot Posture Index [43]. Q angle- center of the goniometer placed upon the middle of the patella, one arm of the goniometer placed along the line connecting ASIS with the middle of patella, other arm was placed along the line connecting the middle of patella and the tibial tuberosity	Injury: Any running-related injury to lower extremity or lower back that causes at least one week of restricted running Diagnoses by physiotherapist ~ 1 week after injury; if extensive exam needed referred to university hospital medical center division of sports traumatology
Yagi et al., 2013 [40]	230 high school runners (134 male, 96 females); 3 years	Range of motion: Hip rotation- measured with the hip and knee flexed at 90° in the sitting position; the hip and knee were rotated internally and externally to firm end feel with the angles relative to the initial position. Ankle dorsiflexion-measure in two positions with knee in extension and 90° flexion; ankle was passively moved into dorsiflexion from a neutral-starting position until a firm end feel was elicited (examiner first identified the neutral position of the subtalar joint and then kept the neutral position while dorsiflexing the foot until a firm end point was felt) Flexibility: Straight leg raising – supine, passively into hip flexion until firm resistance was felt and the pelvis tilted posteriorly Alignment (knee varus or valgus and ankle eversion inversion in standing closed feet), Navicular drop test-distance between the navicular tuberosity and the floor during [1] quiet tandem stance with the subtalar joint placed in neutral, and no load on the foot, and [2] relaxed tandem stance with full load on the foot Q angle- center axis of a long-arm goniometer placed over the center of the patella, proximal tibia was palpated, and the lower goniometer arm was aligned along the patellar tendon to the tibial tubercle, upper arm of the goniometer was pointed directly at the anterior superior iliac spine Strength: Hip abduction isometric break test with HHD	Could not run for 7 days due to shin pain - radiographs taken (if reinjured counted in study as additional subject) and diagnosis by sports physician

NR not reported, *m/wk*. miles per week, *yr*. year, *ROM* range of motion, *HHD* Hand held dynamometer, *MTSS* medial tibial stress syndrome, *SF* stress fracture

Abbreviations

aOR: Adjusted odds ratio; aRR: Adjusted risk ratio; HHD: Hand held Dynamometer; HR: Hazard ratio; OR: Odds ratio; RR: Risk Ratio; RRI: Running-related Injury

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The authors declare that there is no conflict of interest.

IRB

None

Authors' contributions

SMC provided idea, design, writing, review of manuscript and overall content of material; JM provided review of articles and quality tool; SS and CC provided writing, review and overall content of manuscript. All authors read and approved final manuscript.

Authors information

Shefali Christopher has been a sports physical therapist for 10 years. As a clinician, she predominantly treated runners and used musculoskeletal clinical assessments to evaluate and treat injured runners. As part of her PhD, from the University of Newcastle in Australia, she wanted to investigate the utility of the tests she was using and see if they had any predictive capability.

Ethics approval and consent to participate

Not applicable.

Consent for publication

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Competing interests

The authors declare that they have no competing interests.

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CHAPTER 4. Predictive Risk Factors for First-Onset Lumbopelvic Pain in Postpartum Women: A Systematic Review

Christopher S, McCullough J, Snodgrass SJ, Cook C. Predictive risk factors for first-onset lumbopelvic pain in postpartum women: a systematic review. Journal of Women's Health Physical Therapy. 2019 Jul 1;43(3):127-35. doi: 10.1097/JWH.0000000000000133

4.1 Overview

The literature review (chapter 2) identified risk factors for running-related pain in the general population and in female runners; however, the only factor examined specifically in postpartum runners was lumbopelvic pain. Lumbopelvic pain has been most commonly studied in postpartum women, most likely due to an expected relationship between this type of pain and the physical changes that occur during pregnancy. The prevalence of lumbopelvic pain has been reported to be as high as 89.9% in pregnant women (Wu et al., 2004) and 30% in postpartum women (Van Beukering, 2002). Postpartum runners also commonly report lumbopelvic pain when running (up to 35%), so this is an important type of pain to consider in this group (Blyholder et al. 2017); however, no studies have investigated this pain in postpartum runners.

Several studies have investigated lumbopelvic pain either during pregnancy or during pregnancy plus the postpartum period; others focused on a single risk factor (mode of delivery) and its relation to lumbopelvic postpartum pain. In order to gain a comprehensive understanding about the risk factors for lumbopelvic pain in the general postpartum population, studies that investigate the factors that contribute to first time lumbopelvic pain in the postpartum period are needed. As there are many factors that might contribute to lumbopelvic pain in postpartum runners—many of which may not be related to running—it is important to first understand the factors that contribute to lumbopelvic pain in postpartum women generally, not specifically in postpartum runners.

Therefore, the fourth chapter of this thesis is a systematic review to determine risk factors (modifiable and nonmodifiable) for first onset lumbopelvic pain during the postpartum period. This systematic review will increase the understanding of the risk factors for first-time lumbopelvic pain and contribute to future recommendations for preventing or managing postpartum lumbopelvic pain. This information is important for postpartum runners with pain because multiple factors—not just running-related variables—may contribute to their pain. Information from this review has informed other studies in this thesis. Specifically, questions about modifiable and non-modifiable risk factors for lumbopelvic pain were included in the survey for postpartum runners with and without pain.

This paper has been published as original research in the *Journal of Women's Health Physical Therapy*. The following text represents the author's final edited version of the manuscript. My roles in this manuscript was as first author, which included: concept/research design, acquisition of data, analysis and interpretation of data, writing/ reviewing/ editing of manuscript; I take responsibility for the integrity of the work as a whole from inception to published work.

This is the accepted version of the following article: Christopher S, McCullough J, Snodgrass SJ, Cook C. Predictive risk factors for first-onset lumbopelvic pain in postpartum women: a systematic review. Journal of Women's Health Physical Therapy. 2019 Jul 1;43(3):127-35, which has now been formally published in final form at Journal of Women's Health Physical Therapy at 0.1097/JWH.0000000000000133. This original submission version of the article may be used for non-commercial purposes in accordance with the Mary Ann Liebert, Inc., publishers' self-archiving terms and conditions.

4.2 Abstract

4.2.1 Background

Lumbopelvic pain is common during pregnancy and postpartum. This pain has been linked to a variety of comorbidities, such as depression. Although pain is common in the postpartum period, the etiology of first onset pain is unclear and the risk factors associated with this pain in the postpartum period are unknown.

4.2.2 Objectives

The objective of the review was to determine risk factors for first onset lumbopelvic pain during the postpartum period.

4.2.3 Study Design

Systematic Review

4.2.4 Methods

Included articles were prospective cohort studies that identified modifiable and non-modifiable risk factors for first onset lumbopelvic postpartum pain. Articles were selected following a comprehensive search of four databases. The Quality in Prognostic Studies tool was used to evaluate the quality of studies. Risk factors from the articles were categorized as extrinsic, intrinsic or mixed and ranked by the strength of their association statistic.

4.2.5 Results

Four articles met the inclusion criteria. The pooled incidence of first onset lumbopelvic pain was 32%. Of the eleven risk factors investigated for low back pain, C-section delivery with epidural anesthesia, duration of first stage of labor, age of the mother, race and urinary tract infections were significantly predictive of first onset low back pain. Nine risk factors were investigated for pelvic pain; none were significant.

4.2.6 Conclusion

First onset low back pain is present amongst postpartum women. The five risk factors identified in single studies were non-modifiable. High quality prognostic studies need to more consistently investigate risk factors for first onset back pain in the postpartum pain.

4.3 Introduction

Lumbopelvic pain is common during pregnancy and postpartum periods, with a prevalence ranging from 3.9% to 89.9% (Jan M. A. Mens et al., 2012; Wu et al., 2004). This wide range of prevalence is due to the presence of pain at different periods of childbirth (early pregnancy, late pregnancy and postpartum), different study designs and different definitions of lumbopelvic pain (low back, pelvic girdle or both) (Jan M. A. Mens et al., 2012). Pelvic girdle pain is more commonly reported during pregnancy and lower back pain is most common in the postpartum period (Ostgaard et al., 1996).

Pain, specifically low back pain, has been linked to anxiety, depression, somatization symptoms, stressful responsibility, job dissatisfaction, mental stress at work, negative body image, weakness in ego functioning and poor drive satisfaction in the general population (Andersson, 1999; Hoy et al., 2014). Back pain has also been significantly associated with clinical depression in the postpartum period (J. M. A. Mens et al., 1996). Postpartum women with pelvic girdle or back pain have been reported to delay their return to becoming active again, which has correlated to a higher level of disability (Bastiaenen et al., 2006; Vlaeyen et al., 1995). The pathological mechanism of lumbopelvic postpartum pain is unclear, highlighting the need for more research (Wu et al., 2004).

To our knowledge, there have been no systematic reviews that investigate the risk factors for first onset lumbopelvic pain in the postpartum population, as the aetiology of this pain is poorly understood (Chia et al., 2016). Previous reviews have investigated lumbopelvic pain either during pregnancy, or both pregnancy and postpartum, or focused on a single risk factor (mode of delivery) and its relation to lumbopelvic postpartum pain. One study found that weight gain and retention was a risk factor for persistent back pain during and after childbirth and recommended weight management and diet control to decrease persistent back pain postpartum (To & Wong, 2003). Such recommendations do not exist for first onset lumbopelvic pain in the postpartum period, as it has not been studied. The objective of this systematic review was to determine risk factors (modifiable and non-modifiable) for first onset lumbopelvic pain during the postpartum period to increase an understanding of these risk factors and contribute to future recommendations for preventing or managing postpartum lumbopelvic pain.

4.4 Methods

4.4.1 Study Design

This study used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement during the search and reporting phase of this systematic review (Moher et al., 2010) (Chapter 4 Appendix B). The systematic review was also registered with PROSPERO International prospective registry of systematic reviews (# blinded here).

4.4.2 Search Strategy

A computer-based search strategy was conducted to include articles up to July 2018. To identify studies reporting musculoskeletal pain in the postpartum population the following databases were searched in consultation with a biomedical librarian: PubMed, Cumulative Index of Nursing and Allied Health Literature (CINAHL), Embase, and SPORTDiscus. Keywords and standardized vocabulary (e.g. medical subject headings (MeSH) for PubMed) were combined with Boolean operators to build the searches. Search terms for PubMed search can be found in Chapter 4 Appendix B. The searches for CINAHL, Embase and SPORTDiscus were built off the PubMed search using controlled vocabulary for each database. A detailed hand search involving references from the selected articles and gray literature (related articles in print or electronic format that are not controlled by commercial publishers) (Banks, 2004) was conducted, as computerized searches can occasionally omit relevant articles. Searches were limited to humans and English language.

4.4.3 Inclusion/Exclusion Criteria

We included prospective cohort studies with longitudinal designs (≥6 months) examining risk factors for a first onset of lumbopelvic pain during the postpartum period (first day after delivery up to menopausal age of mother). Lumbopelvic pain was defined as either lumbar or pelvic musculoskeletal pain (e.g. pelvic girdle, pubic symphysis, coccyx pain, posterior pelvic pain, symphysiolysis, SIJ syndrome) (Ostgaard et al., 1994; Vleeming et al., 2008; Wu et al., 2004). To reflect risk factors that would better inform primary prevention strategies in the postpartum period, we required the studies to include individuals who were pain free (no history of lumbopelvic pain) at baseline (any time before childbirth) (Taylor et al., 2014). Studies were excluded if participants had lumbopelvic pain prior to becoming pregnant, pain during the pregnancy period, (Bergström et al., 2014; Woolhouse et al., 2012) there were interventions performed for pain (to eliminate the effect of placebo), pain existed only cephalad to the upper back, or there was any surgery performed antenatal (Woolhouse et al., 2012). We excluded studies that did not report a measurement of pain, did not report strength of association statistics (e.g. odds, hazard or risks ratios) and did not report data to calculate of the association statistic. We primarily required risk ratios as they are predictive association statistics, but we included odds ratios as they are reported in cohort studies that use logistic regression. Risk ratios are the ratios of risk that a subject will develop an outcome (lumbopelvic pain) when given a specific exposure (Sistrom & Garvan, 2004). Odds ratio is the odds that a particular outcome would occur in relation to a specific exposure (Szumilas, 2010; Viera, 2008); it is commonly used in case control studies, but also has predictive ability when used in a regression equation.

4.4.4 Study Selection

Abstracts and selected full text articles were reviewed independently by two authors (SC and JM). Disagreements on whether to include an article were resolved by consulting a third author (CC).

4.4.5 Data Extraction

Data regarding study population, pain location and measurement method, predictive risk factors and strength of association statistics were extracted from full text articles by one reviewer (SC) and confirmed by author (JM). When risk ratio was not reported, the primary author (SC) calculated the statistic and was confirmed by author (JM). Descriptions of pain identified in the included studies and the methods of measurement have also been outlined in Table 4.1. Incidence of first onset lumbopelvic pain was calculated by pooling total number of subjects with first onset lumbopelvic pain and dividing that number by the total number of subjects among the studies (Friedenreich, 2002).

4.4.6 Quality Assessment

Risk of bias was evaluated using the QUIPS (Quality in Prognostic Studies) assessment tool (Hayden et al., 2013). This tool investigates prognostic studies for bias in six domains: study participation, study attrition, prognostic factor measurement, outcome measurement, study confounding, and statistical analysis reporting. Items were scored low, moderate or high in each domain. If consensus was not reached a third author (CC) made the final decision. Included full text articles were each assessed for bias independently by two authors (SC and JM). The QUIPS tool was considered appropriate because the focus of the review was prognostic risk factors and the tool was originally developed to study prognostic factors for low back pain.

4.4.7 Risk Factors

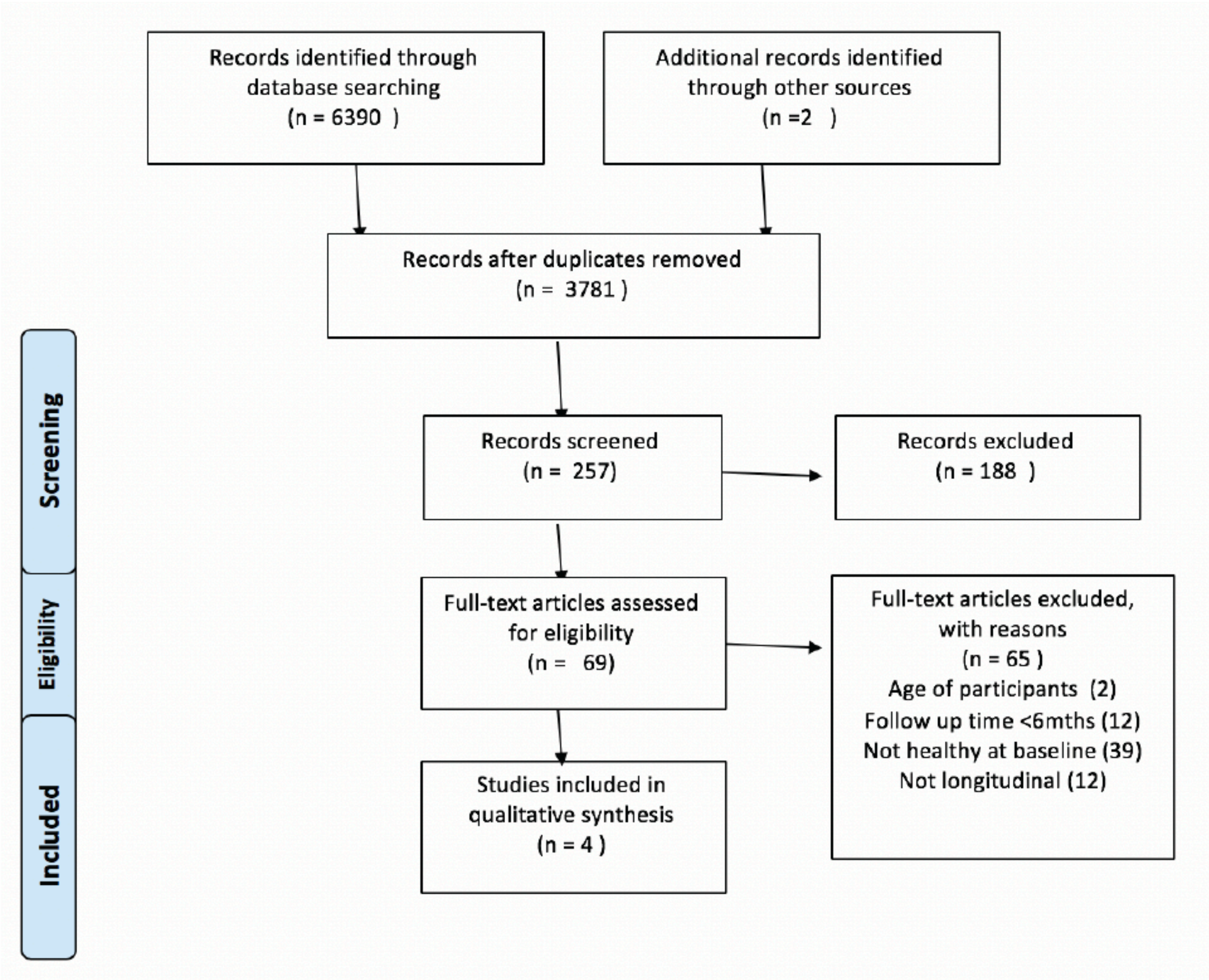
Risk factors were categorized broadly as extrinsic (originating from or on the outside) (Definition of EXTRINSIC, n.d.), intrinsic (belonging to the nature or constitution of a person) (Definition of INTRINSIC, n.d.) and mixed (in instances where causes could originate from outside the body or inside, e.g. an infection). This was performed to understand which factors may or may not be modifiable. To understand strength of relationships between variables, risk factors within these categories were further categorized by the strength of association. Risk ratios >1, where the risk of the outcome was greater than the exposure, were categorized as 1.0-1.5 (minor risk factor), 1.5-2.0 (moderate risk factor), or 2.0+ (major risk factor) (Taylor et al., 2014). Protective risk factors were operationally defined as factors with a strength of association less than 1.0, where the risk of outcome is lower with the exposure. These risk factors were divided into 0.0-0.5 (major protective factor), and 0.5-1.0 (minor protective factor) (Kim et al., 2018). Odds ratios >1, where the odds of the outcome were greater with participants that received an exposure, were categorized 0-1.5 (minor odds), 1.5-2.0(moderate odds), or 2.0+ (major odds). Odds ratios <1, where the odds of outcome were lower in the exposure group, were divided into 0.0-0.5 (minor protective odds), and 0.5-1.0 (moderate protective odds) (Kim et al., 2018; Taylor et al., 2014).

4.5 Results

4.5.1 Study Selection and strategy

Initially, the search yielded 3781 results once duplicates were removed. After abstract screening 69 full-text articles were retrieved. This high number was the result of unclear reporting of first onset pain in the literature (e.g. an abstract may not have mentioned if pain was first onset pain or persistent). Articles that included data on new first onset pain were eligible for inclusion, even if that was not the focus of their study. Following the full-text screening, four articles were included in this review. See figure 4.1 from PRISMA flow diagram.

Figure 4.1 PRISMA flow diagram



4.5.2 Quality of Studies

The results of the assessment of quality using the QUIPS (Quality in Prognostic Studies) tool are reported in Table 4.1. The item with the lowest quality was the outcome measure category, where 1/4 studies had high bias (Chia et al., 2016) and 1/4 had moderate bias (Loughnan et al., 2002). Study attrition (Chia et al., 2016) and study confounding (Loughnan et al., 2002) was also associated with high bias in 1/4 of the studies. There was no bias in analysis and reporting or prognostic factor measurement (risk factors measured in the study).

Table 4.1 Quality of prognostic study tool results in the four articles

	Study participation	**Study attrition**	**Prognostic Factor Measurement**	**Outcome measurement**	**Study confounding**	**Statistical analysis and reporting**
Blomquist et al., 2014	low	low	low	low	low	low
Chia et al., 2016	low	high	low	high	low	low
Kuyumcglu et al., 2006	low	low	low	low	low	low
Loughnan et al., 2002	moderate	low	low	moderate	high	low

Low, moderate or high bias per item in study

4.5.3 Data Extraction

Three of the four included studies required further statistical calculation by the primary author (SC). Kuyumcuoglu et al. (2006) provided the number of subjects at 6 months who had back pain with anesthesia and without, and therefore a risk ratio was calculated. Blomquist et al. (2014) also only provided the number of participants when reporting on certain risk factors, so authors calculated relative risk. Loughnan et al. (2002) reported odds ratio for certain risk factors. However, risk factors such as anesthesia and mode of delivery required further calculation. Since we were investigating risk factors such as anesthesia compared to no anesthesia and the relationship with first onset lumbopelvic pain, we grouped the number of subjects with different types of anesthesia together as “anesthesia” to compare to “no anesthesia” in one study (Loughnan et al., 2002).

4.5.3.1 Incidence of First Onset Low Back Pain

The range of first onset low back pain incidence was 19%-53%. The mean incidence was 31.75%. The number of participants included in each study sample ranged from 60 (Kuyumcuoğlu et al., 2006) to 40,057 participants (Chia et al., 2016) with follow-up periods from 6 months (Kuyumcuoğlu et al., 2006) to 11 years (Blomquist et al., 2014). Table 4.2 describes attributes of each study (author, study details, pain measurement method, outcome).

Table 4.2 Predictive risk factors for lumbopelvic pain reported in the studies included in this review (n= 4)

Author, year	**Patients= N, Age (yrs) f/u period, Incidence**	**Type of pain Measure method**	**Extrinsic Factors**	**Intrinsic Factors**	**Mixed Factors**
Blomquist et al., 2014	N= 1070 Age C-section 39.8yrs Vaginal: 40.1yrs (36.6-43.6) F/u 6-11yrs after first delivery Incidence: 19.35% (mode of delivery C-section-22% At least one vaginal birth-17%)	Pelvic Pain Oxfordshire Questionnaire: Asked about pelvic pain not associated with menses/ intercourse, classified as non, mild, moderate, or severe	Mode of delivery (risk of pain with C-section exposure) Pelvic pain: RR **1.28 95% CI 0.998, 1.6411 Moderate/ Severe pain: RR **1.16 95% CI 0.69, 1.96 Prolonged second stage: RR**0.88 95% CI 0.46, 1.68 Vaginal delivery birth >4kg ever: RR **1.59 95% CI 0.61, 4.13 Operative delivery (risk of vacuum or forceps): RR **0.98 95% CI 0.40, 2.41	Race: RR**1.07 95% CI 0.49, 2.32 Maternal age >35yr: RR**0.96 95% CI 0.53, 1.74 Multiparous: RR **1.05 95% CI 0.58, 1.90	Perineal laceration: RR **0.87 95% CI 0.39, 1.91 Episiotomy: RR **0.68 95% CI 0.31, 1.44
Chia et al., 2016	N= 40,057 Age: NR F/u: 3 yrs	Low back pain ICD-9 codes	LBP overall follow-up duration (3 yrs) CD with Spinal Anesthesia: OR 1.01 95% CI 0.96, 1.06; aOR 1.05 95% CI 1.00, 1.11	Maternal age: Multivariate logistic regression of potential predictors: Age, yrs aOR1.02 (1.02–	UTI: OR 1.18 95% CI 1.11, 1.24; <0.001

	Incidence: Overall 53.54% Vaginal delivery with LBP - 31.59% (8561) C-section with spinal anesthesia- 31.82% (2756) C section with Epidural anesthesia- 35.74% (1536)		CD with Epidural anesthesia: OR 1.20 95% CI 1.13, 1.29; aOR 1.25 95% CI 1.17, 1.34; p<0.001	1.03) <0.001 Diabetes mellitus: aOR 0.96 95% CI 0.83, 1.11 Obesity aOR: 1.01 95% CI 0.75, 1.35 Pregnancy related hypertension: aOR 1.04 95% CI 0.73, 1.47 Multiple gestation: aOR 1.00 95% CI 0.85, 1.19 Complicated obstetric conditions (pre-eclamsia, eclampsia): aOR 0.89 95% CI 0.75, 1.07	UTS: 0.78 95% CI 0.65, 0.94
Kuyumcglu et al., 2006	N= 60 Age: Epidural 24.3+ 5.3 Non-epidural 23.5+ 4.7 F/u 6 months Incidence: Overall-26.67%	Low back pain VAS 0-10	Anesthesia: RR**0.87 95% CI 0.38, 2.03 N.S. (at 6 months)		

	(16) Epidural-13% non-epidural-13%				
Loughnan et al., 2002	N 306 f/u period 6 months Incidence Overall 28% (101)	Backache Frequent Backache-presence; when it started; how it affected their daily function	Duration of first stage labor: OR 1.11 for a 1 h increase; 95% CI 1.04, 1.18; 0.002 Anesthesia (Epidural. Meperidine and both): RR**0.56 95% CI 0.14, 2.26 Anesthesia (just epidural) RR** 1.05 95% CI 0.75, 1.47 C-section/ forceps delivery: RR**1.30 95% CI 0.94, 1.81 Induced RR**1.16 95% CI 0.82, 1.64	Race-Non caucasian ethnic group: OR 1.73 95% CI 1.02, 2.94; 0.04 Married RR**1.17 95% CI 0.80, 1.72 Social Class RR**1.29 95% CI 0.83, 2.02	

N- # of subjects, f/u- follow up, yrs- years, VAS- visual analogue scale, C-section-cesarean section, highlighted- significant *p* value, ** OR/ RR calculated by author SC, OR- odds ratio, RR -risk ratio, CI- confidence interval, UTI – urinary tract infection, UTS- urinary tract stone, N.S-non significant

4.5.3.2 Identification of risk factors

4.5.3.2.1 Back Pain

Three studies (Chia et al., 2016; Kuyumcuoğlu et al., 2006; Loughnan et al., 2002) investigated predictive risk factors for first onset postpartum back pain. There were eleven risk factors investigated among the three articles included in this review (mode of delivery, anesthesia, length of first stage labor, maternal age, race, obesity, diabetes, pregnancy related hypertension, multiple gestations, obstetric complications (preeclampsia, eclampsia) and medical events (e.g. urinary tract infections and stones).

4.5.3.2.1.1 Extrinsic Risk Factors

Three studies investigated delivery and anesthesia. One study (Chia et al., 2016) found that women who had had a cesarean section (C-section) delivery along with epidural anesthesia were significantly more inclined to report first onset lumbar pain that persisted up to 3 years later compared to those with vaginal delivery (OR: 1.20 95% CI 1.13, 1.29; aOR 1.25 95% CI 1.17, 1.34) (Chia et al., 2016). Loughnan et al. (2002) investigated length of first stage labor associated with first onset low back pain and found that the risk of first onset low back pain significantly increased with a 1 hour increase in labor time (OR 1.11 for 1hr increase 95% CI 1.04, 1.18) (Loughnan et al., 2002). Both risk factors were categorized as minor odds (Table 4.3).

None of the risk factors investigated were specifically modifiable. Non-modifiable factors identified were race and mother's age. Factors that may have modifiable potential (if modification would not affect the health of the mother and the baby) were mode of delivery and duration of first stage labor.

4.5.3.2.1.2 Intrinsic Risk Factors

One study investigated age and found that age (older) was significantly predictive of first onset low back pain (OR 1.02 95% CI 1.02, 1.03) (Chia et al., 2016). Race was also significantly associated with lower back pain as non-Caucasian women had increased low back pain (OR 1.73 95% CI 1.02, 2.94) (Loughnan et al., 2002). Age was categorized as minor odds and race was categorized as moderate odds (Table 4.3).

Table 4.3 Strength of significant odds ratios for postpartum first onset low back pain

	Authors	Minor odds 1.0-1.5	Moderate odds 1.5-2.0
Extrinsic factors	Chia et al., 2016[9]	Cesarean Delivery with Epidural Anesthesia	
	Loughnan et al., 2002	Length of First stage labor	
Intrinsic factors	Chia et al., 2016	Maternal Age	
	Loughnan et al., 2002		Race- Non-Caucasian
Mixed factor	Chia et al., 2016	Urinary tract infection	

4.5.3.2.1.3 Mixed Risk Factor

One study investigated urinary tract infection (UTI) and low back pain (Chia et al., 2016). Since the cause for developing a UTI may be intrinsic or extrinsic, it was categorized as mixed (Ramzan et al., 2004). The study found that UTI was significantly predictive of first onset low back pain (OR 1.19 95% CI 1.11, 1.24) (Chia et al., 2016). This factor was categorized as minor odds (Table 4.3).

4.5.3.2.2 Pelvic Pain

One article investigated pelvic pain (Blomquist et al., 2014). Nine risk factors were investigated (intrinsic factors such as race, maternal age, and parity, extrinsic factors such as mode of delivery, birth weight of child, operative delivery (vacuum or forceps) length of second stage labor and mixed factors such as perineal laceration and episiotomy). None of the risk factors investigated were significantly associated with pelvic pain during the postpartum period.

4.6 Discussion

The primary objective of this systematic review was to identify modifiable and non-modifiable predictive risk factors for first onset postpartum pain. We identified four longitudinal studies that met the inclusion criteria, specifically, that the participants that were pain free at baseline (never having experienced lumbopelvic pain) (Taylor et al., 2014). We used this inclusion criteria to identify predictive risk factors for first onset lumbopelvic pain (Taylor et al., 2014). The risk factors that were predictive of back pain in this review were C-section delivery with epidural anesthesia, duration of first stage of labor, age of the mother, race and urinary tract infections. None of the risk factors investigated were specifically modifiable. Factors such as delivery and duration of first stage labor had modifiable potential if there were no health concerns for either mother or baby. Overall, lumbopelvic pain itself may be modifiable.

The pooled incidence of first onset lumbopelvic pain in postpartum women calculated from the studies in this review was 33%. It is therefore important for healthcare professionals to recognize that first onset low back pain is present in the postpartum period and refer the patient to appropriate therapy to avoid chronic pain. The presence of lumbopelvic pain has been well documented in studies with long term follow up (up to 10 years) (Blyholder et al., 2017) with the incidence of pain in back pain as high as 71% (Ostgaard et al., 1997) during pregnancy with 37% still experiencing pain 18 months postpartum (Ostgaard & Andersson, 1992). In the US, annual visits to the physician for low back pain and neck pain exceed $52 million and the direct medical costs surpass an estimated $250 billion USD annually (Spine: Low Back and Neck Pain). These values may be underestimated as they do not factor in indirect costs such as lost work productivity (Clewley et al., 2018). The scarcity of prospective cohort studies investigating first onset lumbopelvic pain in the postpartum period also highlights the fact that the postpartum period may be one of the most neglected periods of a woman's life in terms of her own health (WHO | WHO Recommendations on Postnatal Care of the Mother and Newborn, 2016). Traditionally, in the US, a comprehensive medical postpartum visit takes place during the first six weeks after childbirth, before and after which the mother does not have any scheduled contact with her physician or midwife. In April 2018, the American College of Obstetricians and Gynecologists released a committee opinion recommending postpartum care to be an ongoing process, especially with chronic conditions (Optimizing Postpartum Care - ACOG). By recognizing lumbopelvic pain early and referring out appropriately, health care costs and the chronicity of pain may be avoided.

Extrinsic factors that were predictive of back pain in this review were C-section delivery with epidural anesthesia and duration of first stage of labor. Length of first stage labor was a predictive risk factor in one study included in this review (Loughnan et al., 2002). During labor, the mother may be in a variety of positions that assist with rotation and descent of the baby (sitting, standing, side laying or supine) (The Cochrane Collaboration, 1996). Loughnan et al., (2002) found that every 1 hour increase in laboring time increased the odds of the mother developing back pain. It has been hypothesized that muscles may be stressed and strained the longer the laboring mother stays in certain positions, leading to back pain (MacArthur et al., 1990). Also, as labor is accompanied by acute nocioceptive pain (Lowe, 2002). The mother may not be able to distinguish whether the pain is from the process of labor or from her positioning in order to change positions. Therefore, the longer the mother labored the greater the odds of her developing first onset low back pain.

Chia et al. (2016) found C-section with epidural anesthesia to be predictive of low back pain, and also hypothesized this was potentially related to postures during delivery. During delivery with anesthesia, laboring mothers may be in stressful child birthing positions for hours prior to a C-section. Chia et al. (2016) theorized that due to the presence of anesthesia normal joint protective reflexes are lost, allowing the mother to be in stressful positions for long periods of time and not recognize the discomfort and need for a position change. Another theory linking epidural anesthesia and back pain was the possibility of epidural hematomas from needle insertion (MacEvilly & Buggy, 1996). Back pain was reported in cases of epidural hematomas, either spontaneous or procedure related (Sage, 1990; Schmidt & Nolte, 1992; Scott & Hibbard, 1990). The hematoma caused from the needle insertion activates the nociceptors in the muscular (Mense, 1993) and periosteal tissue (Gronblad & Liesi, n.d.), leading to back pain. One may argue that postures may be modifiable during labor, if safe for the baby and mother. Melzack et al. (1991) investigated position during labor and recommended shifting positions during early labor to decrease labor pain, as long as it is safe for the mother and baby. To our knowledge labor positions have not been exclusively studied as a predictive risk factor for back pain and may be a confounding variable in these larger risk factor studies.

Intrinsic factors that were predictive of back pain were race and age, each in one study. Loughnan et al. (2002) found that postpartum women who were not Caucasian (25% Gujarati Asians) were more likely to have first-time back pain. One study theorized the link between back pain and Asian women to be dietary or sociological, needing further investigation (MacArthur et al., 1993). Chia et al. (2016) found that older women may have greater odds of low back pain. Older age and back pain has been well researched (Meucci et al., 2015) and most recently a study investigating the prevalence of low back pain reported the most common age for females to be affected by low back pain was 41-50 years (Ramdas & Jella, 2018). Further studies are needed to explore whether age increased the odds of low back pain or whether the postpartum state is the variable predictive of low back pain.

Only one variable was predictive of back pain in the mixed factor category. Chia et al. (2016) found urinary tract infections increased the odds of first onset lumbopelvic pain. Most likely, a UTI is related to the general health or complications associated with delivery/hospitalization and is only an indirect contributor to LBP (Schwartz et al., 1999). Recurrent UTI's are highly prevalent in women with the recurrence rate up to 30% for women that have had one UTI and 25% of these women have further subsequent episodes (Smith et al., 2018). A study investigating community-acquired urinary tract infection reported a higher risk of infection for up to 12 months after a previous UTI (Almomani et al., 2018). One of the symptoms associated with UTI (kidney or bladder infection) is low back pain and management of these infections could reduce pain and increase function in this population (Forster et al., 2018; McKibben et al., 2015; Pietrucha-Dilanchian & Hooton, 2016; Zatorski et al., 2016). Therefore, it is likely that the association between UTI and long term back pain reported by Chia and colleagues (2016) was due to a history of recurrent UTIs. To truly elucidate the direct relationship between

UTI and back pain would demand a causal mediation design, which was not used by Chia and colleagues (2016).

Physical, occupational and psychosocial risk factors for first onset low back pain have not been studied in the postpartum population. A related review by Taylor et al. (2014) looked at incidence and risk factors for first incident low back pain in the general population. They identified physical factors such as standing, walking and lifting, or moving heavy objects as risk factors for first onset lumbar pain in the community setting. In the occupational setting, investigators found that physical factors such as reduced velocity of lifting tests and time spent driving a car for one's occupation were associated with first onset low back pain. Among psychosocial factors in the community setting, higher general health questionnaire scores were predictive of first onset lower back pain. In the occupational setting, psychosocial factors such as perception of heavy lifting efforts and psychosomatic factors were related to first onset low back pain. These physical and psychosocial factors in either a community or occupational setting were not investigated in the literature for first onset pain in the postpartum population, despite a large proportion of postpartum mothers or returning to an occupational setting and performing physical childcare tasks. In 2017, the US Bureau of Labor Statistics reported that the labor force participation rate for women with children under 3 was 60-67.5 percent (Employment Characteristics of Families Summary) (depending on marital status). Mothers are also performing a variety of physical childcare activities involving standing, walking, lifting (picking up baby) and moving heavy objects (i.e. a car seat with an infant in it). With regards to the psychosocial risk factors, the Center for Disease Control reported 1 out of 10 women developed symptoms of depression (Ko et al., 2012). With the increased awareness of postpartum depression and its association with pain, physical demands of childcare and an increase of mothers returning to work, future studies should consider investigating physical, occupational and other psychosocial risk factors.

The strength of this review was limited by the study design of articles investigating first onset lumbopelvic pain. To predict risk of first onset lumbopelvic pain, studies needed to have a prospective longitudinal study design (>6 months). During the search we found numerous articles that used case control methods, using a "snapshot" (cross sectional) approach to explain relationships and associations amongst variables. "Predictive modeling is forward-looking whereas an explanatory model is retrospective where you are testing an existing set of hypothesis" (Shmueli & Others, 2010). Future research should use prospective longitudinal cohort study designs to truly understand the nature of new first onset lumbopelvic pain.

Among the included studies, the types of risk factors investigated and the methods of pain measurement varied, which prevented data pooling and meta-analysis. There were inconsistencies in the measurement methods and variance in risk factors measured. Each of the three studies that investigated back pain in this review had a different method of pain measurement. One study used the visual analogue scale, one study used ICD-9 codes to identify back pain and one simply asked questions about the backache. None of the studies used the Oswestry disability index or the pelvic girdle pain questionnaire, which have been reported to be a valid outcome measures for lower back pain and pelvic girdle pain (Fairbank & Pynsent, 2000; Stuge et al., 2011). Due to this difference in pain measuring/reporting, most studies had significant risk of bias reporting the outcome measured, which may influence the results of this review. Risk factors measured varied significantly between studies. Of the four included studies, twenty different risk factors were investigated of which none was included in more than one study. This limits the conclusions that can be drawn from this review.

4.7 Conclusion

From this review one may cautiously conclude that C-section with epidural anesthesia, length of first stage labor, race, age and urinary tract infections may each increase the odds first-time postpartum back pain, as these were reported in single studies. These factors were all non-modifiable. High quality prognostic studies need to more consistently investigate these modifiable and other non-modifiable risk factors for first onset low back pain in the postpartum period. Current evidence identifies history of pain or presence of pain during pregnancy to be risk factors for lumbopelvic pain during the postpartum period and thus intervention strategies prior to the postpartum period may attempt to address this pain. However, for women with first onset lumbopelvic pain in the postpartum period, risk factors and thus intervention strategies still remain unclear.

4.8 Chapter 4 Appendices

4.8.1 PRISMA Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	3
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	3-4
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	4
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	4-5
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	4
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	appendixB
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	5

Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	5-6
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	5-6
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	6
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	5
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	6-7
Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	NR
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	6
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	7
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	8, table 4.2
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	7
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	Table 4.2
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of	NA

		consistency.	
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	NR
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	8-10, table 4.3
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	10
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	14
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	14-15
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	No Funding, see title page

4.8.2 Search Strategy

Search terms used in PubMed:

("Hip Joint"[Mesh] OR "Hip"[Mesh] OR "Hip Injuries"[Mesh] OR hip[tiab] OR "Pelvic Pain"[Mesh] OR pelvic[tiab] OR pelvis[tiab] OR “Back pain”[tiab] OR "Back Pain"[Mesh] OR "Low Back Pain"[Mesh] OR Musculoskeletal[tiab] OR "MUSCULOSKELETAL SYSTEM"[mesh] OR "Musculoskeletal Pain"[mesh] OR "Abdominal Muscles"[Mesh] OR "Abdominal"[tiab] OR "Abdominal Wall"[tiab] OR Abdomen[tiab] OR core[tiab] OR Lumbopelvic[tiab] OR "Lumbosacral Region"[Mesh] OR lumbar[tiab] OR "Joints"[Mesh] OR joint[tiab] OR joints[tiab] OR "Spine"[Mesh] OR spine[tiab] OR spinal[tiab]) AND ("Pain"[Mesh] OR Pain[tiab] OR painful[tiab] OR discomfort[tiab]) AND ("Postpartum Period/pathology"[Mesh] OR "Pregnancy Complications/physiology"[Mesh] OR "Pregnancy Complications/physiopathology"[Mesh] OR Postpartum[tiab] OR postnatal[tiab] OR "Puerperal Disorders/physiology"[Mesh] OR "Puerperal Disorders/physiopathology"[Mesh] OR puerperal[tiab] OR "Pregnancy/physiology"[Mesh] OR "Pregnancy/physiopathology"[Mesh] OR pregnancy[tiab] OR birth[tiab] OR childbirth[tiab] OR partum[tiab] OR natal[tiab] OR nulliparous[tiab]) AND (randomized controlled trial[pt] OR controlled clinical trial[pt] OR randomized[tiab] OR randomised[tiab] OR randomization[tiab] OR randomisation[tiab] OR randomly[tiab] OR trial[tiab] OR groups[tiab] OR Clinical trial[pt] OR “clinical trial”[tiab] OR “clinical trials”[tiab] OR "evaluation studies"[Publication Type] OR "evaluation studies as topic"[MeSH Terms] OR "evaluation study"[tiab] OR evaluation studies[tiab] OR "intervention studies"[tiab] OR "intervention study"[tiab] OR "intervention studies"[tiab] OR "case-control studies"[MeSH Terms] OR "case-control"[tiab] OR "cohort studies"[MeSH Terms] OR cohort[tiab] OR "longitudinal studies"[MeSH Terms] OR "longitudinal"[tiab] OR longitudinally[tiab] OR "prospective"[tiab] OR prospectively[tiab] OR "retrospective studies"[MeSH Terms] OR "retrospective"[tiab] OR "follow up"[tiab] OR "comparative study"[Publication Type] OR "comparative study"[tiab]) NOT ("Review" [Publication Type] OR Editorial[ptyp] OR Letter[ptyp] OR Case Reports[ptyp] OR Comment[ptyp]) NOT (animals[mh] NOT humans[mh])

CHAPTER 5. Common Musculoskeletal Impairments in Postpartum Runners: An International Delphi Study

Christopher SM, Garcia AN, Snodgrass SJ, Cook C. Common musculoskeletal impairments in postpartum runners: an international Delphi study. Archives of Physiotherapy. 2020 Oct;10(19) https://doi.org/10.1186/s40945-020-00090-y

5.1 Overview

The literature review identified risk factors for running-related injury in the general running population and in female runners, as well as identified risk factors for pain in the postpartum population. Only one study was identified that measured running injury and pain specifically in postpartum runners (Blyholder et al. 2017); previous injury was the only risk factor associated with running-related pain. Thus, there was very little evidence to guide the overall question of this thesis: what are the risk factors for running-related pain in postpartum runners?

When incomplete evidence exists to inform decision making, expert opinion is often used as a first step to determine the direction for research (Dawson & Barker, 2010; Fink et al., 1984; Powell, 2003). A Delphi technique is a commonly used survey tool that organizes expert opinion (Rowe & Wright, 1999). To use this technique, a researcher surveys a group of experts in a designated field using a list of sequential questions. The survey is designed to determine a consensus from the group on a particular topic (Jünger et al. 2017; Hasson et al. 2000; McMillan et al. 2016). This consensus method is necessary to assist with problem solving, determining priorities, or generating ideas about risk factors for pain in postpartum runners.

In the fifth chapter of this thesis, a Delphi survey was used to ask experts to comment on the musculoskeletal impairments (strength, range of motion, flexibility and alignment tests) they commonly observe when evaluating postpartum runners in pain. Experts were also asked to generate ideas on common risk factors they believe are observed in postpartum runners with pain. The systematic reviews in the previous chapters of this thesis determined the categories of muscle alterations (strength, flexibility, range of motion and alignment) that were used for the open-ended questions in the first round of the Delphi survey.

This paper has been published as original research in the Archives of Physiotherapy. My role in this manuscript was as first author which included: concept/research design, acquisition of data, analysis and interpretation of data, writing/ reviewing/ editing of manuscript; I take responsibility for the integrity of the work as a whole from inception to published work. Human research ethics approval was obtained from The University of Newcastle Human Research Ethics Committee and Elon University Research Ethics Committee.

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RESEARCH ARTICLE Open Access

Common musculoskeletal impairments in postpartum runners: an international Delphi study

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Abstract

Background: Postpartum runners report musculoskeletal pain with running. Because of inadequate research, little is known about the origin and pain-related classification. Through expert consensus, this study is the first attempt to understand the musculoskeletal impairments that these runners present with. The objective of this survey was to gather expert consensus on characteristics of reported impairments in postpartum runners that have musculoskeletal pain.

Methods: A web-based Delphi survey was conducted and was composed of five categories: strength, range of motion, alignment and flexibility impairments, as well as risk factors for pain in postpartum runners.

Results: A total of 117 experts were invited. Forty-five experts completed round I and forty-one completed rounds II and III. The strength impairments that reached consensus were abdominal, hip and pelvic floor muscle weakness. The range of motion impairments that reached consensus were hip extension restriction, anterior pelvic tilt and general hypermobility. The alignment impairments that reached consensus were a Trendelenburg sign, dynamic knee valgus, lumbar lordosis, over-pronation and thoracic kyphosis. The flexibility impairments that reached consensus were abdominal wall laxity, and tightness in hip flexors, lumbar extensors, iliotibial band and hamstrings. The risk factors for pain in postpartum runners were muscular imbalance, poor lumbopelvic control, too much too soon, life stressors, pain during pregnancy and pelvic floor trauma.

Conclusion: This study presents a framework for clinicians to understand pain in postpartum runners and that can be investigated in future cohort studies.

Level of evidence: 5

Keywords: Postpartum, Running, pain, Injury

Introduction

In 2019, USA running reported that 17.6 million people registered for road races with 61% of those registered identifying as female [1]. Of those women 49% were between the ages of 25-44 years, prime childbearing age [1]. The Center for Disease and Control and Prevention reported 29 years as the mean age of women at first childbirth and therefore one can argue that many of the women running may be of childbearing age [2]. A recent survey of female runners reported that 90% of recreation runners exercised regularly during pregnancy, with 72% who ran at any point during pregnancy, and 38% who ran during the third trimester [3]. For those that did not continue to run, reasons such as feeling poorly or uncomfortable, advice from doctor, concern for miscarriage and to gain and maintain weight were noted [4]. After childbirth, one survey reported approximately 50% of

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competitive participants returned to running at six weeks postpartum and one survey investigating competitive runners reported return to running as early as four weeks [3, 4].

Musculoskeletal pain and dysfunction is prevalent in postpartum runners, lumbopelvic pain in most commonly reported [3]. Among women who returned to running, 35% reported postpartum musculoskeletal pain upon returning to running, with 91% of pain complaints related to the lower back, pelvis and/or hips (lumbopelvic) [3]. Lumbopelvic pain is common during pregnancy and postpartum periods and is reported to affect 50% of pregnant women [4, 5]. This pain has been reported to decrease 1–3 months postpartum [6, 7] for most; however, it can become chronic in up to 7% of women [8]. Lumbopelvic postpartum pain is not well understood. Many risk factors have been hypothesized to be the cause of the pain. Research reporting on pain characteristics, patterns and associations with risk factors is lacking.

Women are running after having a baby and nearly all runners surveyed complained of pain upon returning to running [3]. During the postpartum period women are recovering from several pregnancy related changes such as increased weight gain [5], hormonal changes such as joint and connective tissue laxity, postural changes such as increased lumbar lordosis, flattening of feet [6], transient osteoporosis [7, 8] as well as after effects of the birthing process such as tearing of the pelvic floor muscles or recovering from c-section surgery [9].. First onset lumbopelvic pain has also been reported in postpartum women that did not have pain during pregnancy, due to risk factors related to delivery and maternal demographics [10]. Despite reports of musculoskeletal pain in the postpartum runners, conditions involving musculoskeletal pain are both poorly studied and lack specific measurement tools. To our knowledge there are no studies that have explored characteristics of pain in postpartum runners. In addition, the few existing exercise guidelines for the postpartum running population have been generated primarily from non-postpartum athlete studies [11].

When incomplete evidence exists to assist decision-making, expert opinion is often used in absentia [12–14]. A Delphi technique is a commonly used tool for “decision making and forecasting in a variety of studies” that organizes expert opinion [15]. This technique surveys a group of experts in a designated field to answer a list of sequential questions designed to determine a consensus from the group on a particular topic [16–18]. Consensus methods often help with research that is directed at problem solving, determining priorities, or generating ideas [18]. The purpose of the study was to perform a Delphi survey to gather expert consensus on common characteristics of reported musculoskeletal impairments in postpartum runners with pain, as well as generate expert ideas on common risk factors for pain in postpartum runners.

Methods

Study design

This study was a three-round web-based Delphi survey design involving a respondent group and a workgroup [19, 20]. Informed consent was obtained and subjects' rights were protected.

Subjects

The respondent group consisted of content expert volunteers, operationally defined as physical therapists or physiotherapists who were first and or last author of a peer-reviewed publication on female running evaluation and treatment and or postpartum evaluation and treatment, or a presenter at either a national or international conference on the topic. Experts were identified through PubMed searches, conference abstracts, and peer review. The authors were invited via email. Unlike surveys, the sample size of Delphi surveys does not depend on statistical power, but on the dynamics of the expert group arriving at consensus [21]. This Delphi aimed for a large sample to reflect all types of clinicians and researchers who interact with postpartum runners.

The workgroup included investigators who were experienced in mixed-methods research, including Delphi investigations. They summarized the data from round one, thematically coded the data and redesigned the follow-up survey instrument [22]. The workgroup as a whole had a minimum of 10 years' clinical experience and six years' clinical research experience in orthopedic physical therapy. The lead author was a board-certified sports physical therapist and athletic trainer with over seven years' experience treating runners. The other investigators have been involved in clinical research for six to 20 years, including one author (XX) who has had first or senior authorship on six Delphi analyses. (reference that would identify author).

Procedure

The survey consisted of three rounds of questionnaires. Invitations to round I of this study were distributed via Qualtrics email, a survey software which allows collecting and analyzing research data. The email provided a web address link to the consent form and survey. Invitations to rounds II and III survey links were sent to all respondents from round I. Each round was live for 3–4 weeks with weekly reminders.

Instrument

Round I of Delphi

The instrument used in the first round included demographic questions, professional questions and six open-ended questions related to impairments in postpartum runners with musculoskeletal pain. We did not define the location of pain, as we wanted to collect comprehensive information on postpartum runners with pain. We defined postpartum runners as “any female participating in running within two years of giving birth to a baby.” After defining postpartum, the respondents reported the most common strength impairments observed in postpartum runners in the first open-ended question [23]. The following four open-ended impairment-based questions queried topics involving range of motion (ROM), [23] alignment, [23] flexibility, [23] and most common risk factors for pain in postpartum runners. A sixth open-ended question allowed additional comments on the clinical presentation of postpartum runners (Additional file 1) [23].

Round II of Delphi

From the qualitative analysis of responses from round I, thematic coding was performed (SMC, ANG, CC). The questions in the second round were a list of impairments for each of the strength, ROM, alignment, flexibility, risk factors, and categories constructed from the thematic coding from round I of the survey. The purpose of round II was to allow all the respondents to review the responses from round I for clarification and correction of terminology, and to identify the most important impairments related to each of the categories in the survey. The respondents used a 4-point Likert scale that ranged from strongly disagree to strongly agree to score the impairments and their level of agreement that the impairment was related to the category included (Additional file 2).

Round III of Delphi

In round III, the survey instrument was built using the same impairments list and rating scale used in round II with additional graphs demonstrating the descriptive statistical score outcome for each category and impairment. The respondents were asked to re-score each impairment after viewing round II results. Figure 1 corresponds to a screenshot of one round III survey question for the strength category.

Data analysis

The survey instrument was built on Qualtrics survey software (version XM, Provo, Utah). After each round, the data were downloaded from Qualtrics into an excel spreadsheet for analysis [22]. The impairments in each

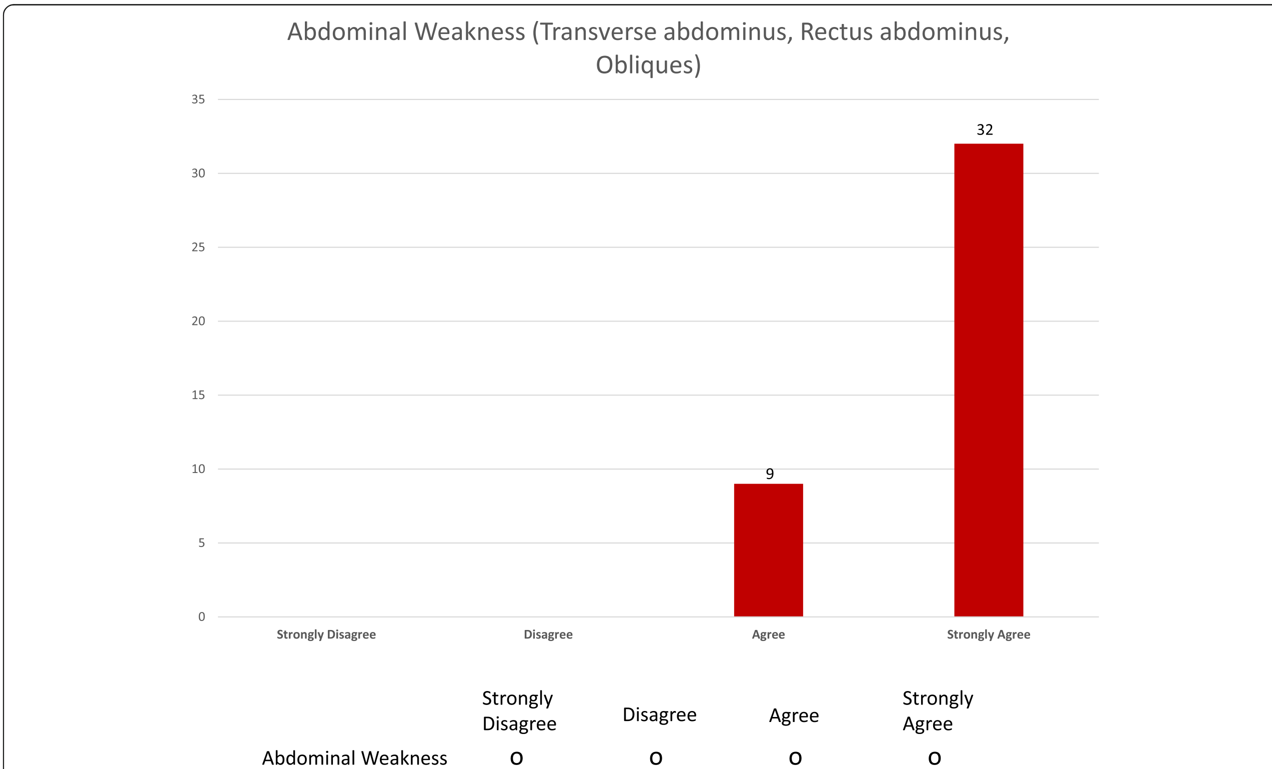

Fig. 1 Screenshot of round III survey question using impairment list from round II with additional graphs. X-axis: Likert scale, Y-axis 41 respondents

category that the respondents decided did not relate to the postpartum runner were tallied as strongly disagree or disagree and represented the “Consensus not related” category. The impairments in each category that the respondents decided did relate to the postpartum runner were tallied as strongly agree or agree and represented the “Consensus related” category. A consensus was established if ≥ 75% of the respondents indicated an item as “Consensus not related” or if ≥75% indicated an item as “Consensus related” [24]. In cases where the tally was < 75%, consensus was not established and a decision “Consensus not met” was made [12].

After establishing consensus, the impairments were ranked by composite score using the following formula: Composite score = (n1x 0) + (n2x1) + (n3x2) + (n4x4), where n was the number of respondents, and 1 was “strongly disagree”, 2 was “disagree”, 3 was “agree” and 4 was “strongly agree.” The design of a Delphi survey enables expert respondents to rank composite scores without feedback (Round II) and with graphic feedback (Round III) from other experts, and thus some changes were expected between rounds. Wilcoxon matched pairs signed rank was used to determine the meaningful difference between the scores of round II and III using a *p*-value of < 0.05 [25]. Statistical analyses were conducted using SAS, version 9.4 (SAS institute, Cary, NC).

Results

Round I and respondents characteristics

From March 2018 to June 2018, we contacted 117 content experts from female running or postpartum women’s health content areas. Eight respondents had incorrect email addresses; leaving 109 eligible experts. Thirteen experts declined to participate, noting they were not experts regarding this specific population. Fifty-one participants did not reply to invitations nor reminders. Forty-five participants (41%) completed the consent form and responded to the first round (Fig. 2). Thirty-three respondents were female (73.33%) and twelve were male (26.67%). Four experts (8.89%) resided outside the USA and five (91.11%) in the USA.

These respondents reported 0 to > 20 years of physical therapist practice experience with the largest group (40%) at > 20 years of practice experience. The respondents had 0 to > 20 years of research experience with the largest group (37%) with up to 5 years of research experience. Ten participants (22.22%) had advanced certifications in women’s health and 21 (46.67%) had advanced certifications in orthopedics or sports (Table 1).

Rounds II and III

Four respondents did not complete the survey from round II despite weekly reminders; 41 of the 45 respondents participated in round II (93% retention rate between rounds I and II, Fig. 2). Forty-one respondents completed round III (100% retention rate between rounds II and III, Fig. 2). A detailed description of total consensus (%) per impairment category for rounds II and III is reported in Table 2.

Impairment categories (see Table 2)

Strength

Five strength impairments were ranked as “Consensus related” in postpartum runners in round III. One impairment was ranked as “Consensus not related” and five impairments were ranked “Consensus not met” in round III. The item that was most related to strength impairment was abdominal weakness. Hip abductor (gluteus maximus, medius, minimus) hip extensor weakness were ranked second, followed by pelvic floor weakness and hip rotator weakness. Pectoralis major or minor weakness was ranked as the impairments least related to strength in the postpartum runner.

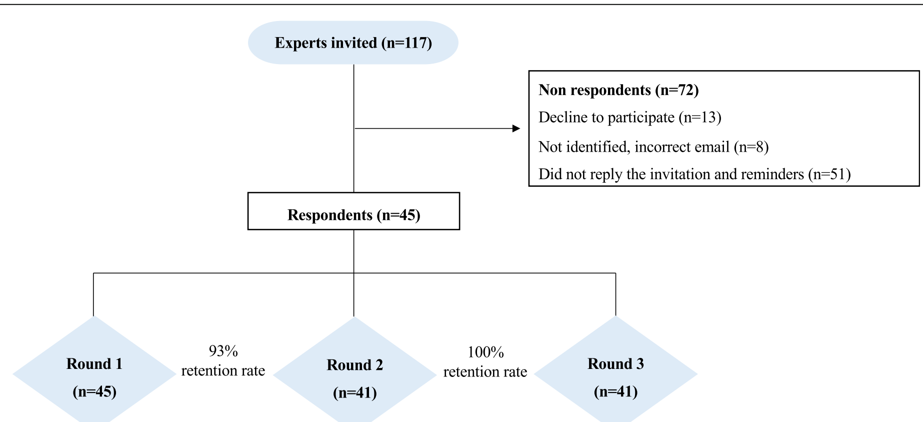

Fig. 2 Flow recruitment and study respondents

Table 1 Respondents characteristics in Delphi round I ($n = 45$)

Variables	Number (percentage)
Demographic variables	
Age	
20–30	5 (11.11)
30–40	16 (35.55)
40–50	14 (31.11)
50–60	7 (15.55)
> 60	3 (6.66)
Gender	
Female	33 (73.33)
Male	12 (26.67)
Country	
USA	(88.89)
Other	(11)
Professional variables	
Years of clinical practice	
0–5	7 (15.56)
5–10	10 (22.22)
10–15	4 (8.89)
15–20	6 (13.33)
> 20	18 (40)
Years of research practice	
None	4 (8.89)
0–5	17 (37.78)
5–10	9 (20)
10–15	6 (13.33)
15–20	6 (13.33)
> 20	3 (6.67)
Advanced certifications	
APTA board specialty (OCS, SCS, WCS)	27 (60)
– WCS	8 (29.62)
– OCS/SCS	19 (70.37)
PhD, EdD, PhDC	9 (20)
Other (i.e., CSCS, ATC, MS, FAAOMPT, CAPP)	19 (42.22)

Experts were physical therapists or physiotherapists who were first and or last author of a peer-reviewed publication on female running evaluation and treatment and or postpartum evaluation and treatment, or a presenter at either a national or international conference on the topic. WCS- Women's health certified specialist physical therapist, OCS- Orthopaedic certified specialist physical therapist, SCS- Sports certified specialist physical therapist, PhD- Doctor of philosophy, EdD – Doctorate in Education, PhDC- Doctor of philosophy candidate, CSCS- certified strength and conditioning specialist, ATC- athletic training certified, MS- Master of science, FAAOMPT- Fellow of the American academy of orthopedic manual physical therapists, CAPP- certificate of achievement in pelvic physical therapy

Range of motion

Five ROM impairments were ranked as "Consensus related" in postpartum runners in round III. Seven impairments were ranked as "Consensus not related" and five ROM impairments were ranked "Consensus not met" in round III. The item most related to ROM impairment was hip extension restriction, followed by anterior pelvic tilt, general hypomobility and no restrictions, thoracic extension restriction, and hip internal rotation restriction. Thoracic flexion restriction was the item most not related, followed by knee extension restriction, shoulder flexion restriction, thoracic side flexion restriction, hip flexion restriction, lumbar side flexion restriction, and lumbar flexion restriction.

Alignment

Five alignment impairments were ranked as "Consensus related" in postpartum women in round III. One impairment was ranked as "Consensus not related" and 10 items were ranked "Consensus not met" in round III. The item that was most related to alignment impairments in postpartum runners was the Trendelenburg sign. Dynamic knee valgus and increased lumbar lordosis ranked second, followed by overpronation, and thoracic kyphosis. The impairment least related to alignment impairments in postpartum women was posterior pelvic tilt.

Flexibility

Five impairments were ranked as "Consensus related" with flexibility impairments in postpartum runners in round III. Seven impairments were ranked as "Consensus not met" in round III. Tight hip flexors were ranked as the top impairment associated with flexibility impairments followed by laxity in abdominal wall, tight lumbar extensors, hamstrings, and iliotibial band.

Risk factors

Twenty-three items were ranked as "Consensus related" as risk factors for injury in postpartum runners in round III. Five items were ranked "Undecided" in round III. Muscle imbalance was most related to risk factors for pain in postpartum runners followed by poor lumbopelvic control, hip weakness, too much too soon, trauma to the pelvic floor, hip pain, increased life stressors, decreased exercise tolerance, and pain with pregnancy (all 100% consensus-related).

Differences between rounds II and III (Table 3)

A meaningful difference was measured between rounds II and III responses (Table 3) [20]. The impairments with significant difference when comparing composite score of rounds II and III (p value < 0.05 on Wilcoxon sign rank test) were lumbar extensor weakness and scapular stabilizer weakness in the strength category, thoracic rotation, lumbar extension, and shoulder flexion restriction in the ROM category, tight hip flexors in the flexibility category, anterior pelvic tilt in the alignment category, and runner body type, lumbopelvic instability,

Table 2 Final impairments in Delphi round III for reaching consensus as common musculoskeletal impairments in postpartum runners

Musculoskeletal Impairments	Consensus (%) Round II	Composite Score Round III	Consensus (%) Round III
Strength			
Abdominal weakness	100	160	100
Hip abductor weakness	100	154	100
Hip extensor weakness	95.12	142	100
Pelvic floor weakness	95.12	156	97.56
Hip rotator weakness	90.24	136	97.56
Range of Motion			
Hip extension restriction	82.93	131	95.12
Excessive counter nutation (anterior pelvic tilt)	90.24	123	92.68
Generally hypermobile, no restriction	68.29	129	90.24
Thoracic extension restriction	75.61	115	78.05
Hip internal rotation restriction	68.29	116	75.61
Flexibility			
Tight hip flexors	85.37	150	100
Laxity in abdominal wall	87.80	144	95.12
Tight lumbar extensors	68.29	118	80.49
Tight hamstrings	65.85	115	75.61
Tight iliotibial band	70.73	113	75.61
Alignment			
Trendelenburg sign	85.37	129	95.12
Dynamic knee valgus	80.49	124	92.68
Increased lumbar lordosis	87.80	124	92.68
Over pronation	70.73	114	80.49
Thoracic kyphosis	70.73	114	75.61
Risk Factors			
Muscular imbalance	100	156	100
Poor lumbopelvic control	100	154	100
Hip weakness	100	152	100
Too much, too soon	95.12	139	100
Trauma to pelvic floor	90.24	138	100
Hip pain	87.80	133	100
Increased life stressors	90.24	133	100
Decreased exercise tolerance	78.05	131	100
Pain during pregnancy	85.37	131	100
Lumbopelvic muscle weakness	97.56	153	97.56
Altered running mechanics	100	143	97.56
Chronic pain history	87.80	140	97.56
Global laxity	78.05	139	97.56
Pelvic floor pain	92.68	137	97.56
Lumbopelvic instability	92.68	137	97.56
Chronic fatigue	80.49	131	97.56
Hip extensor muscle activation	75.61	131	97.56
History of running injury	85.37	141	95.12

Table 2 Final impairments in Delphi round III for reaching consensus as common musculoskeletal impairments in postpartum runners *(Continued)*

Musculoskeletal Impairments	Consensus (%) Round II	Composite Score Round III	Consensus (%) Round III
Poor sleep quality	82.93	131	95.12
Caretaking posture	73.17	130	92.68
Labor duration	73.17	122	92.68
Increased body mass index (BMI)	78.05	124	90.24

diastasis recti, increased Q angle, too much too soon, trauma to the pelvic floor, altered running mechanics, and global laxity in the risk factor category.

Discussion

The purpose of this Delphi study was to identify impairments that contribute to pain with running in the postpartum population. The initial Delphi consisted of forty-one qualified members of the respondent group who finished all rounds who contributed to the results. The study showed a good response rate (100%). Our findings suggest that all impairments meeting the criteria of 75% consensus are potential contributors to pain in the postpartum running population.

Strength impairments that were commonly observed in postpartum runners and reached consensus as impairments were abdominal weakness, hip weakness (rotator, extensor and abductors), and pelvic floor weakness. These factors have only been studied in a limited capacity in the postpartum running population. Two peer reviewed case studies investigating postpartum runners [26, 27] reported the findings of abdominal and hip weakness in the postpartum runners. A recent survey [3] reported 19% of postpartum runners had stress urinary incontinence up to two years postpartum and 27% up to 10 years postpartum, supporting pelvic floor weakness as a strength impairment. Although abdominal, [28–31] pelvic floor, [32] and hip weakness [33] have been documented independently in either the postpartum or running population, high quality evidence from prospective design studies is lacking. While none of these findings are novel in the individual populations, our findings suggest that return to running evaluations in the postpartum population may benefit from core, pelvic floor, and hip strength testing [34–37].

Although laxity is present during pregnancy and postpartum states [38] some flexibility and ROM impairment restrictions that met consensus had conflicting evidence on literature review. Experts reported that tight hip flexors and a limited hip extension ROM were both a flexibility and ROM impairment in postpartum runners. Evidence for this was conflicted, as these impairments were present in one postpartum runner case study [27]; however not present in another [26]. Hip flexor tightness (and lumbar extensor tightness) has been hypothesized to result from postural changes that may take place during pregnancy [39]. Hip flexor stretches are commonly used in treatment programs for pregnancy-related pelvic girdle pain [39, 40]. Tight hip flexors have also been noted in runners compared to non-runners [41]. It could be possible that postpartum runners compensate for laxity with other structures to provide stability [42]. Thus, this Delphi suggests that clinicians should evaluate postpartum runners for these impairments and apply clinical judgement to decide whether the hip requires more motion or the lumbopelvic region requires more strengthening for stability.

The following alignment impairments met consensus for postpartum runners and had conflicting reports in the literature: Trendelenburg sign, dynamic knee valgus, increased lumbar lordosis, overpronation and thoracic kyphosis. In case studies investigating postpartum runners, knee valgus and Trendelenburg sign were supported during functional testing (single leg squat and lunge) in one case study, [26] and increased lumbar lordosis and thoracic kyphosis were noted in one case study [27]. Changes in multiplanar knee laxity have been documented during pregnancy and up to five months postpartum [43]. Pronation has also been documented as a change through pregnancy and postpartum due to laxity and weight gain, and may result in lasting changes in foot structure [44]. Trendelenburg alignment is the result of hip weakness and has been well-studied in cross-sectional studies investigating running injury risk [45–48] and pain [49–51]. Importantly, the association is unclear in prospective studies [23]. As a whole, these findings are supported in the postpartum or running literature. Future studies need further exploration in postpartum runners.

The most common risk factors for postpartum running that were not included in other categories were hip pain, decreased exercise tolerance, pain during pregnancy, too much too soon, life stressors, and pelvic floor trauma. These risks were also studied in either postpartum or running populations. The findings from this category offer a unique perspective in

Table 3 Wilcoxon matched pairs signed rank was used to determine the meaningful difference between rounds using a p-value of < 0.05

Impairment categories	Median- Round II	Median - Round III	P-Value
Strength			
Pelvic Floor Weakness	4	4	0.213
Abdominal Weakness	4	4	0.180
Lumbar extensor weakness	3	2	0.046
Hip abductor weakness	4	4	0.267
Hip adductor weakness	2	2	0.386
Hip rotator weakness	3	3	0.521
Hip extensor weakness	3	3	0.680
Knee extensor weakness	2	2	1
Scapular stabilizer weakness	3	2	0.019
Foot intrinsic muscle weakness	2	2	0.666
Pec Major/ Minor weakness	2	2	0.106
Range of motion			
Hip external rotation restriction	3	3	1
Hip internal rotation restriction	3	3	0.480
Hip extension restriction	3	3	0.597
Hip flexion restriction	2	2	0.167
Thoracic flexion restriction	2	2	0.223
Thoracic extension restriction	3	3	1
Thoracic rotation restriction	2	2	0.033
Thoracic side flexion restriction	2	2	0.229
Lumbar flexion restriction	2	2	0.466
Lumbar extension restriction	2	2	0.022
Lumbar side flexion restriction	2	2	0.108
Knee flexion restriction	2	2	0.055
Knee extension restriction	3	3	0.749
Ankle dorsiflexion restriction	2	3	0.694
Shoulder flexion restriction	2	2	0.019
Anterior pelvic tilt	3	3	0.459
Generally hypermobile	3	3	0.103
Flexibility			
Laxity in abdominal wall	3	4	0.265
Tight cervical extensors	3	3	1
Tight pectoralis muscles	3	3	0.804
Tight lumbar extensors	3	3	0.722
Tight hip flexors	4	4	0.024
Tight hip adductors	2	3	0.758
Tight hip external rotators	3	3	0.754
Tight hip internal rotators	3	3	0.395
Tight IT band	3	3	0.99
Tight hamstrings	3	3	0.335
Tight rectus femoris	3	3	0.352
Tight heel cord musculature	3	3	0.267
Alignment			
For Pubic symphysis upslip/downslip	3	3	0.544
Innominant upslip/downslip	3	3	0.408
Sacral obliquity	3	3	0.476
Innominant Outflare	2	2	0.082
Leg length discrepancy- functional	3	3	0.680
Leg length discrepancy -structural	2	2	0.639
Over pronation	3	3	0.633
Thoracic kyphosis	3	3	0.796
Increased lumbar lordosis	3	3	0.288
Posterior pelvic tilt	2	2	0.587
Anterior pelvic tilt	3	2	<0.000
Sway Back	3	3	0.858
Tredenlenburg sign	3	3	0.771
Dynamic Knee Valgus	3	3	0.401
Genu Valgum	3	3	0.987
Genu recurvatum	3	3	0.575
Risk Factors			
Runner Body Type	4	2	<0.000
Lack of postpartum education from OB GYN	4	4	0.629
Lumbopelvic muscle weakness	4	4	0.118
Muscular imbalance	4	4	0.238
Poor lumbopelvic control	4	4	0.210
Hip Weakness	3	2	0.441
Poor torso rotation	3	3	0.137
Incontinence	3	3	0.485
Pelvic floor pain	3	3	0.693
Hip pain	3	3	0.985
Knee pain	3	3	0.593
Foot pain	3	3	0.146
Hip extensor muscle activation	3	3	0.693
Lumbopelvic instability	3	3	0.001
Decreased exercise tolerance	3	3	0.229
Diastasis Recti	3	3	<0.001
Increased Q angle	3	3	0.015
Too much too soon	3	3	0.047
Hip instability	3	3	0.114
Multiparity	3	3	0.651
Increased BMI	2	2	0.141
Age	3	3	0.252
History of running injury	3	3	0.342
Chronic pain history	3	3	0.825
Pain during pregnancy	3	3	0.236
Poor sleep quality	3	3	0.170
Chronic fatigue	3	3	0.479
Increased life stressors	3	3	0.840
Labor	3	3	0.648
Trauma to pelvic floor	3	4	0.000
Altered running mechanics	3	3	<0.000
Global laxity	3	3	<0.000
Caretaking posture	3	3	0.115
Forward head and increased kyphosis	2	4	0.478

Characteristics statistically significant are highlighted in green. Scores on likert scale 1 = strongly disagree, 2 = disagree, 3 = agree and 4 = strongly agree

recommendations for returning to running. Pain pre-pregnancy and during pregnancy has been associated with pain in postpartum [52–55]. One of the case studies evaluating pain in the postpartum runner reported a history of pain [27]. Both hip pain and pain during pregnancy could be related to a history of previous injury that has been seen to be a risk factor for future injury in runners [56–60]. Future studies should investigate these factors in pregnant runners as they may also be barriers running during pregnancy and return to running postpartum.

Fatigue, the decreased capacity for activity (either physical or mental due to an imbalance of resources needed to perform an activity), [61] has been reported as the most common problem in the postpartum period, affecting 63.8% of new mothers [62]. Lack of sleep, stress, anxiety and breastfeeding difficulties have all been associated as risk factors for postpartum fatigue [63]. Fatigue has also been studied in the running population as a risk factor for injury [57], [64]. "Too much too soon" has also been studied for its relationship with injury with endurance athletes [65] as high spikes in acute training load have been associated with injury [66]. New mothers may be eager to return to former levels of activity and due to limited peer reviewed guidelines and recommendations, may return to aggressively. A survey of postpartum runners reported nearly 50% of survey participants returned to running at six weeks, sooner than most muscle and fascia healing timelines [3, 11]. Trauma to the pelvic floor was also reported as one of the most risk factors for pain in postpartum runners. During childbirth there can be significant injury to the pelvic floor that may lead to significant problems such as incontinence and prolapse [11]. Muscular imbalance was also reported as a risk factor for pain in postpartum runners. Although studies have not reported on the evaluation of this imbalance, studies focusing on individualized treatment using stabilization exercises have shown higher quality of life, lower disability and lower pain intensity [37]. These Delphi survey findings highlight that postpartum runners may need a team of providers such as a lactation consultant, psychologist, physical therapist, and running coach may assist in reducing pain and injury and that clinicians should include questions related to these risks while evaluating the postpartum runner.

Limitations

Delphi methodology starts by asking open ended questions followed by voting on the most common answers. This did not allow for us to further understand the expert's definitions for some of the impairments such as anterior pelvic tilt or hip weakness or risk factor pelvic floor trauma, nor their method of evaluating these impairments. When investigating alignment impairments in postpartum runners, experts ranked anterior pelvic tilt in the "consensus not met" category in round III. An anterior pelvic tilt has been seen to be present as a response to pregnancy and fetal development [67–69]. There is conflicting data in both pregnancy and postpartum [70, 71]. Experts were unable to reach consensus, potentially due to the lack of a clinical reference standard of measurement and conflicting reports of this alignment impairment.

Conclusion

Postpartum runners report pain with running, yet evidence-based cohort research is lacking about the musculoskeletal impairments and risk factors in postpartum runners with pain. Delphi studies collect and analyze expert information and are often the first step to designing future cohort studies. This Delphi study recorded and analyzed the opinions of physical therapy experts in women's health and running to provide clinicians with a comprehensive list of possible impairments to more effectively evaluate and treat the postpartum runner in pain. In addition to providing information for clinicians which was previously lacking, researchers will now have a framework with which to design future cohort studies.

Supplementary information

Supplementary information accompanies this paper at https://doi.org/10.1186/s40945-020-00090-y.

Additional file 1. Delphi Survey instrument used in the first round.
Additional file 2. Delphi Survey instrument used in the second round.
Additional file 3. Items that were "Consensus not related" or "Consensus not met".

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I affirm that I have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript, except as disclosed in an attachment and cited in the manuscript. Any other conflict of interest (i.e., personal associations or involvement as a director, officer, or expert witness) is also disclosed in an attachment.

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CHAPTER 6. What are the Biopsychosocial Risk Factors Associated with Pain in Postpartum Runners? Development of a Clinical Decision Tool

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6.1 Overview

Chapter six is a survey study that investigates risk factors for running-related pain in the postpartum running population. The thesis's earlier studies—the literature reviews and Delphi survey—were crucial in the creation of this survey. The literature reviews helped inform the questions asked in the Delphi survey. The Delphi survey collected risk factors in the categories of strength, range of motion, flexibility, alignment and others, that experts agreed were present in postpartum runners reporting pain. Questions for the survey reported in this chapter were developed from the findings of the Delphi survey and systematic review findings. The survey was designed to confirm some of the findings from the previous studies in a cohort of postpartum runners.

Therefore, the purpose of the study reported in chapter 6 was to identify the biopsychosocial risk factors for running-related pain in postpartum runners. To understand the compounding effects of multiple associative risk factors a clinical decision tool was developed. The study was a cross sectional survey where postpartum runners with and without pain answered questions about running, postpartum and demographic related variables. It aimed to identify the risk factors related to pain. This survey was needed because 35% of postpartum runners are reporting pain, and no information about this pain exists for women running after childbirth.

This paper has been published as original research in Plos One. My role in this manuscript was as first author, which included concept/research design, acquisition of data, analysis and interpretation of data, writing/ reviewing/ editing of manuscript; I take responsibility for the integrity of the work as a whole from inception to published work. Human research ethics approval was obtained from The University of Newcastle Human Research Ethics Committee and Elon University Research Ethics Committee.

RESEARCH ARTICLE

What are the biopsychosocial risk factors associated with pain in postpartum runners? Development of a clinical decision tool

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Data Availability Statement: Data attached in supplemental S2 File.

Abstract

Background

In 2019, a majority of runners participating in running events were female and 49% were of childbearing age. Studies have reported that women are initiating or returning to running after childbirth with up to 35% reporting pain. There are no studies exploring running-related pain or risk factors for this pain after childbirth in runners. Postpartum runners have a variety of biomechanical, musculoskeletal, and physiologic impairments from which to recover from when returning to high impact sports like running, which could influence initiating or returning to running. Therefore, the purpose of this study was to identify risk factors associated with running-related pain in postpartum runners with and without pain. This study also aimed to understand the compounding effects of multiple associative risk factors by developing a clinical decision tool to identify postpartum runners at higher risk for pain.

Methods

Postpartum runners with at least one child ≤36 months who ran once a week and postpartum runners unable to run because of pain, but identified as runners, were surveyed. Running variables (mileage, time to first postpartum run), postpartum variables (delivery type, breastfeeding, incontinence, sleep, fatigue, depression), and demographic information were collected. Risk factors for running-related pain were analyzed in bivariate regression models. Variables meeting criteria (P<0.15) were entered into a multivariate logistic regression model to create a clinical decision tool. The tool identified compounding factors that increased the probability of having running-related pain after childbirth.

Results

Analyses included 538 postpartum runners; 176 (32.7%) reporting running-related pain. Eleven variables were included in the multivariate model with six retained in the clinical

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decision tool: runner type-novice (OR 3.51; 95% CI 1.65, 7.48), postpartum accumulated fatigue score of >19 (OR 2.48; 95% CI 1.44, 4.28), previous running injury (OR 1.95; 95% CI 1.31, 2.91), vaginal delivery (OR 1.63; 95% CI 1.06, 2.50), incontinence (OR 1.95; 95% CI 1.31, 2.84) and <6.8 hours of sleep on average per night (OR 1.89; 95% CI 1.28, 2.78). Having $\geq$ 4 risk factors increased the probability of having running-related pain to 61.2%.

Conclusion

The results of this study provide a deeper understanding of the risk factors for running-related pain in postpartum runners. With this information, clinicians can monitor and educate postpartum runners initiating or returning to running. Education could include details of risk factors, combinations of factors for pain and strategies to mitigate risks. Coaches can adapt running workload accounting for fatigue and sleep fluctuations to optimize recovery and performance. Future longitudinal studies that follow asymptomatic postpartum women returning to running after childbirth over time should be performed to validate these findings.

Introduction

Injuries are the most common reason for reductions or termination of recreational and fitive running [1–3]. Injury incidence, specifically overuse-related injury, has been reported to occur in as many as 92.4% of recreational runners [4]. Because of significant psychological and physiological health benefits, it is best to keep runners running. Running is associated with reductions in psychological distress, depression, anxiety, and improves one's self-image, and mood [5], and is also linked with a decreased risk of cardiovascular disease, and assists with weight management [6,7].

Postpartum runners potentially make up a large portion of community runners as a majority of women participating in running events have been documented to be of childbearing age [8]. In one study of 406 postpartum runners, 45% returned to running within 4 weeks after childbirth, and 70% returned within 8 weeks [9]. Returning to running after childbirth is challenging for many women [10] as a postpartum woman experiences a plethora of perinatal related musculoskeletal and physiological changes. Early return to running may negatively influence the traditional healing and recovery processes associated with childbirth (e.g., pelvic floor damage, scarring, and strength loss) [11]. Receiving rehabilitative postpartum care is not common practice with respect to timing, intensity, and running [12]. Presently, there are no peer reviewed return to sport protocols guiding postpartum women [12], which may be one of the reasons that 35% of postpartum runners experience running-related pain [10].

A recently published Delphi study had experts report on common musculoskeletal deficiencies and risk factors that contribute to pain in postpartum runners [13]. The included risk factors and deficiencies consisted of strength impairments (abdominal, hip, and pelvic floor weakness, range of motion impairments (hip extension restriction, anterior pelvic tilt, and general hypermobility), flexibility impairments (abdominal wall, and tightness in hip flexors, lumbar extensors, iliotibial band, and hamstrings) and alignment impairments (Trendelenburg sign, dynamic knee valgus, lumbar lordosis, over-pronation, and thoracic kyphosis). The risk factors identified by the expert group for pain in postpartum runners were hip pain, decreased exercise tolerance, pain during pregnancy, trying to exercise "too much too soon", life stressors, and pelvic floor trauma.

Experts, not postpartum runners, proposed the previously described risk factors and impairments. To our knowledge, an in-depth investigation identifying risk factors associated with running-related pain in postpartum runners has not been published. This study aims to identify potential risk factors associated with pain in postpartum runners, in a case control group of postpartum runners with and without a self-report of running-related pain. This study also aims to explore the compounding effects of multiple associative risk factors by developing a clinical decision tool to identify postpartum runners at higher risk for pain.

Methods

Design and reporting standards

An international cross-sectional survey was conducted between December 2019 and January 2021. This web-based, anonymous survey was available through social media and flyers posted in public spaces likely to be frequented by postpartum runners in Durham, Raleigh and Burlington, North Carolina, United States. The flyer was also emailed to physiotherapists colleagues, who treat runners or postpartum women, to share the survey flyer on their social media and post in their clinics all around the United States. This study was approved by university institutional review boards. Before consenting to take the survey, participants were provided with study details (S1 File). Methods and results are reported in accordance with the checklist of reporting results of internet e-surveys (CHERRIES) guidelines [14].

Survey

As no standardized questionnaires were identified to investigate pain in postpartum runners, this survey was designed utilizing previously published works on postpartum runners [9,10,12,13,15,16]. The survey draft was reviewed by five experts and content was edited. The survey was then piloted by six postpartum runners to test usability and functionality before launching. Pilot data were not included in the statistical analysis.

Participants were women 18-years and older who had given birth to at least one child in the past three years, were running at least one time per week or trying to run but were unable to due to pain, and were not currently pregnant [17,18]. The first three questions of the survey confirmed eligibility and the survey terminated if inclusion criteria were not met (S1 File). Those who were not running at least once a week were provided an additional question to identify the reason for their limitation (pain, time or other), and were included if pain was the limiting factor. The youngest child's date of birth was provided to confirm eligibility.

Study variables

Descriptive/Independent variables. For demographics, age (years), parity (primiparous or multiparous), race (Caucasian or other), education (high school or greater) and relationship status (married yes/no) were collected. For postpartum variables, diastasis recti diagnosis (yes/no), breastfeeding status (yes/no), incontinence (any), delivery type of youngest child (vaginal, cesarean, or other), fatigue (yes/no), postpartum accumulated fatigue scale score (PAFS), Edinburgh postpartum depression score (EDPS), average hours of sleep (hours) and average sleep interruptions (1–5 or more) were collected. To collect running-related variables participants reported on average weekly running amount (miles), time to first postpartum run (weeks), type of runner (e.g., novice, recreational, competitive/elite), and previous running-related injury (RRI). Since the survey spanned the COVID-19 pandemic, in April 2020 a question regarding the pandemic's effect on running mileage was added to the survey.

When possible, validated surveys were used to measure postpartum related variables. Postpartum fatigue, a common postpartum symptom, was measured by asking participants if they experienced fatigue, and those that said yes answered the PAFS. Those that said no, were coded as 0 for the PAFS score. The PAFS includes questions covering three areas of physical, emotional, and cognitive fatigue and has good validity and internal consistency [19,20]. To measure depression, we used the EPDS, a self-report questionnaire designed to screen new mothers [21] and their emotional experience over the previous seven days [21,22]. It is a widely used screening instrument used for assessing depression and anxiety in the perinatal population [22,23].

Outcome/Dependent variables. In this survey, a report of pain associated with running was the outcome variable. Participants were asked if they had current pain when running, which was scored as "yes" or "no". Although pain descriptors and alleviating/aggravating factors were collected, they were not included in this study.

Missing values

The raw survey data were evaluated for missing values and there were 12 (0.10%), reflected in a total of 6 (1.11%) cases. Little's test for missingness showed the data were missing completely at random. We performed multiple regression-based imputation to replace missing values and pooled the results of five iterations. Upon completion, all analyses were performed on the pooled imputed dataset.

Statistical analysis for data modeling

All analyses were performed using SPSS version 26.0.0.2 (IBM corp. Armonk, NY, USA). Descriptive statistics representing raw data for the categories were calculated, including means and standard deviations or proportions and percentages. When appropriate, frequencies and distributions were also calculated. Independent samples t-tests or Chi square tests were performed to understand differences between postpartum runners with and without pain. Before the bivariate analysis, continuous variables were converted to binomial variables using the midpoint of the ROC (Receiver Operating Characteristic) curve generated discrimination threshold.

Bivariate logistic regression modeling. For the initial step of clinical decision tool modeling, we evaluated dedicated cumulative combinations of factors that were related to postpartum running-related pain [24,25]. Bivariate relationships (one predictor to a single outcome) were analyzed with 19 unique logistic regression analyses for the outcome variable (do you currently have pain with running?). When there were multiple variables that measured the same construct (e.g., fatigue and PAFS score or sleep average hours and number of sleep interruptions) the authors identified the single item or scale that most accurately reflected the latent construct. For example, PAFS total score was used for fatigue and for sleep average hours was used for sleep.

Multivariate logistic regression modeling. Variables that achieved a P value of <0.15 in their bivariate logistic regression were retained in the multivariate regression analysis [24]. To ensure appropriate modeling, multicollinearity was assessed for each of the retained variables using Phi and Cramer's V to reflect the data type (nominal). Variables with multicollinearity R values of less than 0.6 were used in the multivariate analysis. For the multivariate analysis, a backward conditional stepwise logistic regression was used [24]. Variables that had 95% confidence intervals that did not cross 1.0 were considered statistically significant.

Creation of conditions for the clinical decision tool. The retained variables in the multivariate model were used to understand the effect of the cumulative combinations of variables on the presence of pain in the sample, a feature typical to clinical decision rules modeling [24]. The retained regression variables from the aforementioned stepwise regression findings were entered into 2x2 contingency tables such that the combination of variables 1 of X, 2 of X and 3

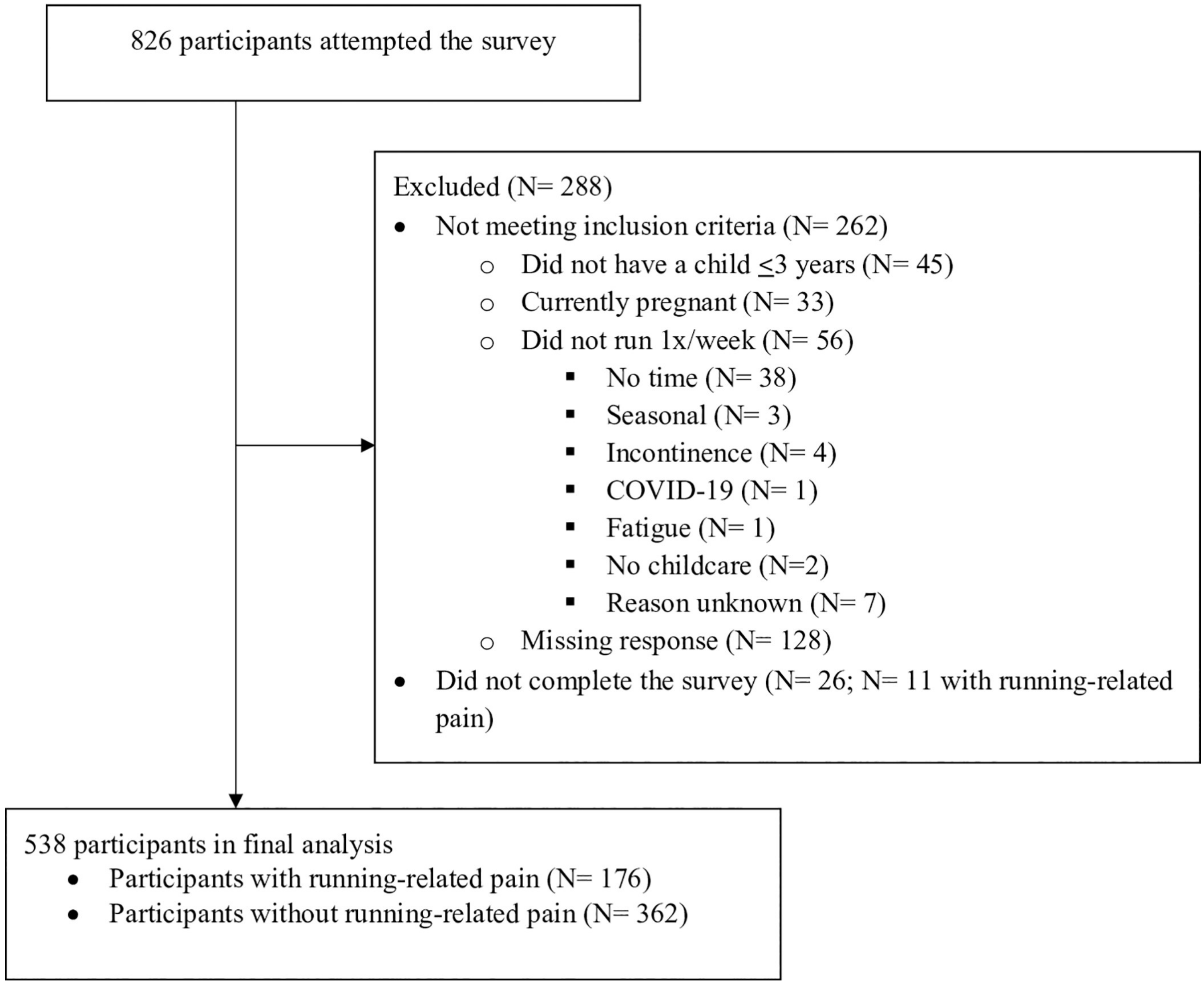

Fig 1. Flow chart of survey study participants.

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of X and so on generated sensitivity, specificity, positive and negative likelihood ratios and 95% CIs [24]. For each combination (e.g., 1 of X), the odds ratio and 95% confidence intervals, *P* value and Nagelkerke R^2 were captured [24,26]. The Nagelkerke R^2 is a goodness of fit measure that helps explain the strength of the independent variable with the model [24]. We also include a post-test probability of a negative and positive finding using a post-test prevalence calculator (Diagnostic post-test probability disease calculator) [27].

Results

Participants

The survey was initiated by 826 participants; 538 who met the inclusion criteria and completed the survey were included in the final analyses (Fig 1). The majority of incomplete surveys involved women who did not meet the eligibility criteria (n = 262), which triggered the survey to terminate early. Twenty-six eligible respondents did not finish the survey. Eligible non-completers had similar average weekly running mileage and proportions of each type of runner. The percentage of non-completers with pain (11/26, 42%) was slightly higher than in the completers (176/538, 33%), suggesting the prevalence of running-related pain in postpartum women might be slightly higher than our survey suggests. Information about the demographics of non-completers could not be analyzed as most did not complete that section of the survey.

Among the 538 eligible respondents who completed the survey, 176 (32.7%) reported current pain with running. Postpartum runners in pain had significantly higher prevalence of any incontinence, vaginal deliveries, fatigue, sleep interruptions, novice runners in the group, previous RRI and PAFS and EPDS scores. They also had lower education level, less average weekly hours of sleep, lower total weekly running mileage, when compared to postpartum runners without pain (Table 1).

Bivariate modeling of associative factors and pain during running

Of the nineteen variables analyzed in the bivariate models, eleven were retained in the multivariate model (Table 2). There were no variables removed for multicollinearity (r values were well below 0.6). When the eleven variables were entered into the multivariate analysis, six variables were retained and were associated with pain with running (Table 3).

Multivariate modeling of associative factors and pain during running

The sensitivity, specificity, positive and negative likelihood ratios, and probabilities of having pain with running or not (clinical decision tool) in the presence of one or more of the six identified risk factors are outlined in Table 4. The probability of having running-related pain increased with each cumulative risk factor. The use of 4 of 6 to "rule in" the risk for postpartum running pain is recommended for the clinical decision tool, as the confidence intervals of the positive likelihood at this level were narrow and it represented a moderate percentage of the sample (N = 23) with postpartum running-related pain (Table 4).

Discussion

Women are running after childbirth and up to 35% are reporting pain; however, studies investigating pain in postpartum runners are sparse [10,13]. This study is the first large survey to investigate risk factors for running-related pain in the postpartum population. By creating a clinical decision tool, this study also provides information on the compounding effect of multiple associative variables and pain in postpartum runners. In this sample of runners, the six significant variables associated with having pain were runner type-novice, postpartum accumulated fatigue scale score (>19), previous running injury, most recent delivery-vaginal, incontinence, and average amount of sleep per night (<6.8 hours). When four or more risk factors were present, our model suggested the probability of having pain increased from 32.7% (pre-test prevalence) to 61% (post-test). While this model needs validation in a longitudinal cohort of pain free postpartum runners to determine its predictive capacity, the results provide a deeper understanding of the risk factors for running-related pain in postpartum runners. This may assist health care providers educate postpartum runners and develop interventions that assist postpartum women stay injury free as they initiate or return to running.

Risk factors associated with postpartum running-related pain

One of the factors that had the highest odds for pain in postpartum runners was self-identifying as a novice runner, a finding that is consistent with previous work [28]. Novice runners are

Table 1. Descriptive statistics for demographics, postpartum, running and COVID-19 related factors between postpartum runners with (N = 176) and without self-reported running-related pain (n = 362).

Variables		Total (N = 538)	Postpartum pain (N = 176)	Postpartum no pain (N = 362)	P value
Demographics	Mean age (SD)	33.62(4.04)	33.38 (3.81)	33.74 (3.75)	0.300
	Parity (1 child)	237 (44.1)	84 (47.7)	153 (42.3)	0.231
	Race (Caucasian)	503 (93.5)	163 (92.6)	340 (93.91)	0.564
	Education level (≥High school)	503 (93.5)	158 (89.8)	345 (95.3)	0.015*
	Relationship status (Married)	526 (97.7)	170 (96.6)	356 (98.3)	0.200
Postpartum					
	Diastasis Recti diagnosis	115 (21.4)	46 (26.1)	69 (19.1)	0.060
	Breastfeeding/pumping	252 (46.8)	85 (48.3)	167 (46.1)	0.637
	Incontinence	230 (42.8)	95 (54.0)	135 (37.3)	<0.01*
	Delivery type				
	Vaginal	367 (68.2)	130 (73.9)	237 (65.5)	0.050*
	Cesarean	132 (24.5)	37 (21.0)	95 (26.2)	0.187
	VBAC/Vaginal assisted	39 (7.3)	9 (5.1)	30 (8.3)	0.183
	Fatigue (yes)	461 (85.7)	164 (93.2)	297 (82.0)	0.001*
	Mean Postpartum accumulated fatigue scale (PAFS) score (SD)	10.54 (8.07)	13.59 (8.67)	9.05 (7.33)	<0.001*
	Mean Edinburgh Postpartum Depression score (SD)	6.70 (4.84)	7.38 (5.07)	6.37 (4.69)	0.024*
	Mean hours of sleep per night (SD)	6.67 (1.17)	6.40 (1.21)	6.80 (1.12)	<0.001*
	Missing values	1 (0.2)	1 (0.6)	0 (0.0)	
	Number of sleep interruptions per night‡				
	0	46(8.6)	11 (6.3)	35 (9.7)	<0.001*
	1	156 (29.0)	41 (23.30)	115 (31.77)	
	2	168 (31.2)	59 (33.52)	109 (30.11)	
	3	94 (17.5)	29 (16.48)	65 (17.96)	
	4	37 (6.9)	17 (9.66)	20 (5.52)	
	5	15 (2.8)	3 (1.70)	12 (3.31)	
	>5	22 (4.1)	16 (9.09)	6 (1.66)	
Running					
	Mean total weekly mileage (SD)	13.07 (12.37)	11.80 (12.99)	13.68 (12.02)	0.100*
	Missing values	1 (0.2)	1(0.6)	0 (0.0)	
	Mean weeks to first run postpartum(SD)	12.72(14.31)	14.53 (16.80)	11.85 (12.87)	0.066
	Missing values	4 (0.7)	3 (1.7)	1 (0.3)	
	Runner type				
	Missing values	2 (0.4)	2 (1.1)	0 (0.0)	
	Runner type- Novice	36 (6.69)	20 (11.5)	14 (3.9)	0.001*
	Runner type- Recreational	401 (74.54)	126 (72.4)	275 (76)	0.380
	Runner type- Elite	101 (18.77)	28 (16.1)	73 (20.2)	0.260
	Currently running with stroller	292 (54.2)	94 (53.4)	197 (54.4)	0.826
	Previous running injury	292 (54.3)	108 (61.4)	184 (50.8)	0.021*
COVID-19	COVID related running changes‡	164 (30.3%)			
	Mileage increased	64 (11.9)	20 (35.71)	44 (40.74)	0.359
	Mileage decreased	31 (5.8)	14 (25%)	17 (15.74)	
	No change in mileage	69 (12.8)	22 (39.30)	47 (43.52)	

*Significant $P < 0.05$; VBAC–vaginal birth after cesarean

‡- Chi square test; Variables represent number (%) or t-test analysis unless otherwise noted.

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Table 2. Bivariate relationship between risk factors and having current pain with running.

Variable (Binomial distinction)		Odds ratio (95% CI)	P value	Nagelkerke R^2
Demographics	Parity (only 1 child)	1.23 (0.87, 1.79)	0.232	0.004
	Race (Caucasian)	0.81 (0.40, 1.65)	0.564	0.001
	Education (≥High school)	0.43 (0.22, 0.86)	0.017*	0.014
	Relationship status (Married)	0.48 (0.15, 1.50)	0.206	0.004
	Diastasis recti diagnosis (yes/no)	1.50 (0.98, 2.30)	0.061*	0.009
Postpartum	Breastfeeding/pumping (yes/no)	1.09 (0.76, 1.56)	0.637	0.001
	Incontinence: Urine, feces and/or gas (yes/no)	1.97 (1.37, 2.84)	<0.001*	0.034
	Delivery type- Vaginal (yes/no)	1.49 (0.10, 2.22)	0.050*	0.010
	Delivery type- C-section (yes/no)	0.75 (0.49, 1.15)	0.188	0.005
	Delivery type- Other (yes/no)	0.40 (0.28, 1.29)	0.187	0.005
	PAFS score (≥19)	2.84 (1.70, 4.73)	<0.001*	0.041
	EPDS (≥12.5)	1.84 (1.13, 3.01)	0.014*	0.015
	Sleep (≤6.83 hours)	2.09 (1.45, 3.01)	<0.001*	0.040
Running	Total weekly mileage (≥15.25 miles)	0.73 (0.49, 1.10)	0.134*	0.006
	First run postpartum (≥24.5 weeks)	1.61 (0.90, 2.89)	0.108*	0.008
	Runner type- Novice (yes/no)	3.29 (1.62, 6.72)	0.001*	0.027
	Runner type- Recreational (yes/no)	0.77 (0.48, 1.26)	0.302	0.002
	Runner type- Elite (yes/no)	0.81 (0.54, 1.21)	0.301	0.004
	Previous running injury (yes/no)	1.54 (1.07, 2.22)	0.022*	0.014

*Met criteria (p <0.15) for inclusion in multivariate model; Abbreviations; PAFS = Postpartum accumulated fatigue scale; EPDS = Edinburgh Postpartum Depression Score.

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more likely to be older, have higher BMI, have had a previous injury, and have no previous experience with running [29]. Novice runners who participate in a self-devised training program are also more likely to be injured compared to those using a structured "couch to 5K" program [27] suggesting the need for a structured program that addresses the potential confounding variables that may increase the risk of injury in a novice runner.

A higher postpartum accumulated fatigue scale (PAFS) score had higher odds for pain in postpartum runners. Fatigue in new parents is well studied, with up to 64% reporting fatigue during the postpartum period [30,31]. In athlete populations, fatigue is often studied to understand underperformance and injury [32]. Insufficient recovery time, the lack of optimal training load, and training intensity have all been associated with fatigue [32,33]. Although fatigue has been well documented in postpartum and athlete populations separately, it has not been

Table 3. Results of final multivariate model (backwards stepwise) demonstrating variables that are associated with current pain with running postpartum (R^2 = 0.161).

Variable	Odds Ratio (95% CI)	P value
Delivery type- Vaginal (yes/no)	1.63 (1.06, 2.50)	0.027*
Incontinence (Urine, feces and/or gas)	1.93 (1.31, 2.84)	0.001*
PAFS score (≥19)	2.48 (1.44, 4.28)	0.001*
Amount of sleep (≤6.84)	1.89 (1.28, 2.78)	0.001*
Runner type- Novice (yes/no)	3.51 (1.65, 7.48)	0.001*
Previous running injury (yes/no)	1.95 (1.31, 2.91)	0.001*

*Significant $P<0.05$; Abbreviations; CI = Confidence intervals; PAFS = Postpartum accumulated fatigue scale.

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Table 4. Clinical prediction tool for postpartum running-related pain based on having different numbers of risk factors and current pain with running.

Number (of 6*) risk factors present	Sensitivity (95% CI)	Specificity (95% CI)	Positive Likelihood Ratio (95% CI)	Negative Likelihood Ratio (95% CI)	Post-test probability when finding is positive (%)**	Post-test probability when finding is negative (%)
1 or more	98.9 (96.3, 99.8)	5.0 (3.70, 5.40)	1.04 (1.0, 1.06)	0.23 (0.04, 1.00)	33.6	10.1
2 or more	87.5 (82.4, 91.6)	30.10 (27.60, 32.10)	1.25 (1.14, 1.35)	0.42 (0.26, 0.64)	37.8	16.9
3 or more	63.60 (57.4, 69.5)	67.4 (64.4, 70.2)	1.95 (1.61, 2.34)	0.54 (0.43,0.66)	48.7	20.8
4 or more	23.30 (18.70, 27.40)	92.80 (90.60, 94.80)	3.24 (2.01, 5.29)	0.83 (0.77, 0.90)	61.2	28.7
5 or more	5.10 (3.10, 5.70)	99.7 (98.7, 100.00)	18.51 (2.46, 390.14)	0.95 (0.94, 0.98)	90.0	31.6
6 of 6	0.60 (0.00, 0.60)	100.0 (99.70, 100.00)	Inf (0.12, Inf)	0.99 (0.99, 1.00)	~100	32.5

*Six significant variables: Runner type-novice, postpartum accumulated fatigue scale score (>19), previous running injury, most recent delivery-vaginal, incontinence and amount of sleep (<6.8 hours).

**Pre-test probability was 32.7% before statistical analysis was performed to evaluate cumulative effects of associated variables. Abbreviations; CI = Confidence intervals.

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studied in postpartum athlete populations. The finding that postpartum runners with greater accumulated fatigue had higher odds of pain than those with less fatigue may highlight the need to monitor this risk factor in the postpartum running population. Coaches and clinicians may have to adjust typical running workload (frequency, intensity, duration) when working with fatigued postpartum runners. It is important to note however that fatigue is often associated with pain and thus this fatigue-related pain may not be related to running [34]. Therefore, postpartum runners initiating or returning to running should be screened not only for pain but also for fatigue which may also contribute to symptoms [34].

Previous running-related injury (RRI) was associated with higher odds for postpartum running-related pain in the current study. To our knowledge, only one previous study reported an association between pain during pregnancy and pain in postpartum runners; however, it was not clear if this previous pain was running-related [10]. A history of a previous injury has been well established as a strong risk factor for future RRI injury in numerous prospective studies investigating non-postpartum populations [4,35–39]. Whereas previous injury may be a non-modifiable risk factor, improved rehabilitation programs may assist reducing any subsequent injuries [38]. Although the relationship between previous and subsequent RRI has not been studied in any population, clinicians may want to screen postpartum runners with previous RRI to identify running-related risk factors as well as increase education on training related risk factors, to decrease pain and future injury in this population [35].

Women with incontinence were found to have increased odds of postpartum running-related pain. Nevertheless, from the results of the present study, it is unknown if the pain caused the incontinence, or the incontinence caused the pain. Pain, specifically low back pain, has been associated with urinary incontinence in large epidemiological studies [40]. Thirty percent of postpartum mothers experience urinary incontinence and 10% experience anal incontinence [41] as pregnancy and parity are well known causes of pelvic floor dysfunction [42]. Participating in a sport, specifically one with high impact such as running, is also a risk factor for incontinence [42]. This finding of an association between incontinence and pain suggests that screening for incontinence in postpartum runners should be routinely performed and that appropriate referrals to pelvic health physical therapists are recommended.

A lack of sleep was also associated with postpartum running-related pain in this study. Sleep deprivation can increase the prevalence of clinical pain and change pain processing [43,44]. Chronic insufficiency of sleep can lead to sensitization and habituation [45,46]. Postpartum women experience significant sleep disruptions after childbirth due to infant sleep and feeding patterns [47,48]. To our knowledge, no studies have investigated the effects of postpartum sleep deprivation and its relationship with performance, recovery, or injury. Nonetheless, adults need between 7 and 9 hours of sleep per night for optimal health, with athletes requiring 9–10 hours per night for optimal performance [49–51]. Sleep deprivation affects pain facilitating agents and the immune system and can hinder muscle recovery and repair of damage when exercising at high intensity [52–54]. It is important for sleep to be screened [55] and postpartum runners should be educated on worsening sleep patterns and strategies to prevent sleep related problems [55].

Mode of delivery, specifically vaginal delivery, increased the odds of pain in postpartum runners. In other studies, 74.9% of the postpartum runners with pain reported a vaginal delivery [10]. To our knowledge, no other studies have investigated delivery type and running-related pain in the postpartum population. Chronic pain intensity has been observed to be higher after vaginal delivery than caesarean delivery, severely affecting mood and quality of life [56–58]. Although we did not query participants about vaginal tearing in this survey, it may be that the participants with vaginal delivery also had significant perineal trauma, which has been linked with persistent postpartum pain [59]. The findings of this study highlight that when evaluating a postpartum runner with running-related pain, questions about delivery should be routinely asked due to the potential contribution to pain intensity and potential recovery.

Limitations

The study design is cross sectional, and correlational, consequently only non-causal associations can be inferred from the findings. Survey results are subjective to recall bias and to address this concern, analysis was restricted to three years postpartum, and runners were asked about their symptoms currently or in the past week. It is possible that this study is not a representative sample of the full postpartum running population (e.g., our sample was predominantly white, with a higher level of education). Survey methodology is limited in that it cannot collect data on possible biomechanical, musculoskeletal, and physiologic impairments that might be measured in a clinical or laboratory environment, however it is a first step towards identifying possible risk factors for running-related pain in postpartum women. There are limitations with the methodology we used to develop the clinical decision tool, methods that are traditionally used to develop clinical prediction rules [60,61]. However, these methods best reflected our purpose of combining parsimonious factors related to pain. A factor analysis or a cluster analysis could have been used, but these models do not reflect the variables associated with pain, they only reflect variables that have similar constructs (independent of pain). Further, as clinical prediction rules are generally developed from longitudinal modeling, our population sample would need to be followed over time to establish evidence for these factors as predictors of pain and clinicians should use caution when considering application of this evidence in practice. Finally, we did not measure intensity of pain in this study but merely if runners had pain or not.

Conclusion

This study created a clinical decision tool that identified the cumulative effect of six risk factors (runner type-novice, postpartum accumulated fatigue scale score (>19), previous running injury, most recent delivery-vaginal, incontinence and amount of sleep (<6.8 hours) that were associated with pain when running. With this information, clinicians can monitor and educate postpartum runners initiating or returning to running. Coaches can adapt running workload accounting for fatigue and sleep fluctuations to optimize recovery and performance. Future longitudinal studies that follow asymptomatic postpartum women returning to running after childbirth over time should be performed to validate these findings.

Supporting information

S1 File. Qualtrics survey seen by participants.
(DOCX)

S2 File. Anonymized data set.
(XLSX)

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CHAPTER 7. Biomechanical and Musculoskeletal Differences Between Postpartum Runners and Nulliparous Controls

Christopher S, Bauer L, Maylone R, Bullock G, Chinworth S, Snodgrass SJ, Vallabhajosula S. Biomechanical and musculoskeletal differences between postpartum runners and nulliparous controls. Submitted to Journal of Women's Health Physical Therapy. June 2021

7.1 Overview

Information on the effects of musculoskeletal, physiologic and biomechanical changes through pregnancy and postpartum on a postpartum runner's running gait is sparse. Despite the literature outlining the physiologic (Bø et al. 2016) and postural postpartum changes that occur in a female runner's body following childbirth (Hagan and Wong 2010; Branco et al. 2013; Carpes et al. 2008; Gilleard 2013; Forczek and Staszkiewicz 2012; Lymbery and Gilleard 2005), as well as evidence of persistent postpartum weakness (Paddon-Jones et al. 2006), there is currently little understanding of these underlying biomechanical and clinical changes when initiating or returning to running after childbirth. The only study that investigated these changes had a small sample size (N=5) and found that postpartum runners had restricted pelvic and trunk rotation, hip range of motion, and decreased cadence from their pre-pregnancy running gait analysis. This lack of research on the effects on pregnancy and postpartum related changes on running gait, combined with possible risk factors for running-related pain identified in this thesis's literature reviews and Delphi survey that cannot be explored via a survey, led me to conduct a laboratory-based study.

Chapter 7 presents the fifth study of my thesis which was designed to investigate differences in overground running kinetics, strength, and flexibility in healthy postpartum runners compared to age-matched nulliparous controls. Information about the effects of pregnancy and postpartum changes on these variables will help health care providers determine if there are postpartum-specific kinematic, strength, and flexibility, differences that need to be considered when a female is initiating or returning to running post childbirth. For example, more information on biomechanics can help a clinician decide if a running gait analysis should be part of initiating or returning to running.

This paper has been published as original research in the Archives of Physiotherapy. My roles in this manuscript was as first author, which included: concept/research design, acquisition of data, analysis and interpretation of data, writing/ reviewing/ editing of manuscript; I take responsibility for the integrity of the work as a whole from inception to published work. Human research ethics approval was obtained from The University of Newcastle Human Research Ethics Committee and Elon University Research Ethics Committee.

ABSTRACT

Background: Women are running as soon as eight weeks postpartum and there is currently little understanding of the effects of pregnancy and childbirth on the postpartum runner (PPR). Pregnancy related musculoskeletal and physiological changes could impact running gait postpartum.

Objective: The purpose of the current study was to investigate differences in overground running kinetics, strength and flexibility in PPRs and age-matched nulliparous controls.

Methods: Vertical and antero-posterior ground reaction force (APGRF) data were collected during overground running and normalized to body weight (NBW). Hip and knee strength, and hamstring flexibility measures were collected using a hand-held dynamometer and inclinometer, respectively. Data were averaged for both legs. Independent samples t-tests and effect size (ES) estimations were conducted using $\alpha=0.05$.

Findings: 9 PPRs (33.10±5.60 years; ≤2 years postpartum) and 9 age-matched nulliparous women (31.67±4.55 years) participated. PPRs had 24.3% greater braking loading rate for APGRF than controls (mean difference (MD) 3.41NBW/s, 95% CI 0.08, 6.74, $P=0.046$; ES 1.08). PPRs had 14% less hamstring flexibility (MD 10.98°, 95% CI 0.97, 20.99; $P=0.034$; ES 1.14), 25.9% less hip abduction strength (MD 0.04NBW, 95% CI 0.00, 0.08; $P=0.045$; ES 1.07) and 51.6% less hip adduction strength (MD 0.06NBW, 95% CI 0.02, 0.10; $P=0.003$; ES 1.68).

Interpretation: These preliminary findings suggest that PPRs demonstrate altered running braking strategies and decreased hamstring flexibility and hip strength compared to nulliparous controls. As running guidelines for PPRs have been derived mostly from expert opinion, this exploratory cohort study suggests that PPRs should be evaluated for musculoskeletal impairments before initiating or returning to running.

7.2 Introduction

Running, recreationally and competitively, is growing rapidly with more participation from females than males and 47% of those female runners being of childbearing age (Running USA Releases Latest U.S. Running Trends Report, n.d.). A survey of female runners reported that 90% of the recreational runners exercised regularly during pregnancy and 38% reported continued running during the third trimester (Blyholder et al., 2017). After childbirth, approximately 50% of the participants returned to running at six weeks postpartum (Blyholder et al., 2017). Another survey showed that after childbirth, around 45% of competitive postpartum runners returned to running within four weeks, whereas up to 70% returned within seven weeks (Tenforde et al., 2015). Of the women that returned to running, 35% reported musculoskeletal pain (Blyholder et al., 2017).

During the postpartum period, the body is recovering from changes in posture (increased lumbar lordosis and pelvic anterior tilt) (Hartmann & Bung, 1999), gait (widening of step width, decreased single support time, and increased hip and knee flexion) (Branco et al., 2013; Gilleard, 2013), and overall physiological changes (increased cardiac response to exercise, decreased VO_2 max, etc.) (Bø et al., 2016; Branco et al., 2013; Gilleard, 2013). The musculoskeletal system is also recovering from childbirth. Due to the effects of Relaxin hormone, increased laxity has been noted (Christopher et al., 2020; MacLennan et al., 1986). Muscle weakness may also be present in postpartum women (Deering et al., 2018), and more severe in women who have been prescribed bed rest during pregnancy or postpartum periods (Bø et al., 2017; Krasnoff & Painter, 1999). The growing uterus during pregnancy may cause changes to the abdominal muscles and can result in a diastasis recti, i.e. separation of the rectus abdominis muscles (Boissonnault & Blaschak, 1988; Mota et al., 2015). The weight of the growing fetus may weaken the pelvic floor muscles (Sangsawang & Sangsawang, 2013). The duration and process of childbirth itself, whether vaginal, cesarean or more complex (e.g. vaginal assisted) may require significant recovery of its own (Hassan Emara et al., 2020). For example, after a cesarean delivery (Pfannenstiel incision), the fascia has been observed to return to up to 59% of its tensile strength by six weeks post-surgery and up to 93% of its original strength by seven months (Ceydeli et al., 2005).

Despite the knowledge of physiologic and postural perinatal changes as well as persistent weakness and laxity postpartum (Bø et al., 2017; Branco et al., 2013; Deering et al., 2018; Gilleard, 2013; Hartmann & Bung, 1999), there is currently little understanding of the effects of these changes on running biomechanics or demands on the musculoskeletal system when initiating or returning to running after childbirth. Women are returning to running without evidence-based rehabilitation guidelines (Christopher et al., 2020). Therefore, the purpose of the current study was to investigate differences in overground running kinetics, strength, and flexibility in healthy postpartum runners and age-matched nulliparous controls. We hypothesize that postpartum runners will have altered running kinetics, muscle strength and flexibility due to pregnancy and postpartum changes, compared to women who have never given birth. This information will help health care providers determine whether there are specific alterations in running mechanics, strength or flexibility in the postpartum period that need to be considered when a female is initiating or returning to running post childbirth (Donnelly et al., 2020).

7.3 Methods

7.3.1 Experimental Approach to the Problem

An exploratory case-control study design was implemented to investigate the potential running kinetics, strength, and flexibility differences between postpartum runners and age-matched nulliparous controls. Ethical approval for this study was received by the University Institutional Review Board. Participants were recruited through flyers and online running groups. All participants were informed of the risks and benefits prior to providing verbal and written consent at the beginning of the study.

7.3.2 Eligibility Criteria

To qualify as a postpartum runner, participants had to have given birth to a child within two years (Deering et al., 2020) and met the following inclusion criteria: 1) age 18 to 41 years, 2) premenopausal, 3) run without pain limitations, 4) run at least once per week, and 5) medically cleared to run. Control group participants were required to be 1) nulliparous, 2) premenopausal, 3) run without pain limitations, 4) run at least once per week, 5) medically cleared to run and 6) age match (with in 2 years) to postpartum runner. As the purpose of the study was to understand the influence of perinatal changes on running, only healthy runners were included.

7.3.3 Overground Running Kinetics

Participants ran in self-selected running shoes across a 23m pathway with two force plates (AMTI Inc., Watertown, MA) embedded in the floor. Speed ranged from 3.61 to 3.99 m/s and was monitored using timing gates (Brower Timing Systems, Draper, UT) (Milner et al., 2006). After a five-minute self-paced treadmill warmup, participants were instructed run across the length of the pathway and no specific instructions were given regarding targeting the force plates. Participants were given three to five practice trials to find their comfortable stride within the speed range. Ground reaction force data were collected at 960 Hz using Qualisys Track Manager software (Qualisys AB, Sweden). Data were filtered using a 4th order low pass butterworth filter with a cut-off frequency of 30Hz. Three successful trials for each leg were collected and an average of the three trials was used for further analysis. A trial was considered successful when the runner’s foot was completely within the force plates and their running speed was within the target range (3.61 to 3.99 m/s). Force plate data were processed using Visual 3D software (C-motion

Inc., Germantown, MD) and a custom written script using MATLAB 24 (MathWorks Inc., Natick, MA).

Stance phase was defined using foot strike and foot off events. The foot strike event was determined when the vertical ground reaction force exceeded 20 N and the foot off event was defined when the vertical ground reaction force fell below 20 N threshold (Tate & Milner, 2017). During stance phase, the following vertical ground force data were obtained: peak impact force, peak active force, and vertical impulse. Also, during the stance phase, the following antero-posterior ground reaction force data were collected: peak braking force, peak propulsion force, braking impulse, and propulsion impulse. All kinetic variables were normalized to body weight. In addition, the average vertical loading rate, instantaneous vertical loading rate, average braking loading rate, and instantaneous braking loading rate were calculated. Loading rates were calculated between 20% and 80% of the period between foot strike and impact peak or braking peak (Milner et al., 2006).

7.3.4 Flexibility and Strength Measurements

For flexibility of the hamstring, the hip active knee extension test was performed (hip in 90° flexion, knee actively extended from 90° of knee flexion to maximum possible by the participant without pain/discomfort) using a digital inclinometer.[22] Strength (isometric hip internal rotator and external rotators, abductor and adductors, knee flexors and extensors) was tested using a digital handheld dynamometer (Commander Echo Muscle Testing Dynamometer, JTECH Medical, Midvale, UT) (Supplemental digital content A) (Faherty et al., 2020; Gabbe et al., 2004). Participants were asked to push against the examiner's force for 3-5 seconds and were verbally encouraged to increase force during the trial. Measurements were taken alternating lower extremities to establish a rest period of approximately 60 seconds between repeated trials. For a test to be considered successful, trials were measured within 10% of each other. Three trials were performed unless they measured more than 10% difference between two or more trials, in which case a maximum of six trials were performed. All strength variables were normalized to body weight. Data from the trials were averaged and used for statistical analysis.

7.3.5 Statistical Analysis

Because this was an exploratory study intended to demonstrate proof of concept for measuring biomechanical, strength, and flexibility discrepancies in postpartum runners, we did not justify our sample size based on an *a priori* power calculation. Instead, we enrolled the number of postpartum runners and age-matched controls that were feasible, given time and budgetary constraints. However, given our final sample sizes, this study would have at least 80% power to detect an effect size of 1.4 or greater, and at least 50% power to detect an effect size of 1.0 or greater, using two-sided tests at the 5% significance level. Groups were compared for demographics and self-reported training days per week. There was no significant difference in variables between measurements made from right and left legs hence an average of values from both legs was used for further statistical analyses to compare both groups (Zifchock et al., 2006). Normality of the data was checked using Wilk-Shapiro test. To compare the groups, independent samples t-tests were used. Effect sizes (ES) were calculated using means and pooled standard deviation in Microsoft Excel. ES magnitudes were categorized into small (0.20-0.50), moderate (0.50-0.80) or large effect size (>0.80). All statistical analyses except ES were performed using SPSS 24 (IBM Inc., Armonk, NY) and significance was set at 0.05.

7.4 Results

7.4.1 Demographics

Postpartum runners were similar to controls in age (Postpartum runners: 33.1±5.6 years, Controls: 31.7±4.6 years; *P*=0.556), height (Postpartum runners:1.71±0.08 m, Control: 1.65±0.05 m; *P*=0.054) and mass (Postpartum runners: 66.47±6.73 kg, Controls, 64.93±10.38 kg; *P*=0.224). Postpartum runners ran significantly fewer days/week compared to the control group (Postpartum runners: 2.83±0.75 days/week, Control group, 4.11±1.39 days/week; *P*=0.027).

7.4.2 Overground Running Kinetics

Instantaneous braking loading rate in postpartum runners was 24.3% greater than that of controls and demonstrated a large effect (mean difference: 3.41 NBW/s, 95% CI 0.08, 6.74; *P*=0.046; ES: 1.08; Figure 7.1). All other kinetic variables were not significantly different between groups (Tables 7.1 and 7.2).

Figure 7.1 Comparison of mean instantaneous braking loading rates between postpartum runners and nulliparous controls. Controls: 12.33±1.94(NBW/s), Postpartum 15.74±4.01(NBW/s), Mean difference (95%CI): -3.41 (-6.74, -0.08), ES: 1.08,*Significant difference (P=0.046)

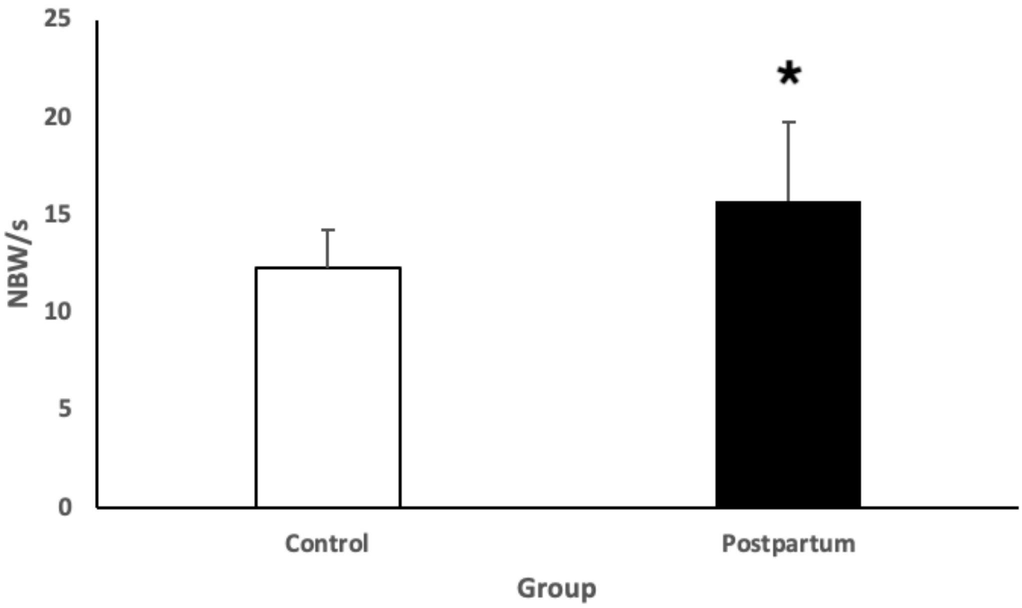

Table 7.1 Comparing mean±SD of overground running kinetics from vertical ground reaction force between postpartum runners (n=9) and nulliparous controls (n=9)

Dependent variable	Control group	Postpartum group	Mean difference (95% CI)	*P*-value	Effect size
Peak impact force (NBW)	1.97±0.45	2.09±0.39	-0.12 (-0.56, 0.31)	0.555	0.29
AVLR (NBW/s)	59.40±12.61	67.63±23.85	-8.22 (-28.35, 11.90)	0.398	0.43
IVLR (NBW/s)	68.83±6.27	77.26±26.12	-8.43 (-31.30, 14.43)	0.444	0.39
Peak active force (NBW)	2.51±0.15	2.43±0.24	0.08 (-0.13, 0.29)	0.211	0.40
Vertical impulse (NBW.s)	6396.68 ±475.99	6612.63±919.37	215.94 (-988.58, 556.69)	0.560	0.29

AVLR – Average vertical loading rate; IVLR - Instantaneous vertical loading rate; NBW – Normalized to body weight; CI – Confidence interval

Table 7.2 Comparing mean±SD of overground running kinetics from antero-posterior ground reaction force between postpartum runners (n=9) and nulliparous controls (n=9)

Dependent variable	Control group	Postpartum group	Mean difference (95% CI)	*P*-value	Effect size
Peak braking force (NBW)	0.42±0.04	0.44±0.06	0.02 (-0.04, 0.07)	0.520	0.32
ABLR (NBW/s)	6.39±1.91	8.54±4.26	-2.15 (-5.65, 1.34)	0.209	0.65
Braking impulse (NBW.s)	1092.35±108.53	1221.71±176.20	-129.36 (-283.17, 24.45)	0.093	0.88
Peak propulsion force (NBW)	0.27±0.04	0.29±0.04	-0.03 (-0.06, 0.01)	0.175	0.69
Propulsion impulse (NBW.s)	634.10±90.52	695.34±83.87	-61.23 (-151.38, 28.91)	0.168	0.70

ABLR - Average braking loading rate; IBLR - Instantaneous braking loading rate; NBW – Normalized to body weight; CI – Confidence interval

7.4.3 Flexibility and Strength

Compared to controls, postpartum runners demonstrated 14% less hamstring flexibility (mean difference:10.98°, 95% CI 0.97, 20.99; *P*=0.034; ES: 1.14; Figure 7.2), 25.9% less hip abduction strength (mean difference: 0.04 NBW, 95% CI 0.00, 0.08; *P*=0.045; ES: 1.07; Figure 7.3A) and 51.6% less hip adduction strength (mean difference 0.06 NBW, 95% CI 0.02, 0.10; *P*=0.003; ES: 1.68; Figure 7.3B). No other strength variables were significantly different between the groups (Table 7.3).

Figure 7.2 Comparison of mean hamstring flexibility between postpartum runners and nulliparous controls. Controls: 83.94±8.78°, Postpartum: 72.95±10.38° (NBW), mean difference (95%CI): 10.98 (0.97, 20.99), ES: 1.14, *significant difference (P=0.034)

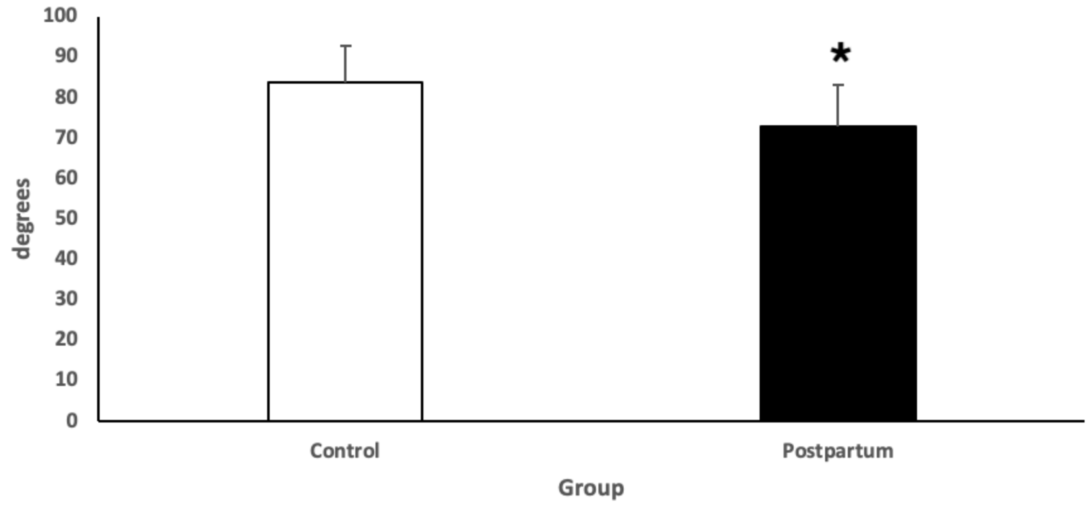

Figure 7.3 Comparison of mean A) Hip abduction strength: Controls: 0.17±0.03(NBW), Postpartum: 0.13±0.04(NBW), Mean difference (95%CI): 0.04 (0.00, 0.08), ES: 1.07; * Significant difference (P=0.045) and B) hip adduction strength between postpartum runners and nulliparous controls. Controls: 0.16±0.04(NBW), Postpartum:0.09±0.03(NBW), Mean difference (95%CI): 0.06 (0.02, 0.10), ES:1.68, * Significant difference (P=0.003)

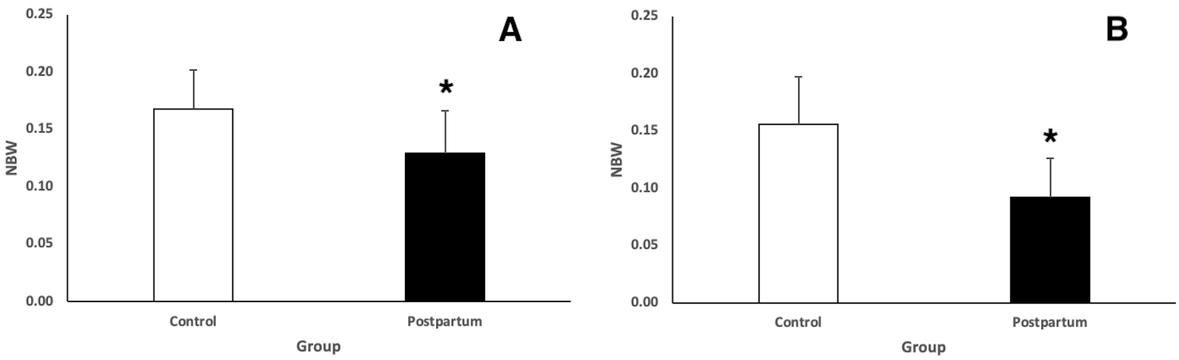

Table 7.3 Comparing mean±SD of bone mineral density, flexibility and strength between postpartum runners (n=9) and nulliparous controls (n=9)

Category	Dependent variable	Control group	Postpartum group	Mean difference (95% CI)	*P*-value	Effect size
Strength	Hip IR (NBW)	0.13±0.04	0.12±0.03	0.01 (-0.03, 0.04)	0.679	0.20
	Hip ER (NBW)	0.16±0.04	0.13±0.03	0.04 (0.00, 0.07)	0.066	0.95
	Knee flexion (NBW)	0.21±0.04	0.20±0.07	0.01 (-0.05, 0.07)	0.650	0.23
	Knee extension (NBW)	0.40±0.06	0.35±0.08	0.05 (-0.02, 0.12)	0.154	0.74

IR– Internal rotation; ER– External rotation; NBW – Normalized to body weight; CI – Confidence interval

7.5 Discussion

The postpartum runner has significant musculoskeletal changes from which to recover after pregnancy and childbirth. Peer reviewed literature investigating postpartum running is sparse (Provenzano et al., 2019). It is unclear if biomechanical or clinical differences exist between postpartum runners and nulliparous age-matched controls. The results of this study showed that postpartum runners had greater instantaneous braking rate, decreased hamstring flexibility and decreased hip abduction and adduction strength compared to control runners. These findings suggest that postpartum runners may have some biomechanical and clinical differences compared to nulliparous controls. Postpartum runners should be screened for these biomechanical and musculoskeletal changes when initiating or returning to running.

During the weight-acceptance phase, when investigating instantaneous braking loading rate, postpartum runners were seen to dissipate antero-posterior force faster compared to nulliparous controls. Participants in the current study exhibited similar vertical and antero-posterior loading rates and peak vertical, braking and propulsion forces compared to nulliparous runners when running overground at similar speeds (Bennell et al., 2004; Milner et al., 2006). Previous studies have highlighted the importance of braking force in relation to injury in female recreational runners (Napier et al., 2018; Napier et al., 2019) Female recreational runners with greater peak braking force had higher risk of sustaining a running-related injury (Napier et al., 2018). These findings may also be critical as bones in the lower extremity are known to be able to withstand greater compressive stress (created by vertical component of the ground reaction force) than shear stress (created by antero-posterior component of the ground reaction force) (Sanyal et al., 2012). It is possible that postpartum participants had increased braking forces due to the lack of lumbopelvic stability, as they were also found to have decreased hip strength compared to controls in this study. This finding highlights the need for a running gait analysis in postpartum runners initiating or returning to running, to evaluate potential increased stiffness on impact (Shih et al., 2019). Gait retraining programs, such as real-time biofeedback, can then be implemented to reduce braking forces (Napier et al., 2019). Future studies need to explore whether such increased braking loading rate coupled with lower shear strength of the bone is associated with increased risk of running-related injury in postpartum women.

Postpartum runners demonstrated less hip abduction and adduction strength compared to nulliparous controls. The hip abductor and adductor muscles control and stabilize the femur and pelvis during all running gait phases, thus weakness might place postpartum women at greater risk of running injury (Reiman & P., 2016). However, the relationship between hip strength and running injury is contradictory (Baggaley et al., 2015; Christopher et al., 2019) as one systematic review found that hip abductor weakness may be associated with iliotibial band injury (Mucha et al., 2017). and another systematic review found that novice injured runners had greater hip abduction strength (Christopher et al., 2019). Although the relationship between hip strength and running injury is not clear, differences were observed in hip abductor and adductor strength between postpartum and nulliparous women in this study. This finding suggests that the strength of the hip muscles should be evaluated when initiating or returning to running postpartum and if weakness exists, exercises should be incorporated into the rehabilitation program.

Postpartum women demonstrated decreased hamstring flexibility compared to nulliparous controls. The hamstrings are important in hip and knee control during the running stance and swing phases (Loudon et al., 2013). Decreased hamstring flexibility is a risk factor for running injury (Hartig & Henderson, 1999). A recent study investigating postpartum runners reported decreased sagittal hip motion during running as compared to their pre-pregnancy running gait (Provenzano et al., 2019). The authors hypothesized that the decrease in motion measured was a protective mechanism to increase gait stability during running (Provenzano et al., 2019). Similarly, in this study, hamstring tightness may be indicative of impaired lumbopelvic hip stability, as hip abductors and adductors of the postpartum runners were significantly weaker. Given this information, when determining return to running readiness for the postpartum population, clinicians should evaluate hamstring flexibility in postpartum women as it could potentially be limited in this population and contribute to running gait abnormalities and potential injury.

7.5.1 Limitations

This study was an exploratory study. Thus, there was limited power to detect between-group differences and results are limited to our sample which may not be representative. However, some between-group differences were observed suggesting further investigation of these biomechanical and clinical variables is warranted. Matching groups by running mileage, running pace, and injury history may also increase the precision of this study design, as postpartum women in this study ran significantly less on average (days/week). The wide definition of postpartum decreases the precision of the results. As this study used a case-control design, results are limited to associations only and cannot demonstrate cause and effect, nor changes over time. Lastly, all attempts were made to blind the examiners however in some instances participants referred to having children or the children were present during the testing session.

7.6 Conclusion

These results suggest there may be important differences in postpartum runners with regard to braking forces during weight-acceptance while running, hamstring flexibility and hip strength, all of which have previously been associated with running-related injuries (Hartig & Henderson, 1999; Mucha et al., 2017; Napier et al., 2018). It is recommended that clinicians evaluate these particular variables or provide postpartum runners with tools for self-evaluation, when determining readiness to initiate or return to running for postpartum. Future prospective studies are needed to investigate potential time dependent (3 months postpartum vs 3 years) differences and kinematic differences in postpartum and nulliparous female runners, as well as include postpartum runners with higher running frequency. Future studies should also investigate sleep, breastfeeding and self-care to account for biopsychosocial factors that may affect running postpartum.

7.7 Supplemental Digital Content A

7.7.1 Positioning for Lower Extremity Flexibility and Strength testing (Gabbe et al; Faherty et al, 2020)

7.7.1.1 Flexibility

Hamstrings active knee extension: the participant laid supine on a plinth with one leg straight and the test leg bent to 90 degrees of hip flexion without pain or discomfort. The femur on the test side was stabilized to maintain hip flexion and prevent compensatory movements. The participant straightened their knee as much as possible. The inclinometer was aligned along the midline of the fibula using the lateral epicondyle of the femur and the lateral malleolus for reference.

7.7.1.2 Lower Extremity (LE) Strength

Knee flexion: the participant lay prone on the table with testing leg flexed to 45 degrees at the knee. Maximal knee flexion strength was measured with handheld dynamometer held superior to calcaneus.

Knee extension: the participant sat at edge of plinth with testing limb at 30 degrees of flexion. Knee extension strength measured against unmoving force (a band fixed to table or researcher maintaining) while placed against distal aspect of the tibia.

Hip abduction: the participant laid on their side with the test leg on top. The non-testing leg may be bent to stabilize. The participant was asked to abduct their test leg against the HHD without flexing or rotating their hips. Handheld dynamometer was placed superior to lateral malleolus on the leg being tested.

Hip adduction: the participant laid on their side, with the testing leg on bottom. Uppermost leg was allowed to be abducted to 25 degrees and bent, with lumbar spine/posterior pelvis stabilized. The handheld dynamometer measured hip adduction while placed against medial malleolus.

Hip internal rotation: the participant will laid prone with testing leg flexed 90 degrees at the knee, stabilized at the lumbar spine. The handheld dynamometer measured hip internal rotation while placed superior to lateral malleolus.

Hip external rotation: the participant laid prone with the test leg flexed at the knee to 90 degrees, stabilized at the lumbar spine. The participant exerted force towards the midline of their body while the researcher used a handheld dynamometer placed just above the medial malleolus*. *Note: This HHD placement is a modification of the methods provided by Hislop and Ekstrom. the resistance is applied farther down the lever arm to prevent the subject from overcoming the resistance of the examiner.

CHAPTER 8. Summary and Conclusions

8.1 Summary of Study Findings

The overarching aim of this thesis was to answer one primary question about postpartum running: What are the risk factors related to pain when running after childbirth? Because of a lack of evidence-based information on initiating or returning to running after childbirth, the first studies in this thesis investigated risk factors for pain in running and postpartum populations, respectively. Study 1 (chapter 3) was a systematic review that investigated musculoskeletal impairments (strength, flexibility, range of motion, and alignment) in runners and identified seven categories of clinical assessments that were associated with running-related injury. The systematic review also found that studies were low quality, had different measurement methods for the same clinical assessment and had significant risk of bias. Study 2 (chapter 4) investigated risk factors for first onset lumbopelvic pain in the postpartum population. Five risk factors were found to predict low back pain, but none of the factors investigating pelvic pain were predictive.

Study 3 (Chapter 5) was a Delphi survey where experts who treat and research female runners or clients with pelvic health complaints reported on the most common musculoskeletal impairments and risk factors for pain in postpartum runners. The experts identified risk factors contributing to pain in this population and musculoskeletal impairments in the categories of strength, range of motion, flexibility, and alignment. In Study 4 (chapter 6) the findings of the three previous studies were used to generate a survey for postpartum runners (≤ 3years) with and without pain. The survey was used to understand running, postpartum and demographic variables, and their association with postpartum running-related pain. Several factors were associated with pain in postpartum runners, and a clinical decision tool was created to understand the compounding effect of multiple associative variables and pain in postpartum runners. To evaluate risk factors that could not be self-assessed in a survey and may be present due to the normal physical and physiological changes of the perinatal period, study 5 (chapter 7) took place in a laboratory and objectively assessed musculoskeletal and biomechanical risk factors in healthy postpartum runners compared to nulliparous controls. The initial exploratory study found that postpartum runners had differences in kinetics, strength, and flexibility when compared to nulliparous controls. The following sections will summarise the results of each study in more detail.

8.1.1 What is the evidence for alterations in muscle strength, flexibility, joint range of motion, and alignment to predict lower extremity injury in runners?

The aim of Study 1 (chapter 3) was to identify alterations in clinical measures of muscle strength, flexibility, range of motion, and alignment that predict lower extremity injury in runners. Clinicians regularly use alterations in musculoskeletal tests and measures as guidelines for rehabilitation and return to sport; thus, understanding the link to running-related injury is imperative. Following a comprehensive search of 4 electronic databases (PubMed, Embase, CINAHL, and SPORTDiscus), 7 studies were included in the review (Buist et al., 2010; Finnoff et al., 2011; Hespanhol Junior et al., 2016; Luedke et al., 2015; Plisky et al., 2007; Ramskov et al., 2013; Yagi et al., 2013). Seven clinical assessments were identified: hip strength (hip abduction and external to internal strength ratio) (Finnoff et al., 2011; Luedke et al., 2015), range of motion (Buist et al., 2010; Yagi et al., 2013), flexibility (Yagi et al., 2013), alignment (Hespanhol Junior et al., 2016; Ramskov et al., 2013), knee strength (Luedke et al., 2015), and ankle alignment (Buist et al., 2010; Plisky et al., 2007; Ramskov et al., 2013; Yagi et al., 2013). In the low quality studies investigating strength, there was conflicting evidence on the hip (Finnoff et al., 2011;

Luedke et al., 2015) and very low quality of evidence on the knee (Luedke et al., 2015). The range of motion category for the hip also had similar low quality conflicting evidence (Buist et al., 2010; Yagi et al., 2013). Only one study (Yagi et al., 2013) investigated hip flexibility; it was of very low quality and reported no association between straight leg raise and running-related injury. Several studies on the hip and ankle provided data for the alignment category (Buist et al., 2010; Hespanhol Junior et al., 2016; Plisky et al., 2007; Ramskov et al., 2013; Yagi et al., 2013); however, they had very low quality and conflicting information on Q angle (Hespanhol Junior et al., 2016; Ramskov et al., 2013) and navicular drop (Buist et al., 2010; Plisky et al., 2007; Yagi et al., 2013) as risk factors for running-related injury.

In general, the studies provided very low-quality evidence for these clinical assessments with multiple confounders present within the studies. Of the seven studies included (Buist et al., 2010; Finnoff et al., 2011; Hespanhol Junior et al., 2016; Luedke et al., 2015; Plisky et al., 2007; Ramskov et al., 2013; Yagi et al., 2013), only one (Hespanhol Junior et al., 2016) investigated these musculoskeletal alterations in general recreational runners that might be similar to women of childbearing age. The participants in a majority of the studies (Buist et al., 2010; Finnoff et al., 2011; Luedke et al., 2015; Plisky et al., 2007; Ramskov et al., 2013; Yagi et al., 2013) were high school or novice runners, not representative of the general running population. There were a limited number of studies in each category, different measurement methods among studies, measurement variability within clinical assessments, varying definitions of injury and runner, and study bias. Although some musculoskeletal alterations were identified, mostly in stand-alone studies, the results of the review make it clear that high quality research is much needed in this area and that existing findings should be interpreted with caution.

8.1.2 What is the evidence for risk factors (modifiable and nonmodifiable) for first-onset lumbopelvic pain during the postpartum period?

Study 2 (Chapter 4) was a systematic review to determine the risk factors for first onset lumbopelvic pain during the postpartum period. Following a comprehensive search of four databases, prospective cohort studies that identified modifiable and non-modifiable risk factors for first onset lumbopelvic postpartum pain were included. Risk factors from the articles were categorized as extrinsic, intrinsic, or mixed, and were ranked by the strength of their association statistic. Four articles met the inclusion criteria (Blomquist et al., 2014; Chia et al., 2016; Kuyumcuoğlu et al., 2006; Loughnan, 2002). The pooled incidence of first onset lumbopelvic pain was 32%, an important finding, since healthcare professionals may screen and refer the patient to appropriate therapy to avoid chronic pain. There were eleven risk factors investigated for low back pain. Five risk factors were found to be associated with first onset postpartum pain: C-section with epidural anesthesia (Chia et al., 2016), length of first stage labor (longer) (Loughnan et al., 2002), race (non-Caucasian) (Loughnan et al., 2002), age (older) (Chia et al., 2016) and urinary tract infections (Chia et al., 2016) .

Of the modifiable factors, cesarean section delivery with epidural anesthesia was associated with the onset of lumbopelvic pain postpartum and hypothesized as a result of postures during delivery or needle insertion related epidural hematoma (Chia et al., 2016). The duration of first stage of labor was another factor associated with first onset lumbopelvic pain postpartum (Loughnan et al., 2002), which was also theorized to be related to labor positions and specifically staying in one position for too long (MacArthur et al., 1990). Because of the acute nociceptive pain during labor (Lowe, 2002), it could be that the laboring mother may have not been able to distinguish whether the pain is from the process of labor or from her positioning, which could hinder her from advocating for a change in positions. The longer the mother labored, the greater the odds of her developing first onset low back pain (Loughnan et al., 2002). Studies have shown that certain birthing positions may shorten labor (Gupta et al., 2017; Valiani et al., 2016); however, there is no evidence for ideal positions that reduce the risk of pain in the postpartum period (Huang et al., 2019).

Some intrinsic factors associated with first-time pain postpartum were the age of the mother and race. Postpartum women who were not Caucasian were more likely to have first-time back pain (Loughnan et al., 2002). Older women were also found to have greater odds of low back pain (Chia et al., 2016). Older age and back pain has been well researched (Meucci et al., 2015); the most common age for females to be affected by low back pain is 41-50 years (Ramdas & Jella, 2018). Nine risk factors were investigated for pelvic pain (Blomquist et al., 2014); none were significant. In summary, this systematic review identified some modifiable risk factors and non-modifiable risk factors for first onset lumbopelvic pain. However, because of the variation in the types of risk factors investigated and methods used to measure pain, we could not perform further data pooling and meta-analysis, which limits the conclusions that can be drawn from this review. High quality prognostic studies are needed to more consistently investigate risk factors for first-onset back pain in the postpartum population.

8.1.3 What are the common musculoskeletal impairments and risk factors for pain in postpartum runners, as perceived by experts in female running or pelvic health?

In study 3 (chapter 5), physiotherapy experts in female running or pelvic health were invited to participate in a Delphi survey. When evidence is non-existent, as in the case of risk factors for running after childbirth, a Delphi survey is the first step. The methodology collects expert opinion to begin to answer the research question; in this case, we explored strength, range of motion, flexibility, alignment impairments and risk factors present in postpartum runners with pain. A web-based Qualtrics survey was conducted. A total of 117 experts were invited; 41 completed rounds II and III. These experts reached consensus that the strength impairments that are risk factors in postpartum runners are abdominal, hip and pelvic floor weakness. For range of motion impairments, they reached consensus on hip extension restriction, anterior pelvic tilt and general hypermobility. For flexibility impairments, they reached consensus on laxity in abdominal wall and tightness in hip flexors, lumbar extensors, iliotibial band and hamstrings. For alignment impairments, they reached consensus on a Trendelenburg sign, dynamic knee valgus, lumbar lordosis, over-pronation and thoracic kyphosis. As a whole, these findings were novel: though supported in the postpartum literature (Deering et al., 2018; Liaw et al., 2011; Marnach et al., 2003; Segal et al., 2013; Treuth et al., 2005) and running literature (Ferber et al., 2011; Fredericson et al., 2000; Mucha et al., 2017; Stanton et al., 2004; van der Worp et al., 2015), they have not been documented in postpartum running populations.

The risk factors identified by the expert group for pain in postpartum runners were hip pain, decreased exercise tolerance, pain during pregnancy, too much too soon, life stressors, and pelvic floor trauma. The risk factors identified in this Delphi study highlighted that postpartum runners may be a unique population that needs a multidisciplinary care team to address potential risk factors related to running pain (Deering et al., 2020). This study provided a framework for clinicians to understand pain, associated musculoskeletal impairments, and risk factors in postpartum runners.

8.1.4 What biopsychosocial and musculoskeletal risk factors are associated with pain in postpartum runners?

In Study 4 (Chapter 6), postpartum runners were surveyed and categorized as with and without self-identified running-related pain. Postpartum runners with at least one child ≤36 months who ran once a week and postpartum runners unable to run because of pain, but identified as runners, were surveyed. One hundred and seventy-six (32.7%) reported running-related pain. Bivariate relationships between running, postpartum, demographic-related variables, and running-related pain were analyzed, and significant variables were entered into a multivariate conditional backwards stepwise logistic regression. Six significant variables were identified through the multivariate regression and were retained in the clinical decision tool. The six significant variables were runner type-novice, postpartum accumulated fatigue scale score (>19), previous running injury, most recent delivery-vaginal, incontinence and amount of sleep (<6.8 hours). Except for previous injury (unsure if running-related), which was seen to be related to pain when running postpartum in one study (Blyholder et al., 2017), up to this point these risk factors have not been studied for their relationship with running-related pain in women running after childbirth. They have been associated with pain and performance in either postpartum (Badr & Zauszniewski, 2017; McGuire, 2013; Thomas & Spieker, 2016) or general running populations (Desai et al., 2021; Johnston et al., 2020) individually but not in postpartum running populations.

This study was also the first to understand the compounding effects of multiple associative variables by creating a clinical decision tool. When four or more risk factors were present, our model suggested the probability of having pain increased from 32.7% (pre-test) to 61% (post-test). While this model needs to be validated in a longitudinal cohort of pain-free postpartum runners to determine its predictive capacity, this deeper understanding of the risk factors for running-related pain in postpartum runners may assist health care providers in educating postpartum runners and developing interventions that assist postpartum women to stay injury-free as they initiate or return to running.

8.1.5 What are the musculoskeletal differences in overground running kinetics, strength, and flexibility between postpartum runners and age-matched nulliparous controls?

Because information on the effect of perinatal related changes on running biomechanics is sparse (Provenzano et al., 2019), a lab-based study was conducted. Study 5 (chapter 7) investigated the biomechanical (kinetic) and musculoskeletal (strength and flexibility) differences between postpartum runners and nulliparous controls. The postpartum runners were matched to controls by age. When comparing age, height and mass, there were no significant differences between groups. Postpartum runners did run fewer days per week than controls. There were some clinical and biomechanical differences between the groups: Postpartum runners had 24.3% greater braking loading rate for anterior posterior ground reaction force (breaking force) than controls. Previous studies have associated braking force and injury in female recreational runners (Napier et al., 2018; Napier et al., 2019). Postpartum runners had 14% less hamstring flexibility. Hamstring tightness may be indicative of impaired lumbopelvic hip stability, as hip abductors and adductors of the postpartum runners were significantly weaker in our study (Chumanov et al., 2007; Kuszewski et al., 2008). Postpartum runners had 25.9% less hip abduction and 51.6% less hip adduction strength. Although the relationship between hip strength and running injury is not clear (Christopher et al. 2019; Baggaley et al. 2015; Mucha et al. 2017), hip strength may have been different between postpartum and nulliparous women due to the physical and physiologic changes from pregnancy and childbirth to the lumbopelvic complex. Overall, there may be important differences in postpartum runners with regard to braking forces during weight-acceptance while running, hamstring flexibility, and hip strength, all of which have been associated with running-related injuries (Hartig & Henderson, 1999; Mucha et al., 2017; Napier et al., 2018). It is recommended that clinicians evaluate these particular variables or provide postpartum runners with tools for self-evaluation when determining readiness to initiate or return to running in the postpartum period.

8.2 Limitations of the Studies

The following section outlines the limitations in each of the studies presented in this thesis.

8.2.1 Study 1 (Chapter 3)

The systematic review of alterations in muscle strength, flexibility, range of motion and alignment (Study 1, chapter 3) in the general running population had several limitations. Studies with post-operative populations were excluded from the review (Hodges and Richardson 1996), so it is possible the runners included in the selected studies had less severe injuries, which potentially influenced the clinical assessment alterations between baseline and future injury. These runners were excluded to better generalize the results to the population of runners most commonly seen in outpatient community-based clinics, which are runners who have never seen a surgeon. On the whole, the studies were limited by these traits: study bias, inconsistent results, different measurement methods among studies, measurement variability within clinical assessments, inconsistent definitions of injury and runner, different statistical modeling so results could not be pooled, and few investigated each assessment.

8.2.2 Study 2 (Chapter 4)

The systematic review of predictive risk factors for first onset lumbopelvic pain in postpartum women revealed a significant variation in types of risk factors investigated by researchers. Of the four included studies (Blomquist et al., 2014; Chia et al., 2016; Kuyumcuoğlu et al., 2006; Loughnan, 2002), twenty different risk factors were investigated, of which none were included in more than one study. There was significant variation in the measurement method of first onset back pain: one study used the visual analogue scale (Kuyumcuoğlu et al., 2006), one study used ICD-9 codes to identify back pain (Chia et al., 2016), and one simply asked questions about backache (Loughnan et al., 2002). None of the studies used the Oswestry disability index or the pelvic girdle pain questionnaire, which have been validated to assess lower back pain and pelvic girdle pain (Fairbank and Pynsent 2000; Stuge et al. 2011). These variations in the different risk factors studied and pain measurement methods prevented data pooling and meta-analysis. Most studies had significant risk of bias reporting the outcome measured (pain), which may influence the results of the review. These limitations affected the conclusions that could have been drawn from this review, highlighting the need for high-quality research in this area.

8.2.3 Study 3 (Chapter 5)

The Delphi study was limited by our inability to understand, from the responses provided, the measurement methods or specific definitions for some of the risk factors identified. For example, open-ended questions such as “what are strength impairments seen in postpartum runners in pain?” (used in round I to gather information on hip weakness) were limited because respondents were not asked for their definitions of weakness nor the measurements used to determine weakness. Hip weakness can be defined and measured several different ways. Because of the purpose of this Delphi (identifying risk factors for postpartum running-related pain) and methodology used (one round of open-ended questions to identify risk factors followed by voting for consensus in round II and III), neither a deeper understanding of the experts' definitions for some of the impairments nor their method of evaluating these impairments could be understood or documented. Additionally, another limitation was a lack of consensus on certain content. Although an anterior pelvic tilt is typically present as a response to pregnancy and fetal development (Hartmann and Bung 1999; Hagan and Wong 2010; Foti et al. 2000), there is conflicting data in both pregnancy and postpartum (Ostgaard et al. 1993). Experts were unable to reach consensus on whether an anterior pelvic tilt was an alignment impairment in postpartum runners with pain, potentially due to the lack of a clinical reference standard of measurement and conflicting reports of this alignment impairment; this was therefore categorized as "consensus not met" in round III.

8.2.4 Study 4 (Chapter 6)

The fourth study was a survey of biopsychosocial risk factors for pain in postpartum runners. The study design was cross sectional, and therefore only non-causal associations could be inferred from the findings. Survey results are usually considered to have subjective recall bias. To address this concern, analysis was restricted to three years postpartum, and runners were asked about their symptoms currently or in the past week. It is also possible that this study is not a representative sample of the full postpartum running population (e.g., our sample was predominantly white, with a higher level of education). Finally, we did not measure intensity of pain in this study but merely if runners had pain or not.

8.2.5 Study 5 (Chapter 7)

Study 5 was the lab-based study investigating kinetics, strength, and flexibility in postpartum runners compared to nulliparous controls. This study was an exploratory study with a small sample. Thus, there was limited power to detect between-group differences, and results were limited to our sample, which may not be representative. Matching groups by running mileage could also increase the precision of this study design, as postpartum women in this study ran significantly fewer days per week on average than nulliparous controls. As this study used a cross-sectional design, results were limited to associations only and could not demonstrate cause and effect, nor changes over time. Lastly, all attempts were made to blind the examiners; however, in some instances participants referred to having a child or the child was present during the data collection.

8.3 Strength of Studies

8.3.1 Overall Strength of the Thesis

The overall strength of this thesis was the evidence-based information that was generated in an area where high-quality investigations are sparse. Systematic reviews and Delphi studies were used to inform investigations in postpartum runners, an understudied population despite the incontrovertible fact that women are running after childbirth. Due to the plethora of physical and physiological changes wrought by pregnancy and childbirth, and the trauma of childbirth itself, women are unsure how to initiate or reintegrate into high-impact sports such as running. Among the women returning to running, more than one-third of the runners are reporting pain at two years postpartum (Blyholder et al. 2017). This thesis was a first attempt at understanding risk factors for running-related pain in this population. Understanding these risk factors can provide education and guidance in an area where only expert opinion exists, and research is sparse.

The literature review highlighted the gaps that informed the first investigations of the thesis. Risk factors for pain and running-related injury in postpartum women were investigated through two different methods: two systematic reviews (Chapters 3 and 4) identified risk factors for pain that could affect postpartum runners, while a Delphi survey (Chapter 5) gathered expert opinion on musculoskeletal impairments and risk factors they identified through practice. Combined, these chapters are a first attempt to understand the risk factors for pain in postpartum runners and contributed to the design the survey (chapter 6) and biomechanics study (chapter 7) that measured these risk factors in a cross-sectional population of postpartum runners with and without pain, and postpartum runners and nulliparous controls, respectively. Before the initiation of this thesis, evidence on risk factors for running-related pain in women running after childbirth was non-existent. Future rehabilitation studies can build on this novel work to improve postpartum care in women who want to initiate or return to high-impact sports such as running.

8.3.2 Specific Strengths of Each Study

Study 1 (chapter 3) identified musculoskeletal alterations in strength, flexibility, range of motion, and alignment that predicted running injury. Physiotherapists commonly use musculoskeletal assessments to screen, evaluate, and treat injured or uninjured runners that present to their clinics. Of the systematic reviews that did exist, none have looked at these specific musculoskeletal variables and their association with running-related pain and injury. As reported in chapter two's literature review, several risk factors have been investigated for their relationship with running injury; however, very few studies investigated musculoskeletal alterations, and a synthesis and quality assessment of the studies did not exist. This unique systematic review provided novel information about common tests and measures that predicted injury. The study also provided guidance for the studies conducted later in the thesis about the strength, flexibility, range of motion, and alignment tests that should be measured as risk factors for injury in postpartum runners.

Study 2 (chapter 4) gathered risk factors for lumbopelvic pain in postpartum women who did not have pain in pregnancy, bringing attention to the important fact that there is a subgroup of women who may have pain only in the postpartum period and that this pain may need to be explored further. This was one of the most important findings of the study. Although there were no modifiable risk factors identified, the study also shed light on the idea that if health care professionals-specifically obstetricians or family practice physicians who are evaluating the mother post-childbirth-simply start asking questions about pain or low back pain, appropriate referrals can be made to address this pain before it gets to a chronic stage. Finally, this study highlighted that even though some risk factors such as delivery type or delivery with epidural were non-modifiable, if a woman can change positions safely during labor, they can possibly decrease muscle strain and fatigue, which is a potential cause for this chronic pain.

Study 3 (chapter 5), the Delphi study, was the first study to identify via expert opinion musculoskeletal impairments and risk factors for pain commonly observed in postpartum runners. Previous studies have investigated runners and postpartum women separately and drawn conclusions about postpartum runners from these populations (Bø et al. 2017; Donnelly et al. 2020; Mihevc Edwards 2020). The Delphi study was a first attempt at collecting initial musculoskeletal impairments observed in postpartum runners from expert physiotherapists working with this population. With this information, clinicians world-wide could gain greater awareness of possible risk factors and start screening postpartum runners so they can consider addressing any observed musculoskeletal risk factors or risk factors associated with running-related pain.

Existing recommendations and return-to-running guidelines have been derived from either general running populations or non-runner postpartum populations; consequently, Study 5 (the survey study – Chapter 6) and Study 6 (the lab-based study – Chapter 7) investigated risk factors in a postpartum running population. The survey found six variables associated with running-related pain for postpartum women and provided a clinical decision tool to evaluate the compounding effect of these associative factors. There were many strengths of this study: not only did it provide associations between running, postpartum, and demographic risk factors for pain in postpartum runners, but it also provided recommendations on running injury and performance. For example, more novice postpartum runners reported having pain when running; as a result, we recommended the development of structured training programs for novice runners. To gain a preliminary understanding of how postpartum runners are affected by the musculoskeletal changes associated with pregnancy and childbirth, the laboratory study identified kinetic, strength, and flexibility related variables that were different in healthy postpartum runners compared to nulliparous controls. Because the sparse literature on risk factors for postpartum runners lacked specific, evidence-based guidelines, studies 5 and 6 (chapter 6 and 7) provide important initial guidance to runners and health care providers working with this population. Until now, guidelines have been derived solely from expert opinion; the studies in this thesis provide the first evidence-based information for the postpartum running population.

8.4 Implications for Research and Clinical Practice

The research conducted in this thesis is novel and much needed to fill the large gap in the literature on risk factors for running-related pain post childbirth. The studies in this thesis identified running, postpartum and demographic variables that were risk factors associated with running pain postpartum. Kinetic and musculoskeletal variables such as increased braking loading rate and decreased hip strength were also identified as variables present in postpartum runners but not in nulliparous controls. Although this research was novel, study designs were of lower quality (cross sectional). This was completed because, at the start of this thesis, no literature existed on postpartum runners. When no evidence exists, the first steps are to identify the variables we need to study; in this case, the specific variables were associated with pain or postpartum changes in runners.

8.4.1 Implications for Future Research

8.4.1.1 Validation of Risk Factors Associated with Running-Related Pain in Postpartum Runners

As the studies investigating risk factors for running-related pain in postpartum runners were of lower quality due to their cross-sectional design, future research should now take the information reported in this thesis and validate the risk factors in cohorts of postpartum runners with and without pain using prospective study designs. For the variables associated with running-related pain found in the first systematic review, a healthy cohort of postpartum runners measured at baseline could be followed prospectively to determine injury incidence and the clinical variables associated with injury. Based on the findings from the Delphi study, the survey study, and the lab-based study, the variables that would be the most important to include in such a study are: strength (abdominal, hip, and pelvic floor weakness), range of motion (hip extension restriction, anterior pelvic tilt, and general hypermobility), flexibility (laxity in abdominal wall, and tightness in hip flexors, lumbar extensors, iliotibial band, and hamstrings), alignment (Trendelenburg sign, dynamic knee valgus, lumbar lordosis, over-pronation, and thoracic kyphosis) demographic (injury history), postpartum (delivery type, incontinence, fatigue, average sleep) running (if novice), and biomechanics variables (braking force).

8.4.1.2 Validation of Pregnancy-Related Changes and the Effects of Pain on Outcomes

To truly understand pregnancy-related changes and postpartum return to baseline following these changes in postpartum runners, it would be ideal to have a large cohort of female runners who are planning on having children to perform a gait analysis before pregnancy, during pregnancy, and after pregnancy. Both healthy and injured runners can and should be included to validate the variables associated with perinatal changes as well as the variables associated with running-related pain. It would be important to differentiate those with current running-related pain and those with a history of running-related pain, as well as those with pain during clinical or biomechanical testing and those with no pain on the day of testing, as all of these factors may affect measurements and thus outcomes.

8.4.1.3 Intervention Studies

Once the risk factors have been identified and validated in prospective studies, future intervention studies can be performed to see if some of the current recommendations from experts, such as pelvic floor strengthening after childbirth (Sigurdardottir et al. 2020), can prevent or decrease pain during running postpartum.

8.4.1.4 Future Reseach Recommendations From Each Study

There are specific recommendations for future research from each of the studies completed in this thesis. As identified in the two systematic reviews (chapter 3 and 4), current literature investigating risk factors for running-related pain or first time lumbopelvic pain had low quality, bias, variability in measurement methods and statistical modeling, and an overall limited number of studies following healthy runners/ individuals over 6 months. Understanding risk factors that contribute to running-related injury or pain may prevent future injury and assist postpartum runners to avoid unhealthy behaviors that may contribute to the progression of the pain to a chronic state. To understand risk factors for running-related pain, specifically musculoskeletal measures used commonly by physiotherapists, future studies should use standardized definitions of impairments and gold standard procedures for measurement, avoid bias such as selection or measurement bias when designing, implementing or writing a study, and most importantly perform predictive studies over a timeline of >6months if the aims of the study are risk factor and pain associations. Study 1 (chapter 3) leaves us with questions about the utility of “table tests” used by physiotherapists world-wide to predict running injury; clinicians may need to instead deploy dynamic tests, running gait assessments, or a combination of factors to predict running-related injury.

The second systematic review (Study 2, chapter 4), which found only non-modifiable risk factors for lumbopelvic pain in the postpartum period, leaves us questioning ‘if there are no modifiable risk factors for first time lumbopelvic pain postpartum, can we intervene at a stage that could be modifiable?’ For example, if a woman has back pain post-delivery due to positioning during delivery, should there be protocols to switch positions during labor vs. stay supine for the entire time, especially if labor is longer than average or they may have an epidural? Future prospective studies could compare labor positions or provide protocols for position changes and then monitor postpartum women over time to see if back pain can be prevented. Although studies have investigated exercises to decrease low back pain postpartum, future studies should investigate if core and back exercises performed routinely during the perinatal period decrease the likelihood of developing low back pain, even if the duration of labor is long and the mother has to stay in a certain position.

The Delphi survey (chapter 5) provides a summary of strength, range of motion, flexibility, and alignment impairments that experts reported observing in postpartum runners that have pain when running. Each of these four categories had multiple impairments (at least 5) that met consensus as risk factors for pain in postpartum runners. Further research is needed to determine which of these impairments are actually present in postpartum runners with pain. Impairments that reached consensus in the Delphi survey should be measured in case-control studies to determine if the impairments are specific to postpartum runners in pain or perhaps present in all postpartum women. Musculoskeletal impairments could also be measured in prospective cohort studies to determine which impairments, if present at baseline before postpartum runners initiate/return to running or develop pain, may be predictive of running-related pain.

The survey study (study 4, chapter 6) and laboratory study (study 5, chapter 7) were performed as first steps in identifying risk factors for pain in postpartum runners. Study 4 surveyed runners with and without pain to determine if there were associations between the running, postpartum, and demographic variables and postpartum running-related pain. The clinical decision tool for the prediction of pain was a first attempt at investigating the effects of multiple associative variables and pain in postpartum runners. Future research needs to validate these risk factors in prospective cohort studies by measuring for risk factors at baseline and following healthy postpartum runners for 6-12 months to document injury and analyze baseline factors associated with the development of pain. The predictive capacity of the clinical decision tool should also be evaluated in a longitudinal cohort of postpartum runners who are pain free at baseline.

Study 5 (chapter 7) was an exploratory study measuring perinatal-related changes and their effect on running kinetics, strength, and flexibility. Due to the small number of participants (9 postpartum and 9 control), increasing the number of participants in the study would be the first step to a deeper understanding on perinatal effects on biomechanical and musculoskeletal running variables. Studies should also measure biomechanical and musculoskeletal variables in runners with current and/or a history of running-related pain during the postpartum period, as well as healthy and injured runners with different demographic (race, education, parity, age), postpartum (number of weeks postpartum, incontinence, delivery type) and running (experience, previous injury) related variables to gain a comprehensive understanding of running-related risk factors in postpartum runners initiating or returning to running. Within-subject variability for some of the variables could also be measured. Future studies on the kinematics and kinetics of postpartum runners should follow a runner through pre-pregnancy, pregnancy, and postpartum and measure the changes to kinetics and kinematics to understand perinatal changes and the effects on running.

8.4.2 Clinical Implications

This thesis was a first step in identifying risk factors for running-related pain after childbirth. As mentioned earlier, women are running following childbirth and reporting pain. Without any guidelines, women are commonly seeking advice and answers, sometimes contraindicatory, from a variety of non-peer reviewed sources. Some women are also not seeking care because they believe that some of the symptoms they are experiencing are “normal” due to pregnancy and childbirth. Physicians are not routinely monitoring for musculoskeletal impairments, and in the United States, the only time the new mother interacts with the obstetrics or family practice physician after childbirth is at six weeks. If complications arise sooner or later than that appointment, the new mother has to advocate for her own care. Currently, one peer-reviewed viewpoint (Deering et al. 2020) and one blog post (Donnelly et al. 2020) are being used as recommendations to initiate or return to running during postpartum. Both documents use studies from either postpartum or running populations to provide clinical recommendations for postpartum runners. This thesis aims to research postpartum runners themselves, and provide information on risk factors for running-related pain after childbirth.

8.4.2.1 Clinical Implications from Each Study

Study 1 found low quality evidence for risk factors related to strength, range of motion, flexibility, and alignment alterations in recreational runners. Although limited by study quality within and amongst the studies, not many factors or studies were found to link common physiotherapy examination tests with running injury. Running is a dynamic activity and the studies in the review examined static clinical tests that may not accurately capture impairments in strength, range of motion, flexibility, and alignment that predict injury in recreational runners. Other than the need for higher quality studies, it may be that static clinical tests, commonly used in the physiotherapy clinic, may not predict running injury. It may be that clinicians should use more dynamic or other measures to capture preinjury deficits. Even though this review summarized musculoskeletal risk factors in recreational runners, these data may be applicable for all runners, even postpartum ones. Because of biomechanical and musculoskeletal perinatal changes, it is suggested that clinicians screen for musculoskeletal alterations in strength, flexibility, range of motion and alignment to determine a postpartum runners' readiness to run.

The rate of running injury is high in recreational runners (van Gent et al. 2007) and present in postpartum runners (Blyholder et al., 2017). It is therefore imperative to establish better baseline predictive clinical assessments to screen postpartum runners for risk factors before introduction or reintegration into impact sports such as running. Clinicians should perhaps consider adding more functional tests that are better aligned with the challenges of running to their evaluations and use traditional clinical tests with caution. There also may be other types of tests that may be predictive of injury—for example, the development of a standardized injury questionnaire.

Study 2 found five risk factors (cesarean delivery (CD) with epidural anesthesia, duration of first stage of labor, age of the mother, race, and urinary tract infections) that were significantly predictive of first-onset low back pain. Like study 1, study 2 also found significant bias in the studies and a lack of quality and homogeneity amongst the studies. Although the risk factors were non-modifiable or mixed (can be argued modifiable or non-modifiable in some cases) the findings provided us with important information about potential modifications for a reduction in lumbopelvic pain. Both cesarean delivery with anesthesia and length-of-labor-related lumbopelvic pain were correlated with muscle strain during the labor and delivery process. A recommendation from these findings is that clinicians should assist the laboring mother in changing positions at certain time intervals to potentially address this risk factor for pain. This may be harder in a cesarean delivery because the patient needs to be supine for surgery; however, while under the epidural, clinicians can focus on positioning or support strategies that may avoid strain on the musculoskeletal system. Also, rehabilitation after the cesarean delivery may increase core strength and decrease pain. While these factors are arguably modifiable, others- age, race- are not. This study highlights that clinical care may needed before, during, and after labor and delivery, especially in populations where chronic pain is present (Bo & Backe-Hansen, 2007).

Study 3, the Delphi study started to provide some recommendations for clinicians working with postpartum runners in pain. Though the Delphi study draws on the lowest level of evidence, expert opinion, it is the first to investigate possible risk factors for pain in the postpartum running population. The results of the Delphi highlighted several musculoskeletal alterations as risk factors for running-related injury—strength, range of motion, flexibility and alignment impairments—that experts agreed were present in postpartum runners. Experts also identified what they believe to be the most important risk factors for running-related pain in the postpartum population; specifically, too much too soon, life stressors, etc. With the information from this study, health care providers can begin to screen postpartum runners for strength, range of motion, flexibility and alignment related impairments and provide them with a comprehensive plan to address these impairments. For example, if a runner presents with an anterior pelvic tilt, the clinician can explore whether this is posture related, core weakness, or tight hip flexors and determine an appropriate exercise plan to address this postural change often seen during pregnancy.

Because no existing information of risk factors for pain in postpartum runners existed, the first studies in my thesis were performed to inform future studies. Study 4 (chapter 6) used information from Chapter 1-3 to design a survey for postpartum runners with and without pain. Through bivariate and multivariate analysis, six variables (novice runner, previous running injury, incontinence, vaginal delivery, less than 6.8 hrs of sleep and >19 on the postpartum accumulated fatigue scale) were identified as risk factors associated with running-related pain. Those variables were then analyzed via 2x2 tables to create a clinical decision tool to understand whether having more than one variable increases the runner's chances of experiencing pain. The results from this study have significant clinical implications. To start, if the postpartum runner is a novice, a recommendation to follow a training plan can be given. If the postpartum runner has fatigue or is not getting enough sleep, running workload could potentially be modified. If the runner has incontinence, she can be screened for pelvic floor strength and an appropriate referral to a pelvic health provider can be made. After a vaginal delivery, the postpartum runner can be monitored for pain because vaginal deliveries have been associated with increased chronic pain in the postpartum period (Bijl et al., 2016; Eisenach et al., 2013; Lavand'homme, 2019) and may contribute to running-related pain. Runners should also be educated about complications from childbirth such as tearing (if any) or prolapse (symptoms of vaginal pressure/heaviness), as they can lead to pain and incontinence (Komatsu et al., 2020). This study recognized that if multiple risk factors existed, the chances of having pain increased as well. This study is the first to recommend specific screening questions that can potentially decrease pain and increase activity in postpartum runners.

Study 5 (chapter 7) was the biomechanical study investigating kinetics, strength and flexibility in postpartum runners compared to nulliparous controls. It was also one of the first attempts to test biomechanical and clinical impairments that may be present in postpartum runners as a result of pregnancy and postpartum related changes. The study found that women had hip weakness, decreased hamstring flexibility, and landed harder when running. The clinical implications of these findings are significant because clinicians can now target these impairments in their evaluation and treatment to help the new mother recover from changes during and after pregnancy, especially when returning to high-impact sports. The clinical recommendation of performing a running gait evaluation (2D or 3D) to assess kinetics (braking rate), a risk factor for future injury (Napier et al., 2018), is novel in this population.

8.5 Future Research Questions

Because most of this thesis focused on background information—collecting risk factors for pain in running and postpartum populations, via systematic reviews and a Delphi study—this thesis produces several natural follow-up questions that should be examined by future researchers. First, a longitudinal study needs to be conducted to determine if the risk factors identified in the Delphi survey or survey of postpartum runners correctly predict pain in postpartum runners. Some of the risk factors for pain need to be validated for their predictability. Healthy runners who are pain-free at baseline should be followed at three months, six months, nine months, twelve months and beyond (if feasible) to determine which factors are associated with running-related pain. This prospective design would validate the risk factors for pain in postpartum runners.

Second, healthy runners need to be followed at baseline even prior to pregnancy to determine which pregnancy and postpartum related biomechanical and musculoskeletal changes affect the postpartum runner. The specific tests that might be useful for baseline measurement are kinematics (breaking loading rate) strength (abdominal, hip and pelvic floor weakness), range of motion (hip extension restriction, anterior pelvic tilt, and general hypermobility), flexibility (laxity in abdominal wall, and tightness in hip flexors, lumbar extensors, iliotibial band, and hamstrings) and alignment (Trendelenburg sign, dynamic knee valgus, lumbar lordosis, over-pronation, and thoracic kyphosis). Following this cohort over time can also provide important information on risk factors for those that develop injury. Finally, a randomized controlled trial should be performed to investigate if interventions for some of the collected risk factors (e.g., more sleep, less fatigue, a structured training plan) can prevent or decrease postpartum running-related pain.

Third, a running readiness screen can be developed. Currently, one non-peer reviewed return to running guideline exists that has recommendations for appropriate referrals and encourages postpartum runners to perform several running readiness screens, that has been published on a personal website. The recommendations have been mostly drawn from studies of postpartum or running populations separately, not form postpartum runners. This thesis has provided variables that were studied in postpartum runners, and future research should develop a screening tool to identify a postpartum runner who may develop injury. Based on the studies in this thesis, the screening should ask questions on running experience, fatigue, sleep, flexibility, incontinence, previous injury and of course, pain. Even though the predictability of these risk factors has not been established, once screened for these risk factors, postpartum runners can be educated on possible strategies to manage them. For example, if cleared to return to running after a physician's clearance and running gait evaluation, and pain risk factors are not present, the postpartum runner may utilize a weekly running plan that increases the mileage by 10% each week (Neilsen et al., 2014). When sleep is below 6.8 hours and fatigue is >19 on the postpartum accumulated fatigue scale, the mother may be advised 1) not to increase mileage, even if her structured training plan suggests this is acceptable or 2) replace the impact workout with something more low impact like a stationary bicycle. (Appendix C). To decrease health care costs, self-assessments can be created where the postpartum runner could screen themselves either at baseline or during a training cycle and determine the next best steps, whether it be globally—such as readiness to initiate a running program—or more specifically—such as whether a workout should be altered that day due to a lack of sleep, fatigue or other factors.

Finally, intervention studies need to be conducted. From the information on risk factors collected in the thesis, a few different studies are proposed. To test the risk factor of being a novice runner, a group of novice postpartum runners can be subdivided into control group and intervention group. The intervention group would be given a 5K training program, whereas the control group will be followed for running habits (mileage, intensity, cross training etc.) After the 12-week program, it would be hypothesized that the postpartum runners receiving the intervention would have fewer injuries in the group compared to the control group. A longer follow up at 6-12 months can be conducted to see if the structured program assisted novice postpartum runners to stay injury free even after the program has ended due to receiving education about running-related risk factors during the program. Similar randomized control trials can be conducted where runners with a previous injury can be divided into control and intervention groups, with the intervention group receiving structured rehabilitation programs. The intervention group that would receive rehabilitation would be hypothesized to have decreased future injury risk when compared to the control group. Lastly similar randomized control trials can be conducted with sleep, fatigue and incontinence, where a group of postpartum runners in pain receive sleep education, pelvic floor screening, rehabilitation, or strategies to manage fatigue to determine if the intervention improves their running-related pain compared to those in the control group. Overall, a number of high-quality trials can be performed to address running-related pain in this population.

8.6 Conclusions

The overall aim of this thesis was to identify risk factors for pain in postpartum runners. As literature investigating this population was sparse, a series of studies covering literature reviews, surveys of experts and postpartum runners, and laboratory data collection of biomechanical factors were performed. The studies collected musculoskeletal impairments and risk factors for pain in running, postpartum, and postpartum running populations.

This thesis is the first to report on important risk factors in postpartum runners. From the survey of postpartum runners with and without running-related pain, postpartum runners had less running experience (were novice runners), had less sleep, had greater fatigue, had symptoms of incontinence (urine, fecal, gas or all), had a vaginal delivery for the last child, and had a previous running-related injury. The biomechanical study showed that when compared to nulliparous controls, healthy postpartum runners may have less hip strength, less hamstring flexibility, and greater breaking loading forces when compared to nulliparous runners, showing that some of these changes may be due to the perinatal period and not necessarily due to injury.

Because women are returning to running and 35% report pain (Blyholder et al. 2017), this thesis contributes to an important gap in the literature. It provides clinical recommendations in an area of literature that did not exist before. By identifying risk factors for pain as well as baseline impairments because of the effects of pregnancy and postpartum, health care providers can assist these women initiating or returning to high impact sports like running.

Future studies should validate some of these findings for their predictability through longitudinal prospective studies. Future studies should also evaluate interventions to determine if some of these risk factors are modifiable, hopefully helping these runners to stay pain free, active, and healthy.

CHAPTER 9. References

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CHAPTER 10. Appendices

Appendix A: Statements from Co-Authors of Published Papers

Co-author Statement from Suzanne Snodgrass

By signing below, I confirm that Shefali Christopher contributed to the concept and research design, acquisition of data, analysis and interpretation of data, as well as writing, reviewing and editing of the publications entitled:

- **Christopher S**, McCullough J, Snodgrass SJ, Cook C. Do alterations in muscle strength, flexibility, range of motion, and alignment predict lower extremity injury in runners: a systematic review. Archives of Physiotherapy. 2019;9(2):1-4
- **Christopher S**, McCullough J, Snodgrass SJ, Cook C. Predictive risk factors for first-onset lumbopelvic pain in postpartum women: a systematic review. Journal of Women's Health Physical Therapy. 2019 Jul 1;43(3):127-35.
- **Christopher S**, Garcia AN, Snodgrass SJ, Cook C. Common musculoskeletal impairments in postpartum runners: an international Delphi study. Archives of Physiotherapy. 2020 Oct;10(19)
- **Christopher S**, Cook CE, Snodgrass SJ. What are the biopsychosocial risk factors associated with pain in postpartum runners? Development of a clinical decision tool. Submitted to PLOS ONE. June 2021
- **Christopher S**, Bauer L, Maylone R, Bullock G, Chinworth S, Snodgrass SJ, Vallabhajosula S. Biomechanical and musculoskeletal differences between postpartum runners and nulliparous controls. Submitted to Journal of Women's Health Physical Therapy. June 2021

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- **Christopher S**, McCullough J, Snodgrass SJ, Cook C. Do alterations in muscle strength, flexibility, range of motion, and alignment predict lower extremity injury in runners: a systematic review. Archives of Physiotherapy. 2019;9(2):1-4
- **Christopher S**, McCullough J, Snodgrass SJ, Cook C. Predictive risk factors for first-onset lumbopelvic pain in postpartum women: a systematic review. Journal of Women's Health Physical Therapy. 2019 Jul 1;43(3):127-35.

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Co-author Statement from Chad Cook

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- **Christopher S**, McCullough J, Snodgrass SJ, Cook C. Do alterations in muscle strength, flexibility, range of motion, and alignment predict lower extremity injury in runners: a systematic review. Archives of Physiotherapy. 2019;9(2):1-4
- **Christopher S**, McCullough J, Snodgrass SJ, Cook C. Predictive risk factors for first-onset lumbopelvic pain in postpartum women: a systematic review. Journal of Women's Health Physical Therapy. 2019 Jul 1;43(3):127-35.
- **Christopher S**, Garcia AN, Snodgrass SJ, Cook C. Common musculoskeletal impairments in postpartum runners: an international Delphi study. Archives of Physiotherapy. 2020 Oct;10(19)
- **Christopher S**, Cook CE, Snodgrass SJ. What are the biopsychosocial risk factors associated with pain in postpartum runners? Development of a clinical decision tool. Submitted to PLOS ONE. June 2021

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- **Christopher S**, Garcia AN, Snodgrass SJ, Cook C. Common musculoskeletal impairments in postpartum runners: an international Delphi study. Archives of Physiotherapy. 2020 Oct;10(19)

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Co-author Statement from Lindsey Bauer

By signing below, I confirm that Shefali Christopher contributed to the concept and research design, acquisition of data, analysis and interpretation of data, as well as writing, reviewing and editing of the publication entitled:

- **Christopher S**, Bauer L, Maylone R, Bullock G, Chinworth S, Snodgrass SJ, Vallabhajosula S. Biomechanical and musculoskeletal differences between postpartum runners and nulliparous controls. Submitted to Journal of Women's Health Physical Therapy. June 2021

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By signing below, I confirm that Shefali Christopher contributed to the concept and research design, acquisition of data, analysis and interpretation of data, as well as writing, reviewing and editing of the publication entitled:

- **Christopher S**, Bauer L, Maylone R, Bullock G, Chinworth S, Snodgrass SJ, Vallabhajosula S. Biomechanical and musculoskeletal differences between postpartum runners and nulliparous controls. Submitted to Journal of Women's Health Physical Therapy. June 2021

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Dr Rebba Maylone Date: 6-24-21

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Professor Vivienne Chuter Date: 050721

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Co-author Statement from Garrett Bullock

By signing below, I confirm that Shefali Christopher contributed to the concept and research design, acquisition of data, analysis and interpretation of data, as well as writing, reviewing and editing of the publication entitled:

- **Christopher S**, Bauer L, Maylone R, Bullock G, Chinworth S, Snodgrass SJ, Vallabhajosula S. Biomechanical and musculoskeletal differences between postpartum runners and nulliparous controls. Submitted to Journal of Women's Health Physical Therapy. June 2021

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Dr Garrett Bullock Date: 22-06-21

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Shefali Christopher Date: June 23rd, 2021

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Professor Vivienne Chuter Date: 050721

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Co-author Statement from Susan Chinworth

By signing below, I confirm that Shefali Christopher contributed to the concept and research design, acquisition of data, analysis and interpretation of data, as well as writing, reviewing and editing of the publication entitled:

- **Christopher S**, Bauer L, Maylone R, Bullock G, Chinworth S, Snodgrass SJ, Vallabhajosula S. Biomechanical and musculoskeletal differences between postpartum runners and nulliparous controls. Submitted to Journal of Women's Health Physical Therapy. June 2021

Dr Susan Chinworth Date: June 24, 2021

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Professor Vivienne Chuter Date: 050721
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Co-author Statement from Srikant Vallabhajosula

By signing below, I confirm that Shefali Christopher contributed to the concept and research design, acquisition of data, analysis and interpretation of data, as well as writing, reviewing and editing of the publication entitled:

- **Christopher S**, Bauer L, Maylone R, Bullock G, Chinworth S, Snodgrass SJ, Vallabhajosula S. Biomechanical and musculoskeletal differences between postpartum runners and nulliparous controls. Submitted to Journal of Women's Health Physical Therapy. June 2021

Dr Srikant Vallabhajosula Date: 06/23/2021

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Appendix B: Journal of Orthopedic and Sports Physical Therapy- Viewpoint

Viewpoint: From Childbirth to the Starting Blocks: Are We Providing the Best Care to Our Postpartum Athletes?

The work presented in this appendix has been published as:

Deering, R. E., Christopher, S. M., & Heiderscheit, B. C. (2020). From childbirth to the starting blocks: Are we providing the best care to our postpartum athletes? Journal of Orthopaedic & Sports Physical Therapy, 50(6), 281-284. doi: 10.2519/jospt.2020.0607. PMID: 32476582.

Overview

The Journal of Orthopedic and Sports Physical Therapy publishes Viewpoints that are perspectives and/or opinions related to sports and musculoskeletal physical therapy topics. They can be an editorial, a perspective or a professional commentary that merges clinical practice and research. The intent of these Viewpoints is to provide a clinical meaningful synopsis or discussion on a particular topic.

As a result of my work in the area of returning to running after childbirth, the publications in this thesis and presentations on this topic at the American Physical Therapy

Association’s national conference, two expert clinician-researchers in the field of postpartum running invited me to co-author this Viewpoint “From Childbirth to the Starting Blocks: Are We Providing the Best Care to Our Postpartum Athletes?”. This demonstrates my recognition in the field of research on postpartum athletes. The Viewpoint presented a 1500-word summary on the current lack of research on postpartum return to sport and proposed a model of care for elite athletes returning to sport after childbirth based on the best available evidence at this time. It proposed a continuum of care where the first phase focuses on healing, the second phase focuses on rehabilitation and the third phase focuses on return to sport. This Viewpoint recommends that the new mother is supported by a team of providers who can attend to her unique needs in each phase. I recognized that the literature supporting such recommendations is sparse, and this is emphasized in the article. This Viewpoint is provided as an appendix to this thesis in order to demonstrate additional contributions to the literature that I have achieved during this PhD.

RITA E. DEERING, PT, DPT, PhD[1-3] • SHEFALI M. CHRISTOPHER, PT, DPT[4,5] • BRYAN C. HEIDERSCHEIT, PT, PhD, FAPTA[1]

From Childbirth to the Starting Blocks: Are We Providing the Best Care to Our Postpartum Athletes?

A professional distance runner presents to your clinic 4 weeks after having her first child. Her sponsors require her to rapidly regain her prepregnancy level of competitive performance. Although she ran right up to delivery, she is anxious about making it to the start line of the New York City Marathon in 2 months. She has questions about topics unique to her postpartum state, which are not typically addressed by her usual athletic support team, including breastfeeding, pumping, strength training, injury risk following childbirth—the list goes on. You seek evidence to guide your recommendations but quickly realize there is a huge problem . . . there is no evidence.

Exercise is important to maternal health and well-being, yet there is little evidence to guide a mother's return to exercise.[3] Standard postpartum medical care is continuously evolving. The American College of Obstetricians and Gynecologists (ACOG) recently advocated for earlier and more frequent health care contact in the first 12 weeks after childbirth (often called the "fourth trimester") to better address medical issues (eg, hypertension, infection, pain) and maternal mental health.[7] While this is important progress in postpartum care, the musculoskeletal system (excluding the pelvic floor) continues to be largely ignored.

Evidence related to musculoskeletal health and safe return to exercise after childbirth is limited, with an even greater dearth of knowledge regarding safe return to high-intensity exercise and competitive sport.[3] This Viewpoint, which is intended for clinicians who treat postpartum athletes, will (1) explore possible reasons for this gap and (2) propose a model for comprehensive postpartum care for the athlete, including members of the care team and progression of care.

SYNOPSIS: There is minimal evidence to guide return to exercise after pregnancy and childbirth, and even less information on safe return to competitive sport. The International Olympic Committee has suggested a 3-phase approach to postpartum recovery in athletes. This Viewpoint expands on that 3-phase model and incorporates a multidisciplinary approach to ensure comprehensive care of postpartum athletes to facilitate safe return to sport with optimal health and performance outcomes. Adopting a multidisciplinary approach may also open new research avenues to ameliorate the dearth of knowledge regarding musculoskeletal recovery and facilitate the development of guidelines to inform clinicians and postpartum women about safe return to exercise, particularly, high-intensity or high-impact activities. *J Orthop Sports Phys Ther 2020;50(6):281-284. doi:10.2519/jospt.2020.0607*

KEY WORDS: *multidisciplinary treatment, pregnancy, sports*

Why Are Postpartum Exercise Recommendations So Ambiguous?

Lack of Standardized Terminology The meaning of certain words varies depending on profession or source, which can lead to confusion across health care providers and patients. For example:

- "Postpartum" can mean anything from the post-birth hospital stay to the time from delivery of the placenta to the cessation of breastfeeding.[10] Given the profound physiological and psychosocial differences between a woman who has given birth 2 days prior and a woman who is still breastfeeding 2 years later, recommendations for physical activity and exercise will, and should, be different. It is imperative that researchers and health care providers be explicit about how they define the postpartum period.
- Physical activity/exercise definitions are vague and inconsistent. For example, ACOG Committee Opinion 804 states, "Some women are capable of resuming physical activities within days of delivery."[2] But "physical activities" is not defined and could mean anything from a comfortable stroll to resistance training and distance running. Lack of clarity leaves well-intentioned recommendations vulnerable to misunderstanding and risks compromising the mother's outcomes.

Lack of Quality Evidence The International Olympic Committee published a

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5-part summary of evidence on exercise and pregnancy in athletes. The summary highlighted important topics for the postpartum athlete, including return to sport and musculoskeletal complaints, and found no studies involving elite athletes in most areas of the report.[3]

Lack of quality evidence may be due to the following:

1. The (erroneous) claim that musculoskeletal dysfunction is normal: women are often told that pain, incontinence, and impaired movement and exercise tolerance are "normal" during and after pregnancy, and therefore do not warrant further examination or treatment.[10] However, while musculoskeletal dysfunction (such as lumbopelvic pain) is common during and after pregnancy,[4] several conditions (eg, pelvic girdle pain and incontinence) can be effectively treated and sometimes prevented.[8,9]
2. Difficulty obtaining research funding for postpartum musculoskeletal disorders: the dismissal of pregnancy- and childbirth-related musculoskeletal dysfunction as "normal" likely reduces the perceived significance of the issue by research funding bodies. The limited available support makes it difficult to conduct adequately powered clinical trials to evaluate exercise prescription and progression in the general postpartum population, as well as in athletes who wish to return to sport after having children.
3. Lack of a structured interdisciplinary care model, which in some countries places the burden of care on the birth provider to address all aspects of postpartum recovery. Thus, other disciplines extensively rely on referral from the birth provider to establish clinical data sets, or must independently recruit postpartum women to participate in research studies outside of their normal medical care. This approach to recruitment can be logistically burdensome, may introduce selection bias, and may ultimately create a barrier to advancing research in this population.

Proposed Model of Care

A multidisciplinary treatment approach has been beneficial in the treatment of chronic low back pain[6]; therefore, we propose an interprofessional team approach to maximize recovery following childbirth, particularly in athletes. Care for the postpartum athlete should be comprehensive and tailored to the individual, based on her specific recovery (including musculoskeletal impairments), sport demands, and performance goals (**FIGURE 1**). Consistent with the recent International Olympic Committee statement, we recommend viewing the journey from childbirth to return to sport as having 3 phases[3]: recovery, rehabilitation/training, and competition (**TABLE 2**).

The athlete will have different needs at each phase. Each member of the care team will have a different role during each phase, while working in an integrated manner. To ensure continuity of care, all providers should be aware of evaluation and treatment recommendations of other specialists, through review of the medical record, telecommunications, or team meetings.

The Recovery Phase The needs of the recovering athlete include relative rest while physiological homeostasis is restored, support while transitioning to motherhood and bonding with her infant (including addressing lactation concerns), and management of pregnancy- and birth-related musculoskeletal concerns. Consistent with musculoskeletal literature on other conditions,[10] recovery typically encompasses the first 12 weeks after childbirth. However, following an uncomplicated pregnancy, childbirth, and recovery, women may progress to the next phase in less than 12 weeks. In contrast, women who experience complications may be in the recovery phase longer than 12 weeks.

The birth provider (physician), the primary health care contact, has the role of assessing gynecologic recovery, wound healing, and cardiovascular health and screening for issues with maternal-infant bonding/maternal mental health.[3] The birth provider will refer the athlete to other disciplines, as needed. However, due to the unique musculoskeletal implications of pregnancy and childbirth, a women's health physical therapist should be involved in this phase to address topics such as interrecti distance, childcare body mechanics (car seats, cribs, infant feeding), management of cesarean incision site and/or perineal tearing (to facilitate healing and manage pain and movement restrictions), lumbopelvic pain, and pel-

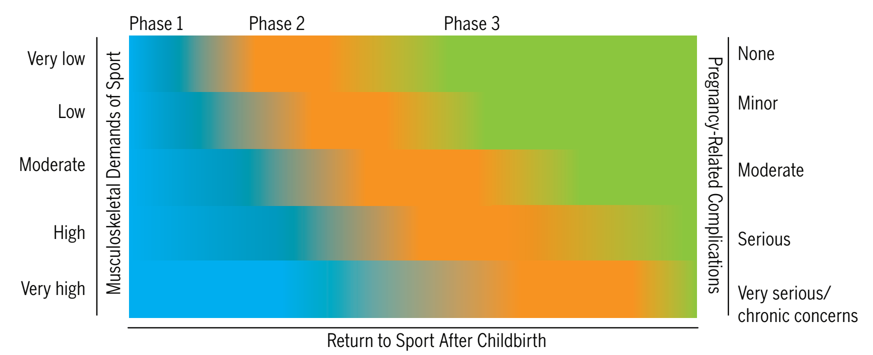

FIGURE 1. Return-to-sport timelines will vary and be heavily influenced by the interaction of a woman's individual recovery from the physiological and musculoskeletal complications associated with pregnancy and childbirth with the musculoskeletal demands of her sport. A woman who has little to no health or musculoskeletal concerns following childbirth but participates in a very demanding sport, such as running or gymnastics, may take longer to return to sport than a woman who is a competitive archer. Conversely, a competitive archer who experiences severe pregnancy-related complications, such as sepsis due to a retained placenta, may spend substantially longer in the recovery phase than a woman in the same sport who had an uncomplicated recovery. It is important not to tie progression to specific time frames, but rather to specific health and musculoskeletal parameters in the context of the demands of the sport.

vic floor dysfunction (including pelvic organ prolapse).[3,10]

The Rehabilitation/Training Phase The athlete's needs in this phase are restoration of musculoskeletal function and cardiovascular endurance, and gradual reintroduction of sport-specific tasks once medically cleared to begin training. Postpartum women are more susceptible to neuromuscular fatigue and demonstrate impaired motor control.[5] Interrecti distance has been associated with strength and fatigability of the abdominal muscles,[5] and postpartum urinary incontinence commonly interferes with exercise.[8]

The athlete's primary health care contact is the physical therapist, who, ideally, will have expertise in both women's health and sports physical therapy. However, this combination of training is quite rare and may necessitate 2 individuals to ensure appropriate biomechanical analysis of movement (particularly during sport-specific activities), while continuing to address pregnancy- and childbirth-related musculoskeletal disorders and general orthopaedic concerns.[10] Mental health should continue to be screened and referral to specialists made as appropriate, as incidence of posttraumatic stress disorder is higher at 6 months than at 6 weeks after childbirth,[1] and because injury, medical complications, or slower-than-expected progress may negatively impact mood. For elite athletes, the coach is closely involved, guiding training and performance goals of the athlete. The physician will be consulted as needed.

The Competition Phase When the athlete has returned to full participation in her sport, she transitions to the competition phase. The rehabilitation/training and competition phases are somewhat fluid—the athlete may be competing below her prepregnancy level while still in the rehabilitation/training phase, and may re-enter that phase between competitive events or as a result of injury. The primary goal of the competition phase is athletic performance. The athlete may be navigating this phase independently or collaboratively with her coach. Explicit education should be provided to the athlete (and coach) on when and how to involve the health care team in the event of injury or performance concerns.

Summary

Our model is intended as a first step to comprehensive care, and should evolve

FIGURE 2. Progression of care for the postpartum athlete in a 3-phase model. Phase 1 prioritizes medical status and initial recovery from childbirth. If no major concerns regarding postpartum healing are present, rehabilitation and sport-specific training can begin. Rehabilitation and training will continue until the athlete has reached the desired level of athletic performance. The athlete may re-enter phase 2 between competitive events or when injury occurs or performance issues arise. Abbreviations: BP, blood pressure; HR, heart rate; LBP, low back pain; PGP, pelvic girdle pain.

as new evidence emerges and health care practices continue to progress. Research is sorely needed to determine the best way to provide comprehensive postpartum care in an effective and fiscally responsible manner. An interdisciplinary approach may open new research avenues for competitive funding opportunities, thus helping to ameliorate the lack of high-quality evidence and improve best-practice recommendations. We hope an integrated care model can improve the postpartum experience of female athletes and facilitate advances in evidence-based care.

Key Points

- Return to exercise and competitive sport after childbirth should be based on specific health and musculoskeletal parameters in the context of the demands of the sport, not on arbitrary time frames.
- A comprehensive team approach to postpartum care may improve mothers' outcomes and open doors for research opportunities.
- More research is needed to identify best-practice guidelines for return to exercise and competitive sport following pregnancy and childbirth. ◉

STUDY DETAILS

AUTHOR CONTRIBUTIONS: All authors contributed to concept development, writing of the manuscript, and development of the figures.

DATA SHARING: There are no data in this manuscript.

PATIENT AND PUBLIC INVOLVEMENT: There was no patient/public involvement in the development of this Viewpoint.

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Appendix C: Journal of Women's Health Physical Therapy - Clinical Commentary

Rehabilitation of the postpartum runner: A four phased approach

The work presented in this appendix has been submitted to the Journal of Women's Health Physical Therapy's Fourth trimester special issue:

Christopher, S. M, Gallagher, S, Olson, A, Cichowski, S, Deering, R. E (2021). Rehabilitation of the postpartum runner: A four phased approach.

Overview

The Journal of Women's Health Physical Therapy publishes clinical commentaries, which are scholarly manuscripts that contain opinions or perspectives of relevance to women's health. They are often written by leaders in the topic of relevance and are comprised of ideas and opinions intended to not only inform practice but to advance it.

The American Physical Therapy Association's Pelvic Health Academy's leaders invited me to assist them with writing this clinical commentary. This invitation shows I am beginning to be recognized as a leader in this field. They wanted to publish research-based return to running guidelines that clinician members of the pelvic health academy could use to rehabilitate a postpartum runner. While I recognized that research in this area was only just beginning to emerge with the studies presented in this thesis, I also believed it was important to contribute to this commentary so that I could contribute to highlighting where the research gaps exist. This commentary is a 3500-word expert opinion that presents a novel four phased protocol. After a major sports injury, such as anterior cruciate ligament injury, athletes typically participate in rehabilitation programs that progress their rehabilitation in a formal way and prepare them for return to sport. This document uses the best evidence currently available (usually from guidelines published for other running populations, not postpartum) along with expert opinion to provide an analogous protocol for women returning to running after childbirth. It is provided as an appendix to this thesis in order to demonstrate additional contributions to the literature that I have achieved during this PhD.

Abstract

Women are running after childbirth, however there are gaps in literature supporting when and how to safely initiate or return to running postpartum. The body undergoes changes during pregnancy and following childbirth, regardless of method, that may impact strength, neuromuscular control, and endurance. These changes may influence its ability to withstand the high impact forces of running. Many patients experience new or worsened symptoms of musculoskeletal or pelvic floor dysfunction following pregnancy or childbirth and require physical therapy to resume normalized function. After most major injuries, it is common practice to participate in formalized rehabilitation; however, this is not the norm for athletes returning to sport post childbirth. Pelvic and sports physical therapists must understand biomechanical features of running gait and safely progress strength, endurance, and neuromuscular control of the kinetic chain when guiding a patient to run postpartum. This clinical commentary builds on existing guidelines, research, and expert opinion to propose a four-phase protocol to help postpartum patients initiate or resume running. The result is an in-depth exercise prescription (intensity, frequency, type), examples of exercises (hip, abdominal, pelvic floor, and foot), running progression, and progression goals to prepare postpartum runners and prevent postpartum running injury.

Background

Running is becoming more popular during and after pregnancy. About 70% of runners who become pregnant continue to run during pregnancy.[1] After childbirth, runners commonly resume running between 2 weeks to 2 months postpartum.[1,2] Postpartum runners have reported pelvic floor dysfunction and musculoskeletal pain;[2,3] however, running also produces psychological and physiological health benefits, including reduced risk of premature mortality and cardiovascular disease, improved endurance, and weight management.[4,5] Due to these benefits, and the ease of access to running, it is important to facilitate postpartum runners running. Healthcare providers and postpartum people increasingly seek guidance on resuming running after childbirth. While high rates of running-related injury (RRI) have been reported in the general population,[6] scientific evidence on resuming high impact exercise after childbirth is lacking.[7,8]

Pregnancy and childbirth produce unique musculoskeletal changes in the pelvic floor, trunk, hip, and foot muscles, and ligaments, which affect running form.[9] Like any sports injury, childbirth itself can result in major injury that should require rehabilitation to return-to-sport.[10] However, women are initiating or returning to running without guidance. Despite the sparsity of literature in postpartum running populations, several expert opinions have proposed return to running screens based on musculoskeletal changes in the general postpartum population and return to running following injury in the general running populations.[7,11,12] This clinical commentary builds on this guidance[13] and provides pelvic health and sports clinicians with a four phase rehabilitation protocol for initiating or returning to running in the postpartum period. Our premise is that each individual runner should be empowered to decide when to resume running, in consultation with their healthcare providers.

Screening Postpartum People for Readiness to Run

Determination of readiness to run after childbirth will be largely symptom driven. A patient with musculoskeletal or pelvic health symptoms may be able to gradually resume running in tandem with medical management. The expectation is to minimize these symptoms through exercise prescription, gait retraining, manual therapy, and support of the pelvic organs (including by means of an inserted device, if indicated). The screening or protocol should be stopped immediately if the client has any absolute contraindications, and clinical judgement exercised with any client who presents with relative contraindications (Table 1).

Table 1: Absolute and relative contraindications to exercise

Absolute contraindications: ●Vaginal bleeding not associated with menses (increase in bleeding in first 8 weeks postpartum; persistence or new onset beyond 8 weeks postpartum)[95] ●Abdominal pain ●Hemodynamically unstable (ischemic symptoms combined with systolic BP decrease >10 mm Hg with exercise)[48] ●Pregnancy related or postpartum related conditions in which no vigorous exercise has been advised (such as postpartum cardiomyopathy)[31] ●People with cesarean birth should be cleared by their obstetric provider prior to resuming running[31] ●Breathing difficulties[48] ●Chest pain[48] ●Dizziness[48] ●Neurological symptoms, such as fainting, ataxia, or muscle weakness influencing balance[48] ●Calf pain or swelling
Relative contraindications ● Unassessed urinary or fecal incontinence postpartum ● RRI prior to delivery ● Significant increase in BP (>250/115) or decrease in systolic BP >10 mm Hg without ischemic symptoms[48]

BP: blood pressure; mm HG: millimeters of mercury; RRI: running-related injury

Screening for Pelvic Health

Screening for pelvic floor dysfunction is imperative for clinicians managing the care of postpartum people. Screening questions include:

- Do you experience accidental urinary leakage when you cough, sneeze, laugh, or exercise?
- Do you have a bulge or sense something falling out that you can see or feel in the vaginal area?[14]
- Do you experience accidental leakage of bowel movements?
- Do you experience pain with bowel movements, tampon use, or intercourse?

A response of "yes" to any of these questions warrants a referral to a pelvic health physical therapist or urogynecologist. Pelvic floor muscle examination includes assessment of strength, endurance, coordination, and mobility, as well as evaluation for incontinence and prolapse.[15]

Screening for Impact Readiness

Two screens have been proposed to determine if the runner is ready to begin running.[11,12] Both running screens consist of a series of movements to determine if musculoskeletal pain or pelvic symptoms are present with impact or increased load. Before beginning the return to running protocol outlined in this document, we recommend screening for running impact readiness.

Screening for Running Gait

Many kinematic and kinetic factors have been investigated for the relationship between running gait and injury,[16–18] including peak hip and knee adduction,[17,19] knee stiffness,[20] and step rate.[21] We recommend a running gait analysis to assess biomechanical risk factors for RRI.[9] For clinicians unfamiliar with running gait analysis, Souza provides a guide to 2D analysis.[22]

Screening for Physiologic Variables

Decreased sleep,[23,24] increased fatigue,[25,26] [27] [27,28] and inadequate nutrition[29,30] may contribute to running-related injury (RRI) in postpartum persons. While outside the scope of this document, these variables should be considered when returning to running.

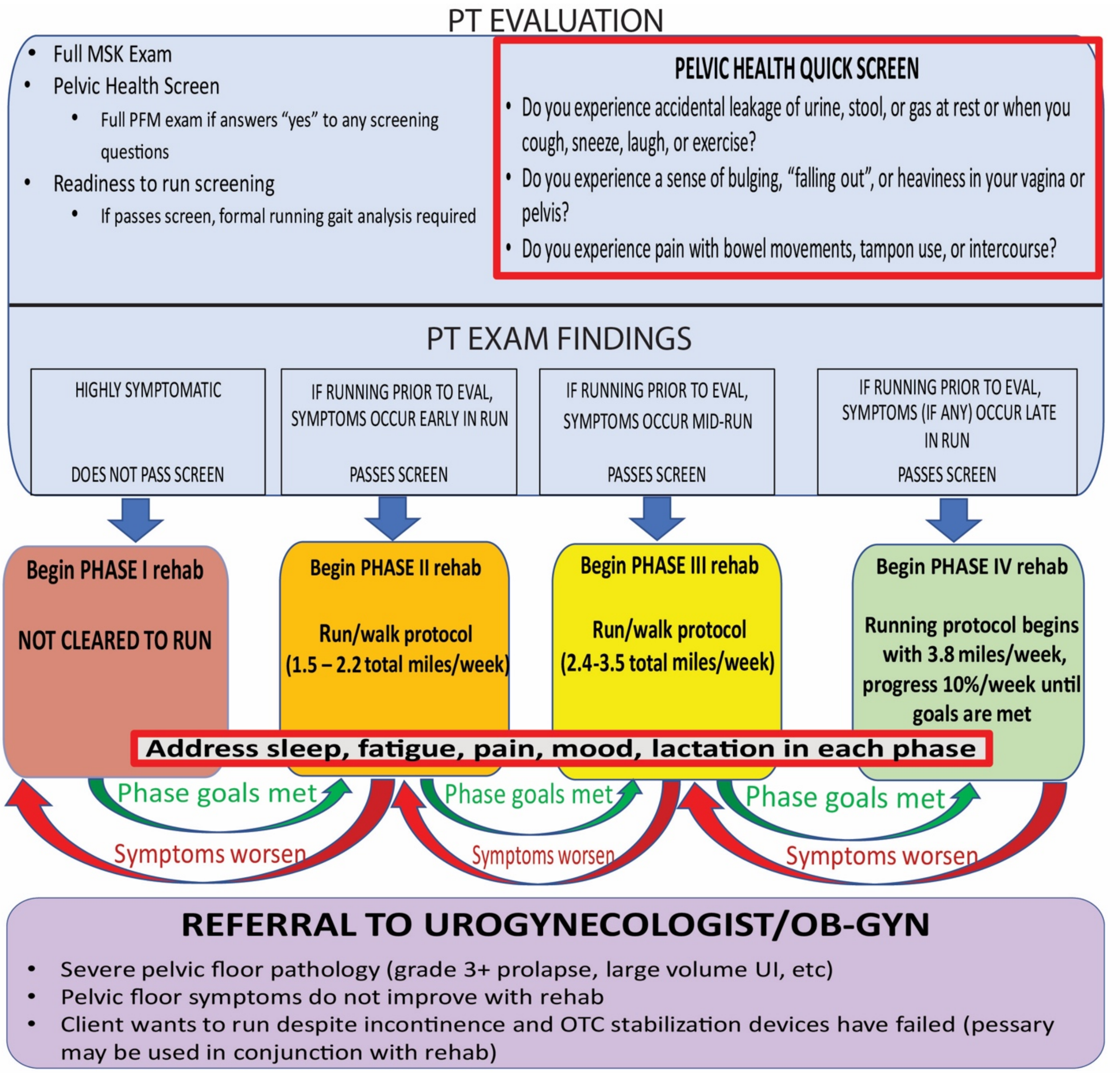
Proposed Rehabilitation Protocol

The American College of Obstetricians and Gynecologists (ACOG) advises postpartum exercise as soon as medically safe, sometimes within days of delivery.[31] Postpartum recovery involves musculoskeletal,[32] biomechanical[33–38] and physiological variables.[39] The widening of the levator hiatus that occurs in vaginal birth may contribute to incontinence and prolapse.[40,41] Healing from birth injuries such as perineal tearing or cesarean incision[8] may require additional time.[8,42–44] We recommend approaching recovery from pregnancy-related changes and delivery-related injuries similar to recovery from other injury or surgery, while respecting the additional postpartum physiological factors. For example, return-to-sport protocols for anterior cruciate ligament injury involve a formal rehabilitation protocol with functional progressions based on sport-specific goals.[45] This proposed protocol mirrors these return-to-sport protocols by proposing a phased approach targeting key muscle groups that influence running gait and are commonly impaired after childbirth: the pelvic floor muscles (PFM), abdominals, posterolateral hip muscles, calf, and foot intrinsic muscles. A progression through isometric, isotonic and plyometric exercises is recommended to assist a postpartum runner return to running without injury. This protocol encompasses the entire kinetic chain to prepare the postpartum runner for effective load management.[46]

How to use the Protocol

The runner may begin at any time postpartum if they have been medically cleared and screened for running impact readiness. Symptoms should be continuously monitored and addressed by the healthcare team. As each individual may have unique pregnancy and postpartum experiences, this protocol should be used as a guide to assist each runner in achieving their running goals. The physical exam will determine which phase of the protocol to initiate (Figure 1): highly symptomatic patients who do not pass the running readiness screens will begin in phase I, while patients with minimal or no symptoms and pass the running readiness screens will begin in phase IV. We highly recommend returning to a previous phase if musculoskeletal symptoms worsen. In addition, an extremely fatigued, sleep-deprived runner may need to stay in the current phase of rehabilitation, or regress in some parts of the protocol (i.e., running) until they are recovered. We recommend runners and healthcare providers monitor training, recovery and symptoms throughout the phases of this protocol to ensure appropriate physiological and musculoskeletal adaptation to training load.[47]

Figure 1. Care Plan for the Postpartum Runner
Care of the postpartum runner begins with a full physical therapist examination, which determines which phase of the protocol to initiate. Symptoms should be monitored throughout the care plan: successful completion of the exercises and running mileage within a phase combined with stable or improving symptoms warrants progression to the next level, while exacerbation of symptoms or inability to complete exercises in a given phase requires regression to the previous phase.



Abbreviations: PT, physical therapist; MSK, musculoskeletal; PFM, pelvic floor muscle; EVAL, evaluation; OB-GYN, obstetrician-gynecologist; UI, urinary incontinence; OTC, over the counter.

Key Elements of the Protocol

Exercise Prescription

The proposed protocol is based on the principles of exercise prescription established by the American College of Sports Medicine (ACSM),[48] providing the specific parameters of frequency, intensity, type, and rest. Exercise types discussed are isometric, isotonic and plyometric. Isometric exercise has been shown to increase tendon stiffness and muscle hypertrophy.[49] Midrange joint positions are commonly used, and duration of isometric holds range from 10-45 seconds with 20-90 seconds of rest. Isometric exercises can also evoke exercise induced hypoalgesia (EIH).[50,51] Isotonic exercises improve muscle strength and hypertrophy.[52,53] Eccentric exercises have added neural benefits[54] and EIH[55], but increased risk of delayed onset muscle soreness; however, neural adaptations seem to help muscle recruitment and override inhibitory signals from pain and swelling.[54] Plyometric training in female athletes may decrease knee injuries[56] and improve running performance[57] by augmenting tendon extensibility and active muscle stiffness (Table 2).[58]

Table 2. Exercise parameters (frequency, intensity, rest and type) for each phase of the postpartum return to running rehabilitation protocol

Phase	Frequency	Intensity			Type
		STRENGTH[48]	ENDURANCE[48]	REST[48]	
Phase I	Days per week: ●Isometric 3-7 ●Isotonic or plyometric 2-3 Days	●Low reps (goal 8-15) ●High load ●Borg RPE of 13-16 for most individuals; RPE 7-12 for very weak or deconditioned individuals)	●High reps (goal 15-25) ●Low load ●Borg RPE 11-14 (fairly light-somewhat hard/hard)	●Isometric: Rest between reps is double the work time ●Isotonic/plyometric: Minimum of 2 minutes rest between sets ●May need to increase (5+ minutes) for very weak, more fatigable individuals	Example principles:[48] ● Isometric exercises ● Isotonic exercises (through pain free and controlled ROM) ●Bilateral closed chain or unilateral open chain ● Stable surface ●Gravity eliminated ●Breath work with activation and relaxation
Phase II		●Low reps (goal 8-15) ●High load ●Borg RPE of 13-16	●High reps (goal 15-25) ●Low load ●Borg RPE 11-14	2-3 minutes	●Isometric exercises ●Isotonic exercises ●Bilateral closed chain or unilateral open and closed chain ●Stable surface ● Adjust to more challenging positions (against gravity, less synergistic muscle activity, challenge base of support)
Phase III				2 minutes	●Isometric ●Isotonic exercises ● Introduce resistance (weights, bands, etc.), ●Vary stable to unstable surface (foam surface,

					ball, balance board, roller, disk)
Phase IV				2 minutes	●Isometric ●Isotonic ●Vary stable to unstable surface (foam surface, ball, balance board, roller, disk) ●Plyometric exercises (running drills, agility drills, jump progressions)

RPE: rate of perceived exertion; reps: repetitions; ROM: range of motion.

The four targeted muscle groups in this protocol (Table 3) are the abdominal, pelvic floor, gluteus medius, and foot muscles. Example exercises for each phase were chosen based on evidence—with specific attention to electromyography (EMG) studies to help determine exercise intensity, and running-specific research regarding injury risk and rehabilitation—and expert opinion. When possible, we recommend exercises with low EMG activity initially to build strength and neuromuscular control, progressing to exercises with higher EMG activity. Example exercises are to guide clinicians, not to act as an exhaustive list. Clinicians are encouraged to use clinical judgment in identifying appropriate exercises for their clients. On scheduled run days, strengthening exercises should be performed after running to avoid fatigue while running. Clinicians should work with patients to identify barriers (e.g., time), and create an individualized version of this protocol to ensure success.[59] For example, a limit of 4 exercises has been recommended in a home exercise program (HEP) to ensure compliance.[60] Phase goals on when to advance have also been provided (Table 4).

Table 3. Four phased rehabilitation protocol for initiating or returning to running post childbirth

	Example Exercises			
	HIP[96]	FOOT	PFM	ABS[97]
Phase I	Supine: ● Bilateral bridge[98,99] Side-lying ● Clamshell[100] Standing: ● Double leg bodyweight squat[96,98,101]	Seated:[81,82] ●Towel scrunches ● Bilateral heel raise ● Isolated great toe extensions ● Arch doming	Supine, side lying, sitting: ●Isolated quick flicks (1-2 seconds) ●Endurance (3-5 seconds)	Supine, side lying, sitting or quadruped: ●ADIM with breathing Supine:[102] ●Knee raise to 90-90 position (Sarhmann level 1) ●Knee lowering from 90-90 (Sarhmann level 2) Supine:[97,103–105] ●Double leg bridge stable surface 10-30 seconds (TrA focus) ●Double leg bridge (stable)with end exhalation (Obliques focus) ●Single leg raise to 45 degrees (all abdominal focus)
	Running progression: Build walking tolerance to 30 mins without musculoskeletal or pelvic symptoms and RPE <11			

<table>
<tr>
<td rowspan="2">Phase II</td>
<td>Supine:[98,99,106]
●Bridge unilateral stable or bilateral unstable

Prone:
●Double limb plank[99]
●Prone hip extension with flexed knee (90) progressing to LE straight, foot plantarflexed (triple extension)[98,107]

Quadruped:
● Straight knee hip extension; WB or NWB[98,107]

Side lying:
●Hip abduction neutral or with lateral rotation[98,108]

Standing:
●Hip abduction (focus on stance leg, pelvic stability)[109]
●Standing Single leg pelvic drops (eccentric hip abduction)[98]
●Single leg squat[110,111]
●Lunge forward[99]
●Step up front[98], retro,[110] lateral[110]</td>
<td>Standing:[81,82]
●Towel scrunches
●Bilateral heel raise
●Isolated great toe extension
●Great toe flexion with 2-5th toe extension
●Medial arch doming</td>
<td>Supine, side lying, sitting:
●PFM activations simultaneous to hip and ADIM exercises
●Sustained contractions and quick flicks</td>
<td>Quadruped ADIM:
● Adding UE and LE movements[112]
● Plank on forearms and knees[97,113,114]

Supine:
●Double leg bridge unstable surface (TrA)[105,115]
●Curl-up[116,117]

Side lying:
●Side plank knees and elbow[97,114]</td>
</tr>
<tr>
<td colspan="4">Running progression: (RPE 11-13)
●Level one: 0.25 walk 0.25 run 0.25 walk 0.25 run (Weekly mileage 1.5 miles)
●Level two:0.25 walk 0.28 run 0.25 walk 0.28 run (Weekly mileage 1.65 miles)
●Level three: 0.25 walk 0.30 run 0.25 walk 0.30 run (Weekly mileage 1.82 mile
●Level four: 0.25 walk 0.33 run 0.25 walk 0.33 run (Weekly mileage 2.00 miles)
●Level five: 0.25 walk 0.36 run 0.25 walk 0.36 run (Weekly mileage 2.20 miles)

Perform each level 3 times with 48hrs of rest and progress if symptom free and RPE <11</td>
</tr>
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Phase III	Prone**:** ●Front plank single limb NWB and WB[106] Quadruped**:** ●Bird dog[99] Side lying ●Hip abduction with medial rotation[108] ; or with added resistance[118] ●Side plank[99] Standing ●Hip abduction progression[106] ●Single limb deadlift[106,119] ●Single limb deadlift with rotation (navel to wall)[120] ●Step-up front retro or lateral[110] ●Lunge lateral[119] ●Single leg squat: stable[106] or unstable[121] ●Skater squat[106] ●Single limb stance: NWB in circumduction[106] ●Monster walk[119] Plyometric: Jumping B LE: ●Forward/backward progressing to lateral/medial	Standing:[81,82] ●Single limb pelvic rotation on fixed femur stance leg (IR/ER of pelvis on femur) focus on foot posture ●DL heel raise with increase weight ●Isolated great toe extension ●Great toe flexion with 2-5th toe extension Movement transitions (sit to stand): ● Maintain arch doming Plyometrics: ●Jump with doming of arch	Standing ●Pelvic floor muscle activations: Quick contractions for 3 sets of 10 ●Endurance holds in combination with hip exercises ●PFM activations simultaneous to other exercises Plyometrics: ●Jumping with pelvic coordination (attention to landing)[128]	Supine:[102] ●Unilateral heel slide from 90-90 position (Sahrmann level 3) ●Bilateral heel slide from 90-90 position (Sahrmann level 4) Standing:[122] ●Back squat (RA focus) ●Bulgarian squat (unilateral) (EO and RA focus) Quadruped ADIM: ●Adding UE and LE movements with resistance/ weight[123] ●Front Plank on forearms and toes[97,113,114] ● Front plank with scapular adduction and posterior pelvic tilt (IO focus)[124] ● Forward plank with single leg hip extension (EO focus)[124] Side lying: ● Side Plank on forearm and toes[97,114]
	Running progression: (RPE 11-13) ● Level six 0.25 walk 0.40 run 0.25 walk 0.40 run (Weekly mileage 2.40 miles) ● Level seven: 0.25 walk 0.44 run 0.25 walk 0.44 run (Weekly mileage 2.65 miles) ● Level eight: 0.25 walk 0.48 run 0.25 walk 0.48 run (Weekly mileage 2.90 miles) ● Level nine: 0.25 walk 0.53 run 0.25 walk 0.53 run (Weekly mileage 3.20 miles) ● Level ten: 0.25 walk 0.58 run 0.25 walk 0.58 run (Weekly mileage 3.50 miles) Perform each level 3 times with 48hrs of rest and progress if symptom free and RPE <11			

<table>
<tr>
<td>Phase IV</td>
<td>Side lying[106]
● Side plank single limb

Standing (add resistance/ challenge surface)
● Step up front or lateral[110]
● Hip abduction progression[106]
● Single limb deadlift[106,119]
● Single limb deadlift with rotation (navel to wall)[120]
● Step-up front retro or lateral
● Lunge lateral[106,119]
● Single leg squat: stable[106] or unstable[121]
● Skater squat[106]

Plyometric:
● Hop forward, sideways or transverse[106,119]
● Box jumps down (start up, jump down)
● Step hops forward & sideways</td>
<td>Standing[81,82,125]
● Single limb heel raises (cueing for stability in the first metatarsal head and through the ankle)
● Rear foot elevated split squat with lead leg in slight plantar flexion. Heel hovering 2 cm off the ground
● Isolated great toe extension with resistance (resistance band, rubber band)
● Great toe flexion with 2-5th toe extension with resistance (resistance band, rubber band)

Plyometric:
● Hops with doming</td>
<td>Standing
● Vaginal weight in standing for proprioceptive input. Active contraction (3-5 seconds, 3 sets of 10)[126]

● Vaginal weight with endurance hold during gentle activities of daily living for no greater than 20 minutes per day[127]</td>
<td>Standing
● Paloff press
● Diagonal rotations with resistance
● Back squat (RA focus)[122]
● Bulgarian squat (unilateral) (EO and RA focus) -unstable[122]
● Standing one leg press, skiing

Quadruped:
● Plank on toes and hands (forward, side, star)
● Roll-out plank (RA focus)[122]
● Forward plank: with single leg hip extension, forearm on swiss ball (stir the pot)[129] or suspension systems[114,130]

Side lying:
● Side plank with leg lifts: upper body rotation, added resistance, challenge base of support</td>
</tr>
<tr>
<td></td>
<td colspan="4">Running progression: (RPE 11-13)
● Level eleven: 0.25 walk 0.63 run 0.25 walk 0.63 run (Weekly mileage 3.80 miles)
● Level twelve: 0.25 walk 0.70 run 0.25 walk 0.70 run (Weekly mileage 4.20 miles)
● Level thirteen: 0.25 walk 0.77 run 0.25 walk 0.77 run (Weekly mileage 4.62 miles)
● Level fourteen: 0.25 walk 0.83 run 0.25 walk 0.83 run (Weekly mileage 5.00 miles)
● Level fifteen: 0.25 walk 0.92 run 0.25 walk 0.92 run (Weekly mileage 5.50 miles)
● Level sixteen: 0.25 walk 1.02 run 0.25 walk 1.02 run (Weekly mileage 6.10 miles)
● Level seventeen: 0.25 walk 1.12 run 0.25 walk 1.12 run (Weekly mileage 6.70 miles)

● Level eighteen:0.25 walk 1.50 run 0.25 walk 0.75 run (Weekly mileage 6.75miles)
● Level nineteen:0.25 walk 1.75 run 0.25 walk 0.50 run (Weekly mileage 6.75 miles)
● Level twenty: 0.25 walk 2.0 run 0.25 walk 0.25 run (Weekly mileage 6.75 miles)
● Level twenty-one: 0.25 walk 2.25 run 0.25 walk (Weekly mileage 6.75 miles)
● Level twenty-two:0.25 walk 2.48 run 0.25 walk (Weekly mileage 7.43 miles)

Perform each level 3 times with 48hrs of rest and progress if symptom free and RPE <11</td>
</tr>
</table>

PFM: Pelvic floor muscles; RA: rectus abdominis; TRA: Transverse abdominis; EO: external oblique; IO: Internal Oblique; B: Bilateral; LE: lower extremity; WB: weight bearing; NWB: Non-weight bearing, RPE: rate of perceived exertion (Borg)

Table 4. Goals for phase progression

HIP/LE	FOOT	PFM	ABS	RUNNING
RPE <13 or Pt reports exercises are not challenging Quality: ● No compensation (see text) ● Smooth ascend and descend (No use of momentum) ● Level pelvis ● No breath holding ● No muscle substitutions (Gluteus medius fatigue per pt response)	RPE <13 or Pt reports exercises are not challenging Quality: ● No compensation (see text) ● Smooth ascend and descend (No use of momentum) ● Level pelvis ● No breath holding ● No muscle substitutions (Foot/calf muscle fatigue per pt response)	No leakage with exercises and or Pt reports exercises are not challenging	RPE <13 or Pt reports exercises are not challenging Quality: ● No doming ● No compensation (see text) ● Smooth ascend and descend (No use of momentum) ● Level pelvis ● No breath holding ● No muscle substitutions (Abdominal muscle fatigue per pt response)	RPE <11 or Pt reports level is not challenging No increase during or after running sessions: ● Pain ● Soreness ● Stiffness ● Incontinence ● Vaginal heaviness

LE: Lower extremity; ABS: Abdominal muscles; PFM: Pelvic floor muscles; RPE: Rate of perceived exertion; Pt: patient

Frequency

The strength exercises suggested in each phase of the protocol should be performed 2-3 days a week; however, isometric exercises and very low intensity exercises, such as those in Phase 1, may be performed 3-7 days/week.[48]

Intensity

To build strength, ACSM recommends low repetitions (8-15) with high load.[48] As "high" load is patient specific, we recommend a rate of perceived exertion (RPE) of 7-12 on the Borg scale in phase I and 13-16 in phases II, III and IV. Muscle endurance is achieved with high repetitions (15-25) of low load (RPE of 11-14).[48] During running, the same recommendations for RPE exist throughout the phases.

Rest

Two to three minutes rest between sets has been recommended when strength training.[48] However, longer rest periods (≥5 minutes) may be needed in postpartum women due to potentially increased fatigability.[61–63]

Exercises

Many muscles contribute to running propulsion and stability during stance. Key muscles associated with perinatal changes are included below. In an attempt to limit the time to complete the HEP, we recommend choosing exercises that target multiple muscle groups in each phase (Table 5).

Table 5. Exercises and their target muscle groups, expert opinion

Exercise/ Muscles affected	PFM	Abdominal	Hip	Foot
Breathing exhale focus	*	* all		
Kegel	*	* TRA		
Towel roll, toe extensions	*			*
Heel raise	*[125]	*[131]	*	*
Plank	*	* all	*	*
Quadruped Bird dog/ LE lift	*[132]	*	*	
Side plank SLS side plank	*	* all	*	*
Bridge	*	*	*	*
SLS bridge	*	*	*	*
Squat	*	*	*	*
SLS squat	*	*	*	*
Lunge	*		*	*
Dead lift			*	*
Two leg jump	*		*	*
Single leg hop	*		*	*

Abdominal

The anterior trunk muscles of postpartum people have been shown to demonstrate decreased strength and steadiness of contraction, and increased fatigability,[61,62] with more severe impairments associated with wider inter-recti distance (IRD) or diastasis recti abdominus (DRA).[61–63] Rehabilitation of all muscles of the abdominal wall is vital, as trunk flexion and rotation, and lumbopelvic stabilization have been shown to be impaired following childbirth.[61–63] Conflicting evidence exists on which exercises are best to reduce IRD long-term [64–67]; however, ultrasound studies suggest that performing an abdominal draw-in maneuver (ADIM) prior to an abdominal curl-up reduces linea alba distortion.[68,69] Therefore, ADIM exercises start in phase I of the protocol, and curl-up exercises are added in phase II, only in the absence of abdominal doming. Phases III and IV focus on higher-level exercises that require significant activity of all abdominal muscles.

Pelvic Floor

Running is an impact activity that increases intra-abdominal pressure.[70] This increase in pressure challenges the pelvic floor to maintain continence and pelvic organ support.[70]. Stress urinary incontinence (SUI) is most prevalent in women performing high impact activities,[71] and is observed in 19% of runners up to 2 years postpartum.[2] Childbirth is also a risk factor for pelvic organ prolapse (POP).[72] Therefore, it is imperative to screen for incontinence and POP symptoms before running. The exercises starting in phase I of the protocol are quick contractions held for 1-2 seconds and performed repeatedly with proper rest, and endurance contractions held for 3-5 seconds for 8-12 repetitions, increasing hold time to 10 seconds in later phases. A referral to a urogynecologist is recommended for runners with prolapse to the hymen or beyond, persistent pelvic floor symptoms despite rehabilitation, or a desire to run despite incontinence and failure of over-the-counter pelvic support devices, such as the Poise Impressa™.

Hip

The key muscle targeted in this section is the gluteus medius, as it stabilizes the pelvis in single limb stance.[73] Specifically, it prevents hip adduction, a risk factor for RRI.[74,75] Gluteus medius weakness has also been associated with LBP in pregnancy, due to a Trendelenburg gait or a strain in the muscle itself.[76] In women with SUI, strengthening the hip abductors along with the pelvic floor muscles showed less daily urine loss.[77] Exercises in phase I with low EMG activity are bilateral leg bridge, squat, and prone bent knee hip extension. Phases II and III have moderate to high EMG (% MVIC), including quadruped straight leg hip extension and single limb stance exercises. Phase IV includes single limb side plank and hops.

Foot

The foot has important roles in running including impact absorption at contact and propulsion.[78] Feet experience changes during pregnancy leading to altered biomechanics and pressure patterns.[79] Excessive pronation has been linked with RRI.[80] Pronation is present in pregnant women and is not observed to return to baseline at 6 weeks postpartum.[79] Foot strengthening exercises were included in this protocol as they have been observed to improve foot muscle volume and propulsive forces in runners.[81] The exercises in phase I begin in sitting and include foot intrinsic isometric holds to improve neuromuscular coordination, strength, and stability. Phases II-IV include progressively more challenging exercises for arch doming and foot intrinsic strength.[81,82]

Running Progression

The postpartum runner must be able to walk for 30 minutes without symptom exacerbation before starting the running progression component of this protocol. The runner should first be evaluated for shoe fit as foot dimensions may increase and dynamic arch stability may decrease after childbirth.[79,83] Running should begin on a flat surface, every other day to ensure recovery between sessions. The runner should monitor symptoms such as pain, incontinence, swelling, prolapse, or muscle stiffness during and after running. We recommend slow progression, through the levels 0-22 suggested (Table 3), to ensure appropriate adaptation to impact loads. If symptoms arise or worsen, running should stop and a running gait evaluation by a physical therapist should be sought. Elite athletes or runners who ran throughout pregnancy and desire a quicker progression may do so under supervision; however, it is recommended that only one variable (velocity, distance, frequency) is increased weekly and running distance increase by no more than 10% weekly.[84] Runners with a step rate below 170 steps/minute should be encouraged to increase step rate by ~10% to decrease ground reaction forces.[21,85,86] As research highlights workload optimization, it is also important to monitor recovery, fatigue,[87] sleep,[88] pain,[2] and heart rate[89].

The running protocol is based on mileage, not time, as increased mileage has been associated with RRI, and as this is a more conservative approach.[84,90] We recommend a speed that feels comfortable to the runner, as changing speeds has been associated with increased loading rate.[91] To control for intensity, we recommend using RPE (11-13) throughout the plan. Before initiating each run, a dynamic warm-up should be performed. A walk-run protocol is used, beginning with a total of 0.5 miles (2 bouts of 0.25 miles) of running interspersed with walking. The protocol progresses total mileage to 2.48 miles running by level 22. Each workout should be performed three times a week for at least 1 week, and symptoms should be stable or improving to advance to the next level.[84]

Phases of progression

Detailed information regarding exercise prescription and recommendations for each phase are provided (Table 3). Patient report of ease of exercise performance, and meeting the objective criteria described below, indicates readiness for progression. It is important to note that a patient can be in different phases for different muscle groups (ex: phase 1 for PFM, phase 2 for hip), so clinicians should be mindful of higher-level exercises that activate multiple muscle groups (Table 5) and choose exercises that are appropriately challenging.

Phase I

The aim of this phase is to establish neuromuscular coordination, strength, endurance (muscular and cardiovascular), and control of the hip, trunk, pelvic floor, and lower extremity muscles. This phase may be prolonged for patients that experienced bedrest or complicated pregnancies, deliveries, or postpartum recovery.[92]

Intensity & Type: Exercises with low to moderate EMG activity (0-40% MVIC,[93] primarily isometric, open chain isotonic, and bilateral closed chain).

Cardio/general fitness: Low impact aerobic exercises including walking, cycling, elliptical, and swimming are ideal. It is recommended to progress by increasing time before intensity.

Goals and progression to the next phase: The patient should demonstrate good lumbopelvic control, proper breathing, and adequate abdominal engagement during all exercises. Monitor for Trendelenburg in single-limb stance. (Table 4). PFM strength should be adequate to avoid leakage during exercise. For the foot, the patient should demonstrate smooth quality of movement with no compensations such as medial or lateral deviations or rotations at the ankle. Running may be initiated (Phase II) if the patient can walk symptom free for 30 minutes (Table 3). As patients may compensate with other muscles while performing an exercise, it is important to query the patient on where they feel the exercise to ensure correct exercise performance.

Phase II

The aim of this phase is to continue to improve strength, coordination, and endurance of the muscles pertinent to running, as well as continue to progress cardiovascular endurance. Phase II introduces positional and stability changes to further challenge neuromuscular control.

Intensity & Type: The goal is moderate-high EMG (20-60% MVIC),[93] primarily achieved through isometric and isotonic exercises progressing from bilateral closed chain or unilateral open chain to unilateral closed chain. Challenging positions such as a narrow base of support or against gravity are utilized.

Cardio/general fitness: Running is introduced via a walk-run program starting with level 1 (weekly mileage 1.5 miles) up to level 5 (weekly mileage 2.2 miles). Cross-training may be progressed to increase cardiovascular endurance, with a goal of 30 minutes aerobic exercise per day. Running should only be performed 2-3 days per week with 48 hours of rest to monitor symptoms. Each running level should be performed for a minimum of one week (3 times).

Goals and progression to the next phase: The patient should report that exercises are no longer difficult and demonstrate good motor control and biomechanics with all exercises. No exacerbation of symptoms with running or strength exercises, abdominal wall doming, or musculoskeletal compensations should be noted.

Phase III

The aim of this phase is to build on muscular endurance, power, dynamic stability, and load management. Phase III progresses exercises in the standing position, bringing added challenge to the muscles against gravity, and includes low-level plyometrics.

Intensity & Type: The goal is high to very high EMG (>60% MVIC), [93] primarily achieved through resistance training and unstable surface variations (foam surface, ball, roller, disk etc.)

Cardio/general fitness: Running is progressed to level 6 (weekly mileage 2.4 miles) through level 10 (weekly mileage 3.5 miles). Each level should be performed for a minimum of one week (3 times). If the running workout takes <45 minutes total and the runner is eager to exercise longer, walking or a low impact exercise choice can be added to reach a total of 45 minutes.

Goals and progression to the next phase: The patient should report that the exercises are no longer challenging and demonstrate good motor control and biomechanics with all exercises. No exacerbation of symptoms with running or strength exercises, abdominal wall doming, or musculoskeletal compensations should be noted.

Phase IV

The aim of this phase is to return to full participation in running. Exercises challenging muscular endurance and power are progressed by adding increased resistance and changing surface stability. Strength exercises and plyometrics are progressed to single leg to increase load tolerance and strength in running specific positions. Compound movements with higher resistance are also recommended. It is imperative to use weights for resistance as running forces can be up to 5 times a runner's body weight.[94]

Intensity& Type: The goal continues to be high to very high EMG (>60% MVIC),[93] primarily achieved through resistance training and unstable surface variations (foam surface, ball, roller, disk etc.).

Cardio/general fitness: The goal is to increase cardiovascular endurance to match the running goals of the postpartum patient. The running progression begins at level 11 (weekly mileage 3.80 miles) and continues until desired goals are reached. At level 18, the amount of walking decreases, while the amount of running in an interval increases. In levels 18-21, length of running interval increases but total mileage is held constant. Some runners may end at level 20 with goals of running 2 miles, for others the progression may continue after level 22 (weekly mileage 7.43 miles). We recommend the runner conservatively increase weekly mileage (only 10% per week).[84] If the runner wishes to add speed work or tempo runs after level 22, running mileage should be held constant as other variables are manipulated. Workouts should be performed at least three times before progressing.

Goals and progression: At the end of this phase the postpartum runner has been symptom free and running up to 2.48 miles per run. If musculoskeletal or pelvic symptoms appear or reoccur, the runner is advised to return to an earlier phase (figure 1). If symptom free, it is recommended that the runner continues to advance strength while advancing or maintaining total weekly running mileage.

Conclusion

Up to 35% of postpartum runners report pain and 19% report incontinence 2 years post childbirth.[2] Although studies investigating this pain and incontinence in postpartum runners is sparse, clinicians recognize several musculoskeletal impairments that may contribute to postpartum running-related pain.[3] Research based guidelines to assist postpartum runners in resuming running are limited. Therefore, this clinical commentary proposes a comprehensive four phase progression, based on evidence where possible, for clinicians working with this population. Clinicians should ensure that a patient is medically cleared and able to walk 30-minutes symptom free prior to beginning running in this protocol. This protocol is not exhaustive; however, it provides evidence and expert opinions on how to progressively rehabilitate a postpartum runner. Clinical judgment should be exercised with each patient, and modification of the protocol based on patient-specific exam findings is encouraged. Future studies should validate this protocol in postpartum runners initiating or returning to running.

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Appendix D: Delphi Survey Consent and Survey Round I

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Common pain characteristic and musculoskeletal impairments in postpartum runners: A Delphi survery

Document Version 1; dated November 17, 2017

- All participants will complete the attached set of survey questions regarding pain characteristics and musculoskeletal impairments in the postpartum runner
- The exact number of questions is 17. Twelve questions on pain characteristics and musculoskeletal impairments and 5 demographic questions.
- This survey will be electronically delivered through a Qualtrics panel with individualized links, to allow for deletion of round I and round II responses if participants drop out later in the study.
- Responses are stored on a secure, web-based server that is only accessible to the primary investigator (Shefali Christopher). Data will be de-identified after round III responses have been reported, before analysis by Shefali Christopher.
- Qualtrics is the electronic survey platform that will be utilized. Qualtrics is commonly used for this type of survey research. Qualtrics security statement can be found here: http://www.qualtrics.com/security-statement/
- An electronic version of the survey can be viewed here: http://elon.co1.qualtrics.com/jfe/form/SV_9LfZwDtKpiyFwlD

Common pain characteristics and musculoskeletal impairments in the postpartum runner: A Delphi Survey

You are invited to participate in the research project identified above which is being conducted by Shefali Christopher, PT, DPT, SCS, LAT, ATC, Assistant professor at Elon University and PhD Candidate from the School of Health Sciences at the University of Newcastle, A/Prof Suzanne Snodgrass and Prof Chad Cook. The research is part of Shefali Christopher's PhD studies at the University of Newcastle, supervised by Suzanne Snodgrass from the School of Health Sciences at University of Newcastle and Prof Chad Cook from Duke University.

Why is the research being done?

To develop a consensus on pain characteristics and musculoskeletal impairments most commonly reported in the postpartum running population.

Who can participate in the research?

We have identified your email address through your involvement in conferences or journal publications as an expert in the rehabilitation of the postpartum or female runner.

What would you be asked to do?

This research is based on the principles of the Delphi method, which is a method for consensus building by using a series of questionnaires. In the first round you will be given a series of questions about pain characteristics and musculoskeletal impairments in postpartum women returning to running. In the second round you will be supplied with the group responses, along with a version of the questionnaire where you are given the opportunity to revise your responses in view of the findings of the group. A general consensus is achieved when there is little disagreement between the respondents. Typically, three rounds of questionnaires are completed (including this one)

The questionnaire takes approximately fifteen minutes to complete and you will most likely be required to complete a questionnaire twice over the next 6-8 weeks. Each subsequent questionnaire should take less time due to the process of reaching consensus.

What choice do you have?

Participation in this research is entirely your choice. Only those people who give their informed consent will be included in the project. Whether or not you decide to participate, your decision will not disadvantage you. If you do decide to participate, you may withdraw from the project at any time.

How much time will it take?

The questionnaire should take about 10-15 minutes to complete.

What are the risks and benefits of participating?

There are no anticipated risks associated with participating in this research.
While there are no anticipated benefits to you personally in participating in this

research, the findings will contribute to the available literature on the subject which may lead to indirect benefits for your practice and knowledge as a physical therapist and your future patients.

How will your privacy be protected?
The collected data will be stored securely on password protected computers of the research team. Data will be retained for a minimum of 5 years as per University of Newcastle policy provisions. The data file will be deleted at that time. Due to the nature of a Delphi survey the response you provide will be identifiable only to one investigator (Shefali Christopher). Only group level responses will be reported. The survey will be stored on a password protected server through Qualtrics software. This company is a common vendor used for survey research and has significant data protection policies in place. Please see the Qualtrics security statement here: http://www.qualtrics.com/security-statement/. Following the data collection period, the data will be downloaded from the Qualtrics server and securely stored on the password-protected computers that are only accessible by the research team. The computer and your data will be within locked-offices of the research team. Your results will be destroyed in accordance with University of Newcastle and Elon University policies. To the extent allowed by law, we limit the viewing of your personal information to people who have to review it. The institutional review board (IRB), Elon University and the University of Newcastle (Australia), and other representatives of these organizations may inspect and copy your information.

How will the information collected be used?
The collected data will contribute towards Shefali Christopher's PhD thesis and may be presented in peer-reviewed publications or conferences. You can access a copy of the published report by visiting this webpage: https://www.elon.edu/e/directory/profile.html?user=schristopher3 after July 2018. Individual participants will not be named or identified in any reports arising from the project. Only group level responses will be reported.

What do you need to do to participate?
Please read this Information Statement and be sure you understand its contents before you consent to participate. If there is anything you do not understand, or you have questions, please contact the research team. If you would like to participate, please click the button below. Completion and submission/return of this online survey will be taken as your consent to participate.

Further information
If you would like further information, please contact the research team below

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Complaints about this research
This project has been approved by the University's Newcastle's Human Research Ethics Committee, Approval NoXXXXX and Elon University's Institutional Review Board (#18-130)
Should you have concerns about your rights as a participant in this research, or you have a complaint about the manner in which the research is conducted, it may be given to the researcher, or, if an independent person is preferred, to the Human Research Ethics Officer, Research Office, The Chancellery, The University of Newcastle, University Drive, Callaghan NSW 2308, Australia, telephone +61 (02) 49216333, email Human-Ethics@newcastle.edu.au, or Stephen Bailey Elon IRB chair, telephone (336) 278-6346 or e-mail baileys@elon.edu.

Q1. For the purpose of this survey, we define postpartum runner as any female participating in running within 2 years of giving birth to a baby.

What are the most common strength impairments observed in postpartum runners?

____

____

____

Q2. What are the most common range of motion impairments observed in postpartum runners?

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____

____

Q3. What are the most common alignment impairments observed in postpartum runners?

____

____

____

Q4. What are the most common flexibility impairments observed in postpartum runners?

____

____

____

Q5. What do you believe are the most common risk factors for pain in postpartum runners?

____

____

____

Q6. For the purpose of this survey we define postpartum runner as any female participating in running within 2 years of giving birth to a baby.

Please choose the pain characteristics most commonly described by postpartum runners:

	Strongly not representative of postpartum runners	Not representative of postpartum runners	Representative of postpartum runners	Strongly representative of postpartum runners
Throbbing	○	○	○	○
Shooting	○	○	○	○
Stabbing	○	○	○	○
Sharp	○	○	○	○
Cramping	○	○	○	○
Gnawing	○	○	○	○
Hot/Burning	○	○	○	○
Aching	○	○	○	○
Heavy	○	○	○	○
Tender	○	○	○	○
Splitting	○	○	○	○
Tiring/exhausting	○	○	○	○
Sickening	○	○	○	○
Fearful	○	○	○	○
Punishing/Cruel	○	○	○	○

Q7. For the purpose of this survey, we define postpartum runner as any female participating in running within 2 years of giving birth to a baby.

Please choose the most common items reported by postpartum runners with pain when you ask “What increases your pain?”

	Strongly does not increase	Does not increase	Increases	Strongly increases
Alcohol	○	○	○	○
Stimulants eg. Coffee	○	○	○	○
Eating	○	○	○	○
Heat/cold	○	○	○	○
Weather changes	○	○	○	○
Pressure	○	○	○	○
Movement	○	○	○	○
No movement	○	○	○	○
Sleep/rest	○	○	○	○
Distraction	○	○	○	○
Urination/defecation	○	○	○	○
Tension	○	○	○	○
Bright lights	○	○	○	○
Running > 5 miles	○	○	○	○
Running > 10 miles	○	○	○	○
Running > 15miles	○	○	○	○

Running with stroller	○	○	○	○
Running without stroller	○	○	○	○
Shoes	○	○	○	○
Delivery type eg. vaginal	○	○	○	○
Running surface	○	○	○	○
Sacroiliac belt	○	○	○	○
Strength training	○	○	○	○
Stretching/rolling/yoga	○	○	○	○
Speed of run	○	○	○	○
Fatigue	○	○	○	○
Massage	○	○	○	○
Loud noises	○	○	○	○
Going to work	○	○	○	○
Other	○	○	○	○

Q8. For the purpose of the survey, we define postpartum runner as any female participating in running within 2 years of giving birth to a baby.

Please chose the pain characteristics most commonly described by postpartum runners when you ask “What decreases your pain?

	Strongly does not decrease	Does not decrease	Decreases	Strongly decreases
Alcohol	○	○	○	○
Stimulants eg. Coffee	○	○	○	○
Eating	○	○	○	○
Heat/Cold	○	○	○	○
Weather changes	○	○	○	○
Pressure	○	○	○	○
Movement	○	○	○	○
No movement	○	○	○	○
Sleep/rest	○	○	○	○
Distraction	○	○	○	○
Urination/defecation	○	○	○	○
Tension	○	○	○	○
Bright lights	○	○	○	○
Running > 5 miles	○	○	○	○

Running > 10 miles	○	○	○	○
Running > 15 miles	○	○	○	○
Running with a stroller	○	○	○	○
Running without a stroller	○	○	○	○
Shoes	○	○	○	○
Delivery type eg. Vaginal	○	○	○	○
Running Surface	○	○	○	○
Sacroiliac belt	○	○	○	○
Strength training	○	○	○	○
Stretching/ rolling/ yoga	○	○	○	○
Speed of run	○	○	○	○
Fatigue	○	○	○	○
Massage	○	○	○	○
Loud Noises	○	○	○	○
Going to work	○	○	○	○
Other _______	○	○	○	○

Q9. For the purpose of this survey, we define postpartum runner as any female participating in running within 2 years of giving birth to a baby.

Please rank the most common words reported by postpartum runners with pain representing pain intensity when you ask “how strong is your pain?”

	1 (most common)	2	3	4	5 (least common)
Mild	○	○	○	○	○
Discomforting	○	○	○	○	○
Distressing	○	○	○	○	○
Horrible	○	○	○	○	○
Excruciating	○	○	○	○	○

Q10 Please rank the most common words reported by postpartum runners with pain representing pain intensity when you ask “how strong is your pain at worst?”

	1 (most common)	2	3	4	5 (least common)
Mild	○	○	○	○	○
Discomforting	○	○	○	○	○
Distressing	○	○	○	○	○
Horrible	○	○	○	○	○
Excruciating	○	○	○	○	○

Q11 Please rank the most common words reported by postpartum runners with pain representing pain intensity when you ask “how strong is your pain at its least?”

	1 (most common)	2	3	4	5 (least common)
Mild	○	○	○	○	○
Discomforting	○	○	○	○	○
Distressing	○	○	○	○	○
Horrible	○	○	○	○	○
Excruciating	○	○	○	○	○

Q12. Do you have any further comments or thoughts on the clinical presentation of postpartum runners?

____

____

____

Q13. What is your age?

○ <20

○ 20-30

○ 30-40

○ 40-50

○ 50-60

○ >60

Q14. What gender do you identify with?

- ○ Female
- ○ Male
- ○ Other

Q15. How many years have you been in clinical practice?

- ○ None
- ○ 0-5
- ○ 5-10
- ○ 10-15
- ○ 15-20
- ○ 20 or more

Q16. How many years have you been in research?

- ○ None
- ○ 0-5
- ○ 5-10
- ○ 10-15
- ○ 15-20
- ○ 20 or more

Q17. Please list any certifications other than physical therapist/ Physiotherapist. Eg. Doctor of physical therapy, Women's health certified specialist.

____

Thank you message displayed to the respondents upon completion.

Thank you for your response. Your response will be utilized to enhance health care providers' understanding of the clinical presentation of postpartum runners and inform future development of surveys of postpartum pain.

If you have any questions regarding this survey please contact Assistant Professor Shefali Christopher PT, DPT, SCS, LAT, ATC at 336-278-6416 or schristopher3@elon.edu.

Appendix E: Delphi Round II Survey

Default Question Block

Delphi Survey Round II: Common pain characteristics and musculoskeletal impairments in the postpartum runner

Welcome to round II of the Delphi Survey. You are invited to participate in the research project identified above which is being conducted by Shefali Christopher, PT, DPT, SCS, LAT, ATC, Assistant professor at

Elon University and Ph.D. Candidate from the School of Health Sciences at the University of Newcastle, A/Prof Suzanne Snodgrass and Prof Chad Cook. The research is part of Shefali Christopher's Ph.D. studies at the University of Newcastle, supervised by Suzanne Snodgrass from the School of Health Sciences at the University of Newcastle and Prof Chad Cook from Duke University.

Why is the research being done?

To develop a consensus on pain characteristics and musculoskeletal impairments most commonly reported in the postpartum running population.

Who can participate in the research?

We have identified your email address through your involvement in conferences or journal publications as an expert in the rehabilitation of the postpartum or female runner.

What choice do you have?

Participation in this research is entirely your choice. Only those people who give their informed consent will be included in the project. Whether or not you decide to participate, your decision will not disadvantage you. If you do decide to participate, you may withdraw from the project up until the point of submitting the final survey.

How much time will it take?

This second round you will be supplied with the group responses, where you are given the opportunity to revise your responses in view of the findings of the group. A general consensus is achieved when there is little disagreement between the respondents. Typically, three rounds of questionnaires are completed (including this one)

The questionnaire takes approximately fifteen minutes to complete and you will most likely be required to complete a questionnaire twice over the next 6-8 weeks. Each subsequent questionnaire should take less time due to the process of reaching consensus.

What are the risks and benefits of participating?

There are no anticipated risks associated with participating in this research.

While there are no anticipated benefits to you personally in participating in this research, the findings will contribute to the available literature on the subject which may lead to indirect benefits for your practice and knowledge as a physical therapist and your future patients.

How will your privacy be protected?

The collected data will be stored securely on password protected computers of the research team. Data will be retained for a minimum of 5 years as per University of Newcastle policy provisions. The data file will be deleted at that time. Due to the nature of a Delphi survey the response you provide will be identifiable only to one investigator (Shefali Christopher). Only group level responses will be reported. The survey will be stored on a password protected server through Qualtrics software. This company is a common vendor used for survey research and has significant data protection policies in place. Please see the Qualtrics security statement here: http://www.qualtrics.com/security-statement/. Following the data collection period, the data will be downloaded from the Qualtrics server and securely stored on the password-protected computers that are only accessible by the research team. The computer and your data will be within locked-offices of the research team. Your results will be destroyed in accordance with University of Newcastle and Elon University policies. To the extent allowed by law, we limit the viewing of your personal information to people who have to review it. The institutional review board (IRB), Elon University and the University of Newcastle (Australia), and other representatives of these organizations may inspect and copy your information.

How will the information collected be used?

The collected data will contribute towards Shefali Christopher's Ph.D. thesis and may be presented in peer-reviewed publications or conferences. You can access a copy of the published report by visiting this webpage: https://www.elon.edu/e/directory/profile.html?user=schristopher3 after July 2018. Individual participants will not be named or identified in any reports arising from the project. Only group level responses will be reported.

What do you need to do to participate?

Please read this Information Statement and be sure you understand its contents before you consent to participate. If there is anything you do not understand, or you have questions, please contact the research team. If you would like to participate, please click the button below. Completion and submission/return of this online survey will be taken as your consent to participate.

Further information

If you would like further information, please contact the research team below

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Complaints about this research

This project has been approved by the University's Newcastle's Human Research Ethics Committee, Approval NoH 2018-0008 and Elon University's Institutional Review Board (#18-130)

Should you have concerns about your rights as a participant in this research, or you have a complaint about the manner in which the research is conducted, it may be given to the researcher, or, if an independent person is preferred, to the Human Research Ethics Officer, Research Services, NIER Precinct, The University of Newcastle, University Drive, Callaghan NSW 2308, Australia, telephone (02) 4921 6333, email Human-Ethics@newcastle.edu.au, or Stephen Bailey Elon IRB chair, telephone (336) 278-6346 or e-mail baileys@elon.edu.

Q1.

For the purpose of this survey, we define postpartum runner as any female participating in running within 2 years of giving birth to a baby.

Please score the following **strength** impairments for their contribution to pain in the postpartum runner. Feel free to comment in the boxes below on any entry as needed.

	Strongly Disagree	Disagree	Agree	Strongly agree
Pelvic Floor Weakness (i.e. levator ani, obturator internus etc.)	○	○	○	○
Abdominal weakness (Transverse abdominus, Rectus Abdominus, Obliques)	○	○	○	○
Lumbar extensor muscle weakness (i.e. paraspinals, erector spinae)	○	○	○	○

	Strongly Disagree	Disagree	Agree	Strongly agree
Hip abductor weakness (i.e. glute max, medius, minimus etc)	○	○	○	○
Hip adductor muscle weakness (i.e. adductor longus, brevis, magnus etc.)	○	○	○	○
Hip rotator weakness (i.e. piriformis, glute max, quadratus femoris etc.)	○	○	○	○
Hip extensor weakness (i.e. glute max)	○	○	○	○
Pectoralis Major/ Minor Weakness	○	○	○	○
Knee extensor weakness (i.e quadriceps)	○	○	○	○
Foot intrinsic muscle weakness (Dorsal interossei, flexor/adductor hallicus etc.)	○	○	○	○

	Strongly Disagree	Disagree	Agree	Strongly agree
Scapular stabilizer weakness (i.e. serratus anterior, rhomboids etc.	O	O	O	O

Q2. Please score the following **flexibility** impairments for their contribution to pain in the postpartum runner. Feel free to comment in the boxes below on any entry as needed.

	Strongly disagree	Disagree	Agree	Strongly agree
Laxity in abdominal wall	O	O	O	O
Tight cervical extensors (i.e. suboccipital)	O	O	O	O
Tight pectoralis muscles	O	O	O	O
Tight lumbar extensors (i.e. erector spinae)	O	O	O	O
Tight hip flexors (i.e. iliospoas)	O	O	O	O
Tight hip adductors	O	O	O	O

	Strongly disagree	Disagree	Agree	Strongly agree
Tight hip external rotators	O	O	O	O
Tight hip internal rotators	O	O	O	O
Tight IT band	O	O	O	O
Tight hamstrings	O	O	O	O
Tight rectus femoris	O	O	O	O
Tight heel cord musculature	O	O	O	O

Q3. Please score the following **range of motion** impairments for their contribution to pain in the postpartum runner. Feel free to comment in the boxes below on any entry as needed.

	Strongly Disagree	Disagree	Agree	Strongly agree
Hip external rotation restriction	O	O	O	O
Hip internal rotation restriction	O	O	O	O

	Strongly Disagree	Disagree	Agree	Strongly agree
Hip extension restriction	○	○	○	○
Hip flexion restriction	○	○	○	○
Thoracic flexion restriction	○	○	○	○
Thoracic extension restriction	○	○	○	○
Thoracic rotation restriction	○	○	○	○
Thoracic side flexion restriction	○	○	○	○
Lumbar flexion restriction	○	○	○	○
Lumbar extension restriction	○	○	○	○
Lumbar side flexion restriction	○	○	○	○

	Strongly Disagree	Disagree	Agree	Strongly agree
Knee flexion restriction	○	○	○	○
Knee extension restriction	○	○	○	○
Ankle dorsiflexion restriction	○	○	○	○
Shoulder flexion restriction (i.e. pectoralis major/ minor)	○	○	○	○
Excessive counternutation relation to innominant (i.e. Anterior pelvic tilt)	○	○	○	○
Generally hypermobile, no restrictions	○	○	○	○

Q4. Please score the following **alignment** impairments for their contribution to pain in the postpartum runner. Feel free to comment in the boxes below on any entry as needed.

	Strongly disagree	Disagree	Agree	Strongly agree

	Strongly disagree	Disagree	Agree	Strongly agree
Thoracic kyphosis (i.e rounded shoulders)	O	O	O	O
Increased lumbar lordosis	O	O	O	O
Posterior pelvic tilt	O	O	O	O
Anterior pelvic tilt	O	O	O	O
Sway back	O	O	O	O
Tredenlenburg sign	O	O	O	O
Dynamic knee valgus	O	O	O	O
Genu valgum	O	O	O	O
Genu recurvatum	O	O	O	O
Pubic symphysis upslip/downslip	O	O	O	O

	Strongly disagree	Disagree	Agree	Strongly agree
Innominant upslip/downslip	O	O	O	O
Sacral obliquity	O	O	O	O
Innominant outflare	O	O	O	O
Leg length discrepancy-Functional	O	O	O	O
Leg length discrepancy-Structural	O	O	O	O
Over pronation	O	O	O	O

Q5. Please score the following **common risk factors** for their contribution to pain in the postpartum runner. Feel free to comment in the boxes below on any entry as needed.

	Strongly disagree	Disagree	Agree	Strongly agree
Altered running mechanics (i.e. dynamic valgus, tredenlenburg gait)	O	O	O	O

	Strongly disagree	Disagree	Agree	Strongly agree
Global laxity	○	○	○	○
Muscular imbalance	○	○	○	○
Lumbopelvic muscle weakness (i.e. pelvic floor)	○	○	○	○
Poor lumbopelvic control	○	○	○	○
Hip weakness	○	○	○	○
Poor torso rotation	○	○	○	○
Incontinence	○	○	○	○
Pelvic floor pain	○	○	○	○
Hip pain	○	○	○	○
Knee pain	○	○	○	○
Foot pain	○	○	○	○

	Strongly disagree	Disagree	Agree	Strongly agree
Hip extensor muscle activation	○	○	○	○
Lumbopelvic instability (i.e. SIJ)	○	○	○	○
Hip instability	○	○	○	○
Decreased exercise tolerance	○	○	○	○
Too much, too soon	○	○	○	○
Diastasis recti	○	○	○	○
Increased Q angle	○	○	○	○
Multiparity	○	○	○	○
Increased BMI	○	○	○	○
Age	○	○	○	○
History of running injury	○	○	○	○

	Strongly disagree	Disagree	Agree	Strongly agree
Chronic pain history	○	○	○	○
Pain during pregnancy	○	○	○	○
Poor Sleep quality	○	○	○	○
Chronic fatigue	○	○	○	○
Increased life stressors	○	○	○	○
Labor (i.e. duration or type)	○	○	○	○
Trauma to pelvic floor (i.e. Episiotomy, instrumented birth)	○	○	○	○
Lack of postpartum education from OB GYN	○	○	○	○
Runner body type (i.e. ectomorphic, endomorphic etc.)	○	○	○	○

	Strongly disagree	Disagree	Agree	Strongly agree
Forward head and increased kyphosis	○	○	○	○
Caretaking posture (i.e. breastfeeding, car seat manipulation, diaper changing)	○	○	○	○

Appendix F: Delphi Round III Survey

Default Question Block

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

ELON UNIVERSITY | DEPARTMENT OF Physical Therapy Education

Common pain characteristics and musculoskeletal impairments in the postpartum runner: A Delphi Survey

You are invited to participate in the research project identified above which is being conducted by Shefali Christopher, PT, DPT, SCS, LAT, ATC, Assistant professor at Elon University and Ph.D. Candidate from the School of Health Sciences at the University of Newcastle, A/Prof Suzanne Snodgrass and Prof Chad Cook. The research is part of Shefali Christopher's Ph.D. studies at the University of Newcastle, supervised by Suzanne Snodgrass from the School of Health Sciences at the University of Newcastle and Prof Chad Cook from Duke University.

Why is the research being done?

To develop a consensus on pain characteristics and musculoskeletal impairments most commonly reported in the postpartum running population.

Who can participate in the research?

We have identified your email address through your involvement in conferences or journal publications as an expert in the rehabilitation of the postpartum or female runner.

What choice do you have?

Participation in this research is entirely your choice. Only those people who give their informed consent will be included in the project. Whether or not you decide to participate, your decision will not disadvantage you. If you do decide to participate, you may withdraw from the project up until the point of submitting the final survey.

How much time will it take?

This research is based on the principles of the Delphi method, which is a method for consensus building by using a series of questionnaires. In the first round you will be given a series of questions about pain characteristics and musculoskeletal impairments in postpartum women returning to running. In the second round you will be supplied with the group responses, along with a version of the questionnaire where you are given the opportunity to revise your responses in view of the findings of the group. A general consensus is achieved when there is little disagreement between the respondents. Typically, three rounds of questionnaires are completed (including this one)

The questionnaire takes approximately fifteen minutes to complete and you will most likely be required to complete a questionnaire twice over the next 6-8 weeks. Each subsequent questionnaire should take less time due to the process of reaching consensus.

What are the risks and benefits of participating?

There are no anticipated risks associated with participating in this research.

While there are no anticipated benefits to you personally in participating in this research, the findings will contribute to the available literature on the subject which may lead to indirect benefits for your practice and knowledge as a physical therapist and your future patients.

How will your privacy be protected?

The collected data will be stored securely on password protected computers of the research team. Data will be retained for a minimum of 5 years as per University of Newcastle policy provisions. The data file will be deleted at that time. Due to the nature of a Delphi survey, the response you provide will be identifiable only to one investigator (Shefali Christopher). Only group level responses will be reported. The survey will be stored on a password protected server through Qualtrics software. This company is a common vendor used for survey research and has significant data protection policies in place. Please see the Qualtrics security statement here: http://www.qualtrics.com/security-statement/. Following the data collection period, the data will be downloaded from the Qualtrics server and securely stored on the password-protected computers that are only accessible by the research team. The computer and your data will be within locked-offices of the research team. Your results will be destroyed in accordance with University of Newcastle and Elon University policies. To the extent allowed by law, we limit the viewing of your personal information to people who have to review it. The IRB, Elon University and the University of Newcastle (Australia), and other representatives of these organizations may inspect and copy your information.

How will the information collected be used?

The collected data will contribute towards Shefali Christopher's Ph.D. thesis and may be presented in peer-reviewed publications or conferences. You can access a copy of the published report by visiting this webpage: https://www.elon.edu/e/directory/profile.html?user=schristopher3 after July 2018. Individual participants will not be named or identified in any reports arising from the project. Only group level responses will be reported.

What do you need to do to participate?

Please read this Information Statement and be sure you understand its contents before you consent to participate. If there is anything you do not understand, or you have questions, please contact the research team. If you would like to participate, please click the button below. Completion and submission/return of this online survey will be taken as your consent to participate.

Further information

If you would like further information, please contact the research team below

Shefali Christopher
Assistant Professor, Elon University
schristopher3@elon.edu

Suzanne Snodgrass
Associate Professor, University of Newcastle
Suzanne.Snodgrass@newcastle.edu.au

Chad Cook
Professor, Duke University
Chad.cook@duke.edu

Complaints about this research

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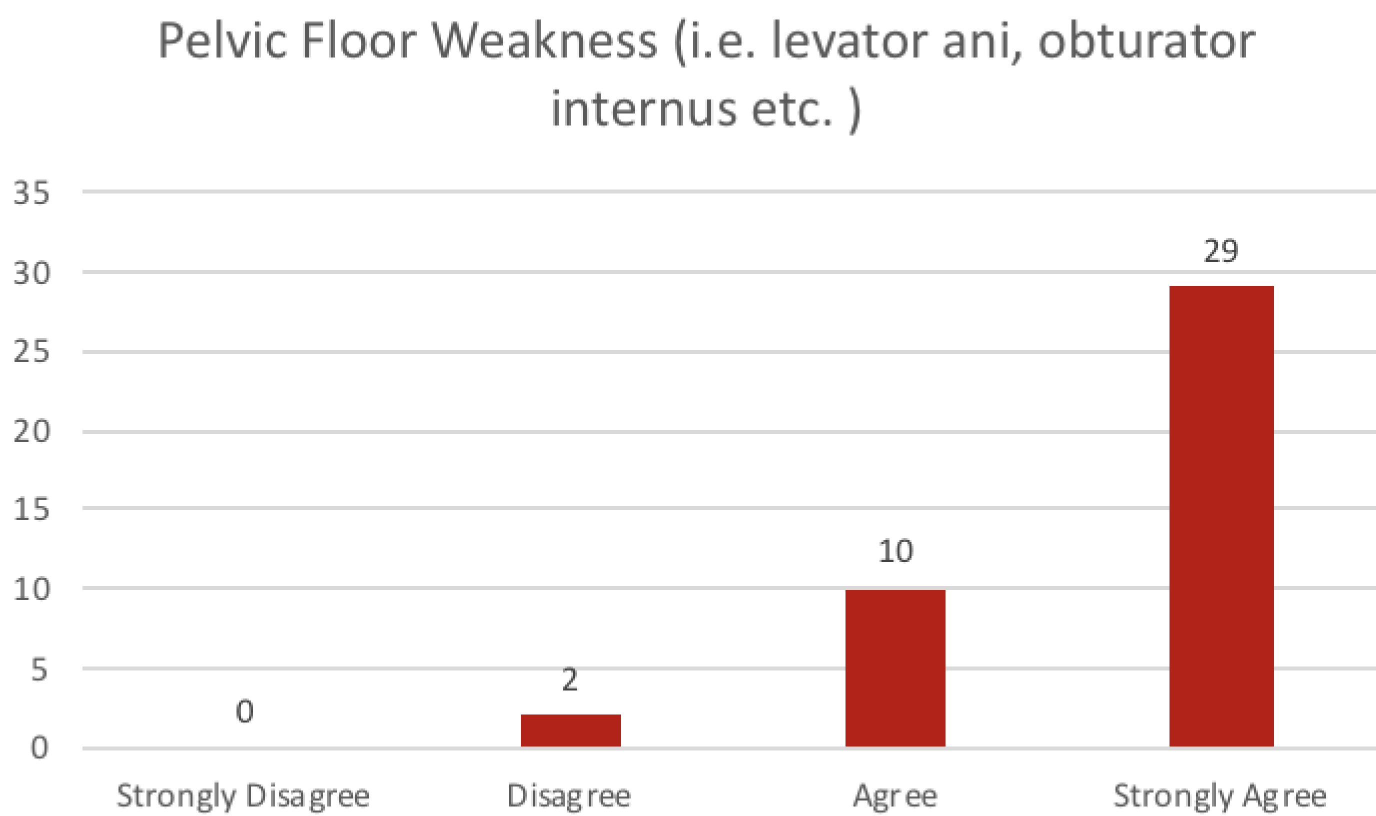
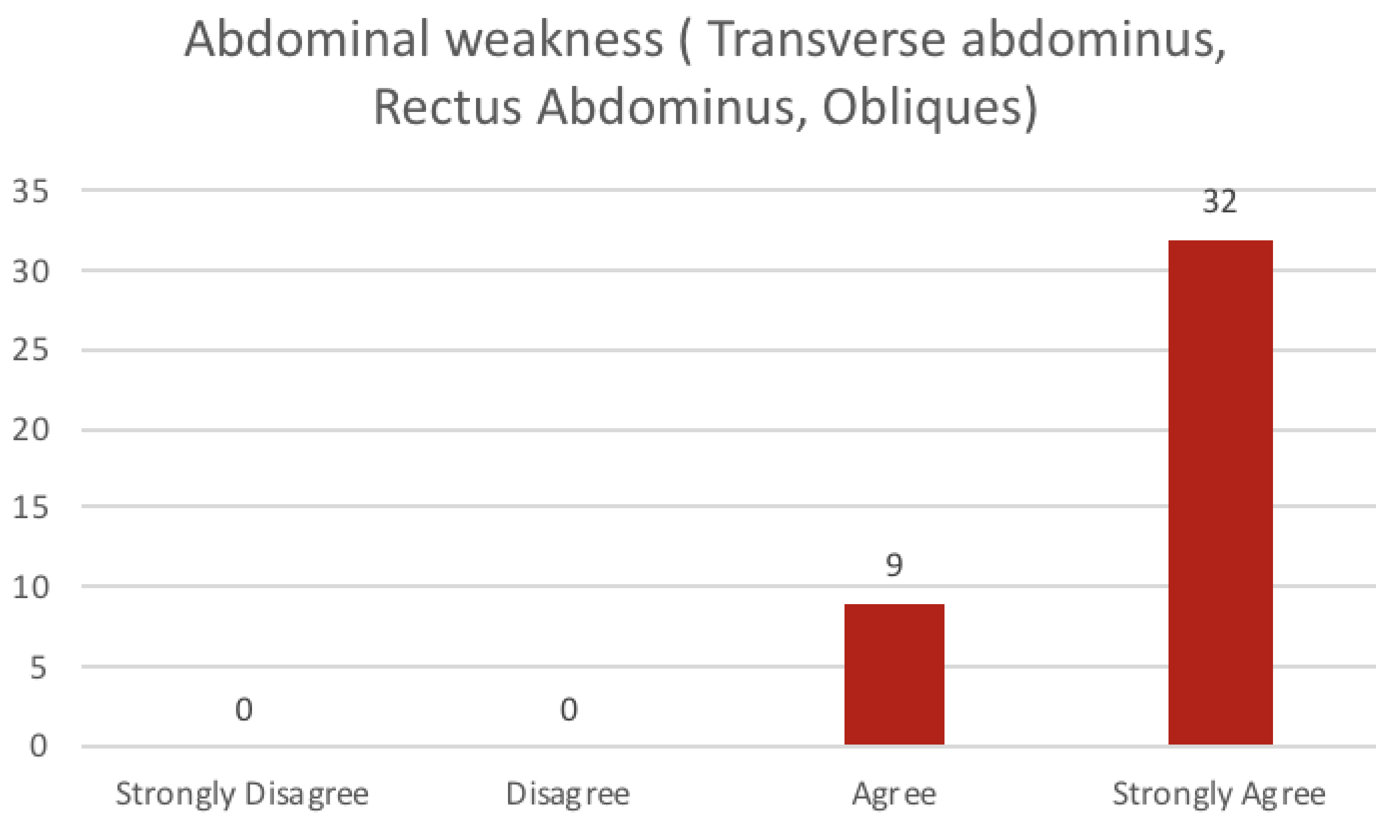
For the purpose of this survey, we define postpartum runner as any female participating in running within 2 years of giving birth to a baby.

In this round of the Delphi study, you will be presented with the summative results from all participants in round II and will be asked to score the same questions again.

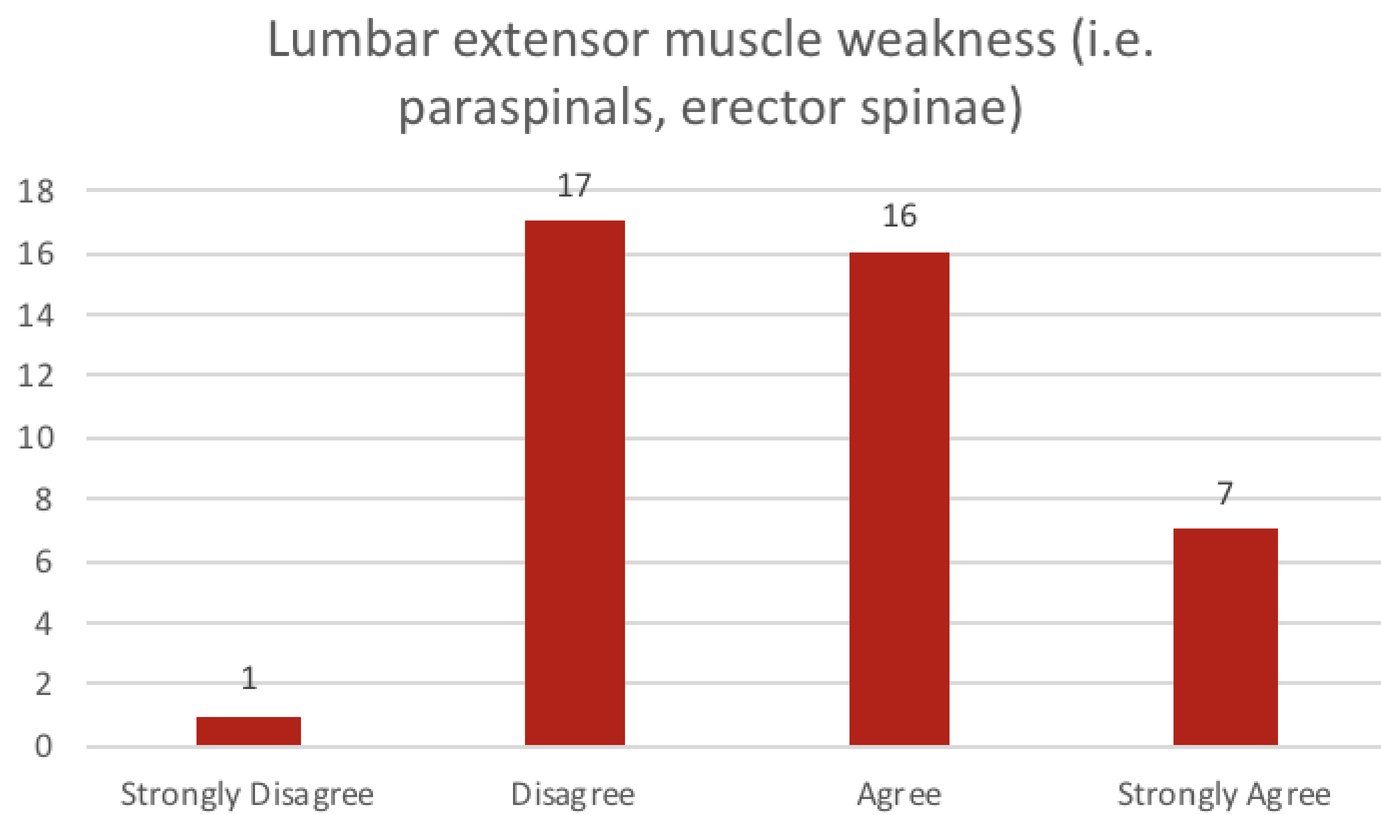
For each of the following strength impairments please indicate whether or not you agree that it contributes to pain in the postpartum runner.



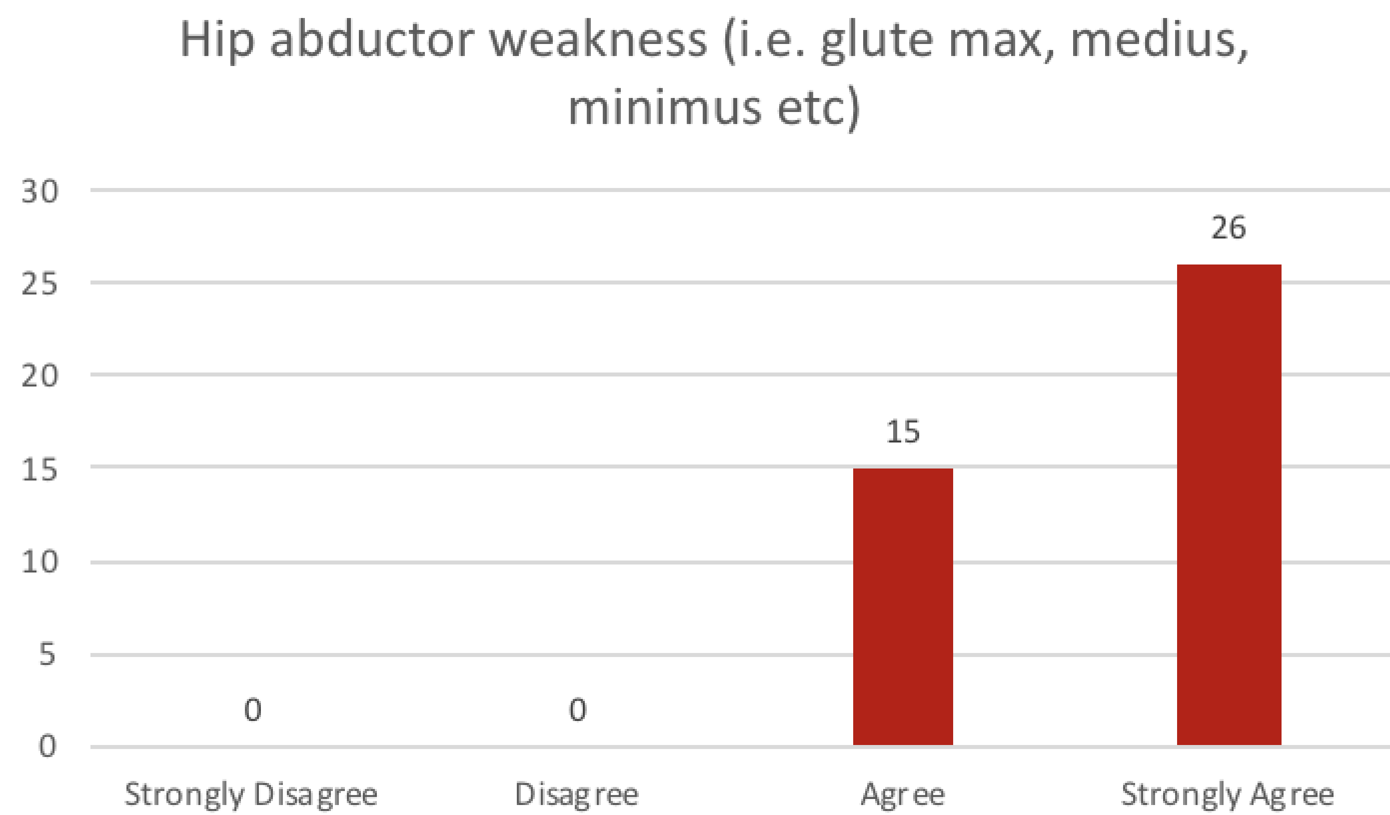
	Strongly Disagree	Disagree	Agree	Strongly Agree
Pelvic Floor weakness	O	O	O	O



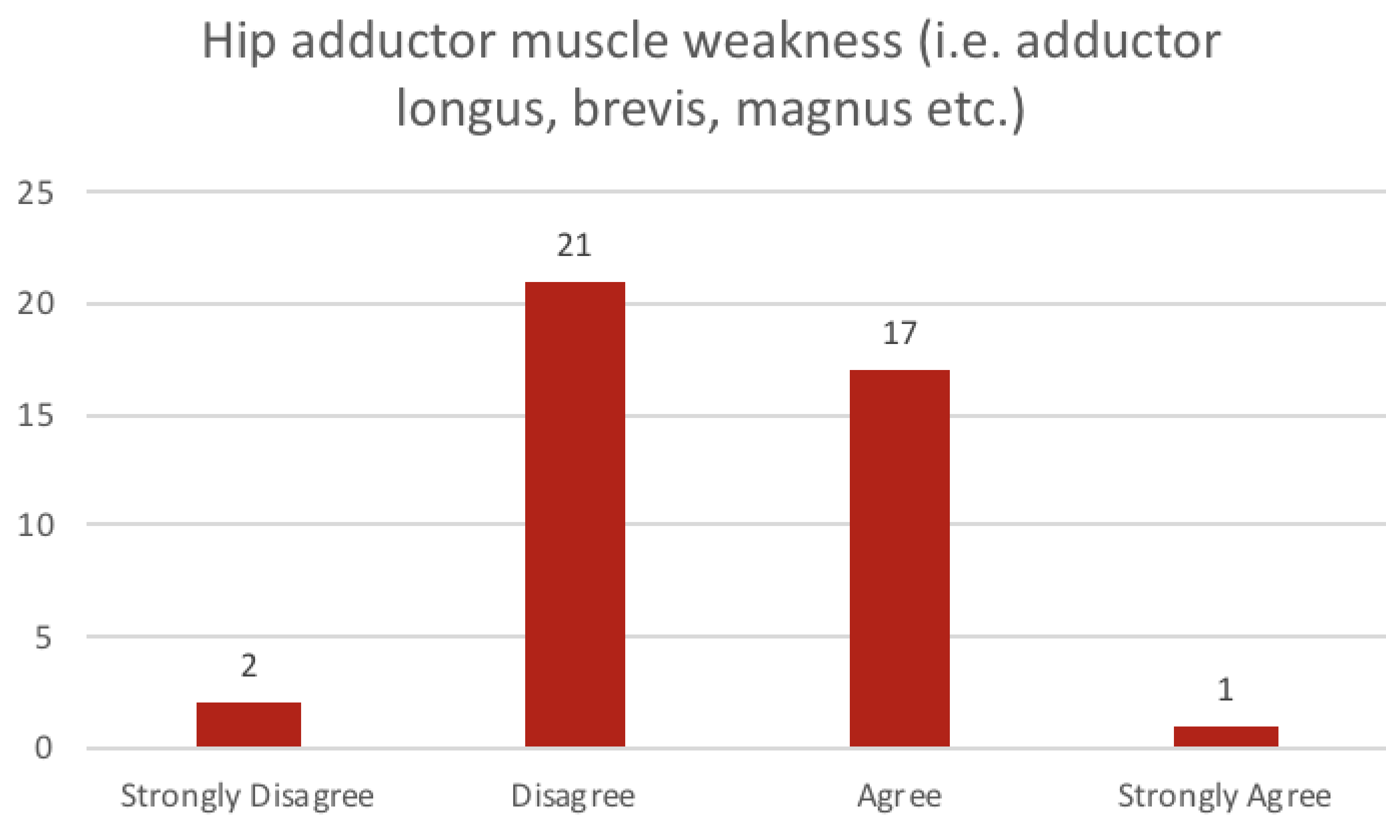
	Strongly Disagree	Disagree	Agree	Strongly Agree
Abdominal weakness	O	O	O	O



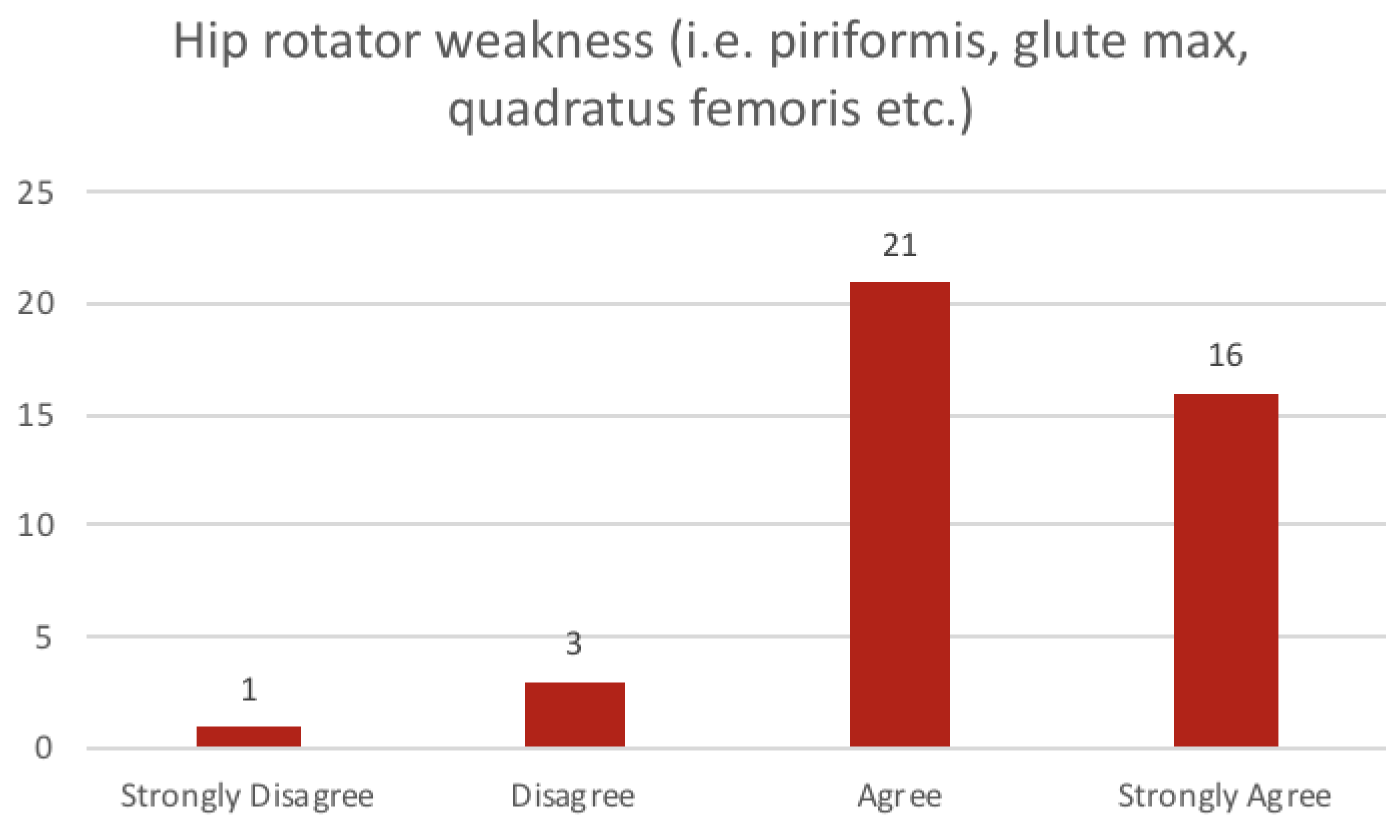
	Strongly Disagree	Disagree	Agree	Strongly Agree
Lumbar extensor weakness	○	○	○	○



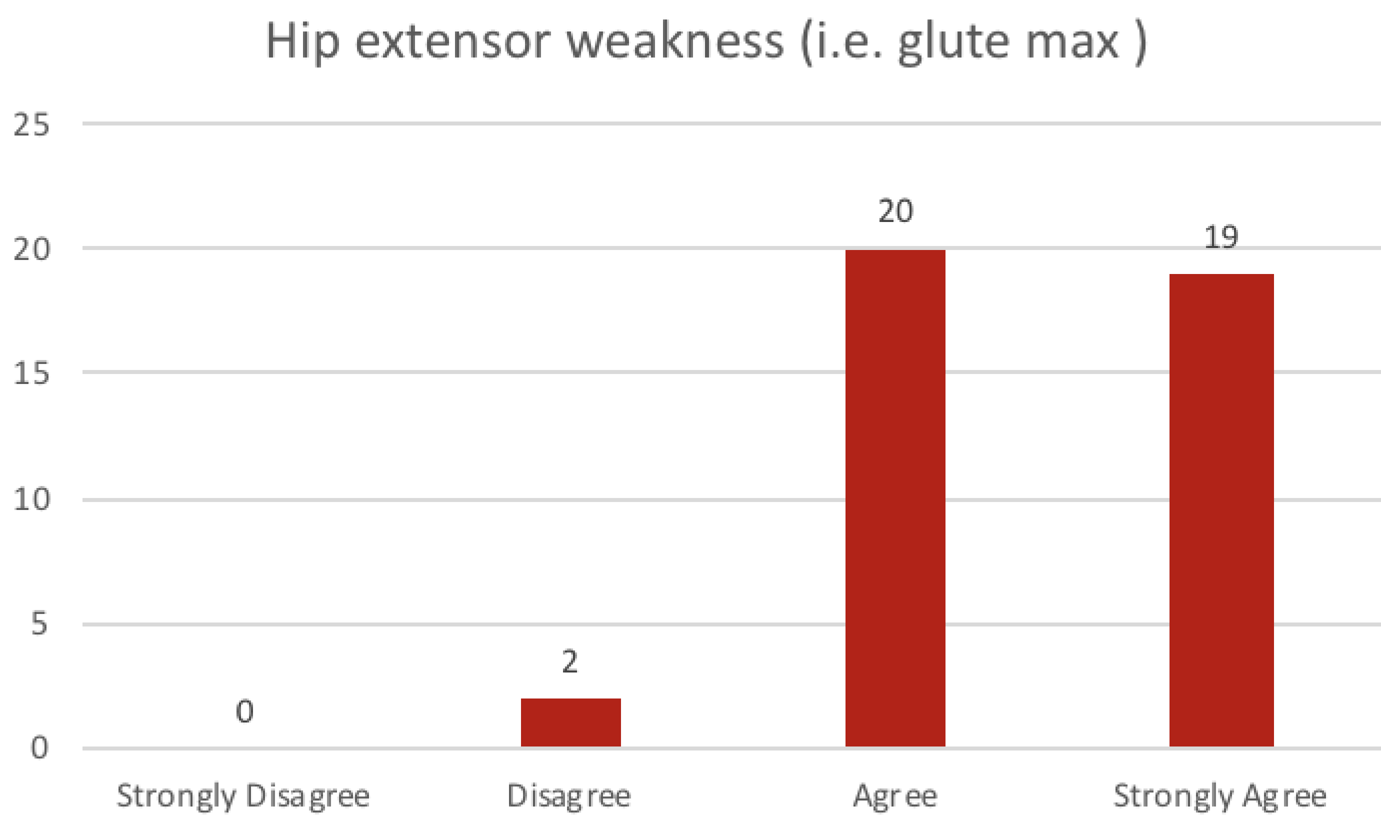
	Strongly Disagree	Disagree	Agree	Strongly Agree
Hip abductor weakness	○	○	○	○



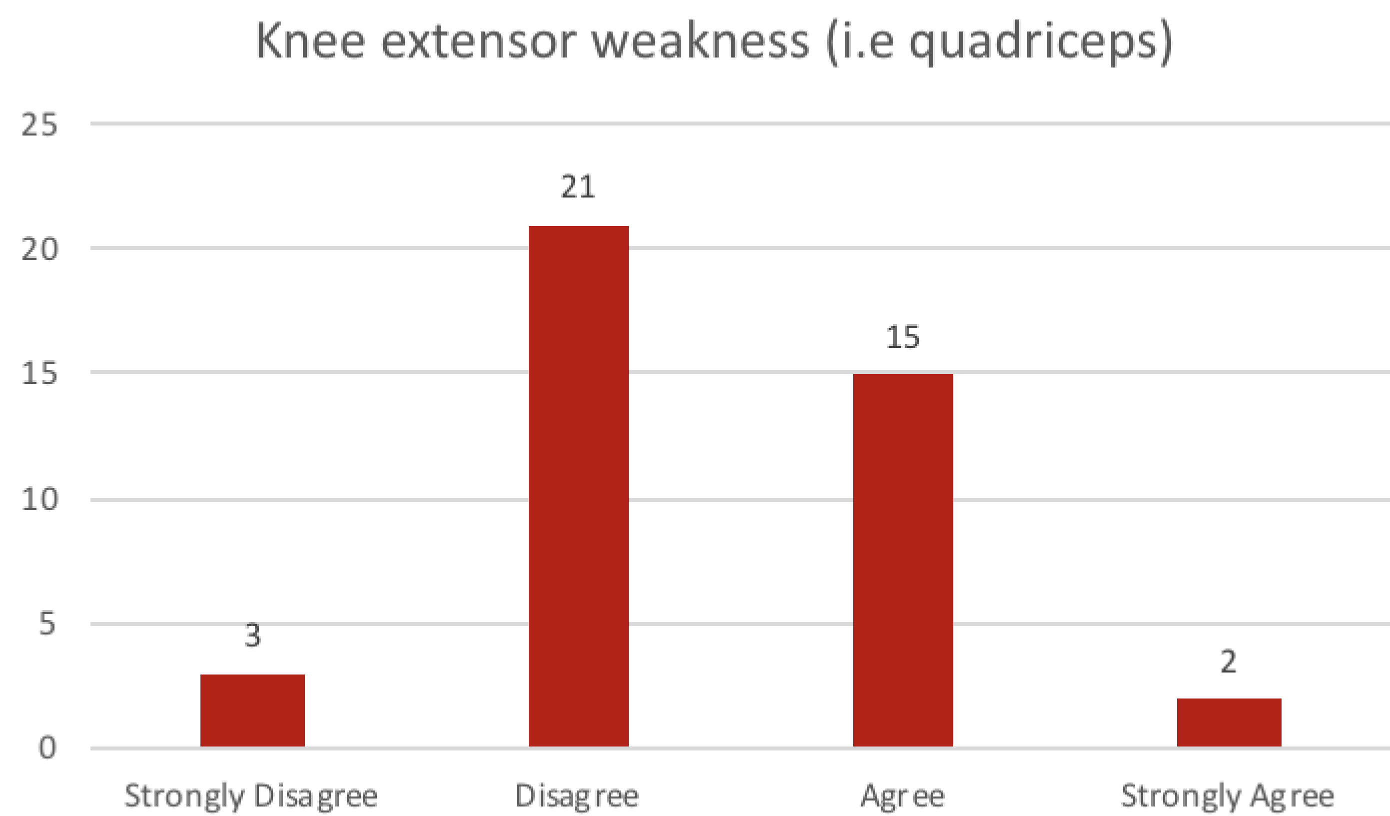
	Strongly Disagree	Disagree	Agree	Strongly agree
Hip adductor weakness	O	O	O	O



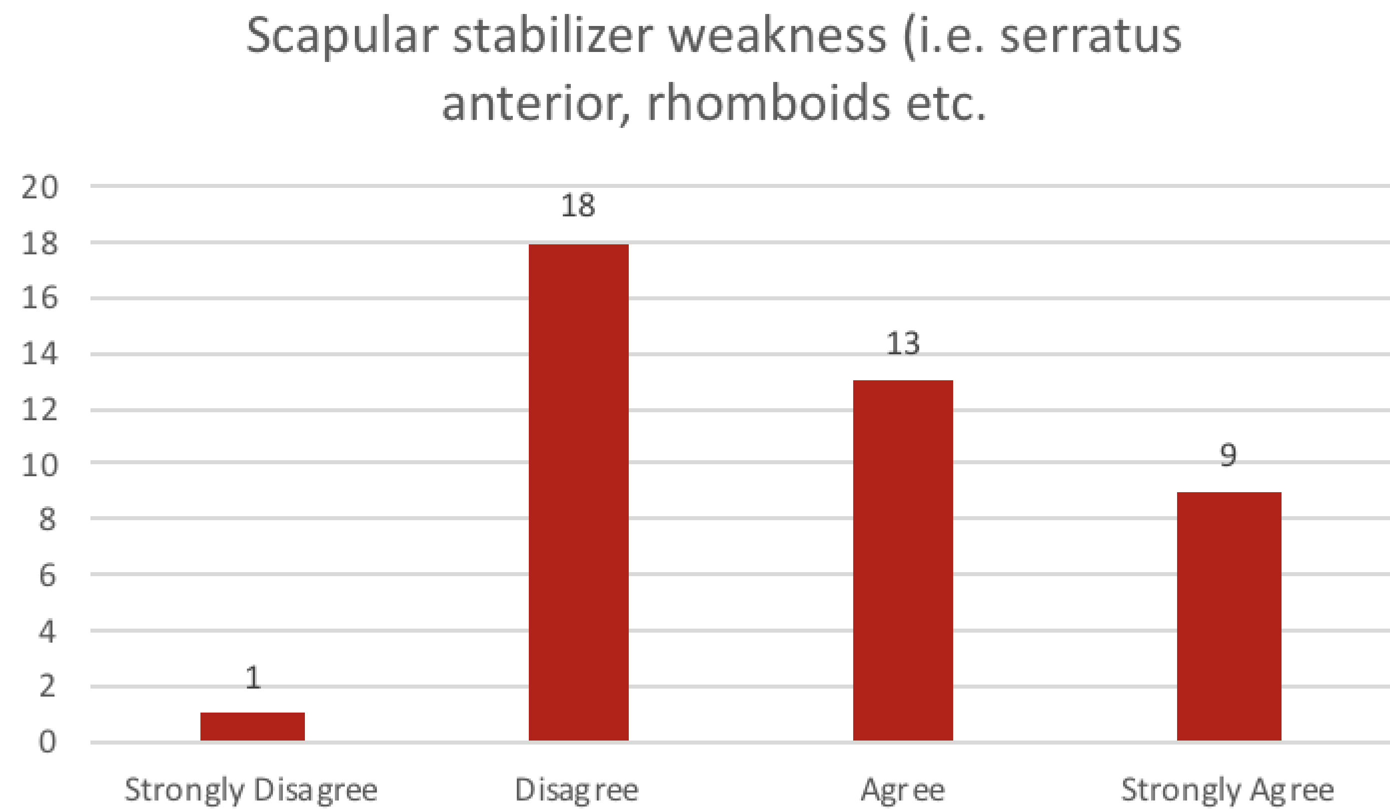
	Strongly disagree	Disagree	Agree	Strongly agree
Hip rotator weakness	O	O	O	O



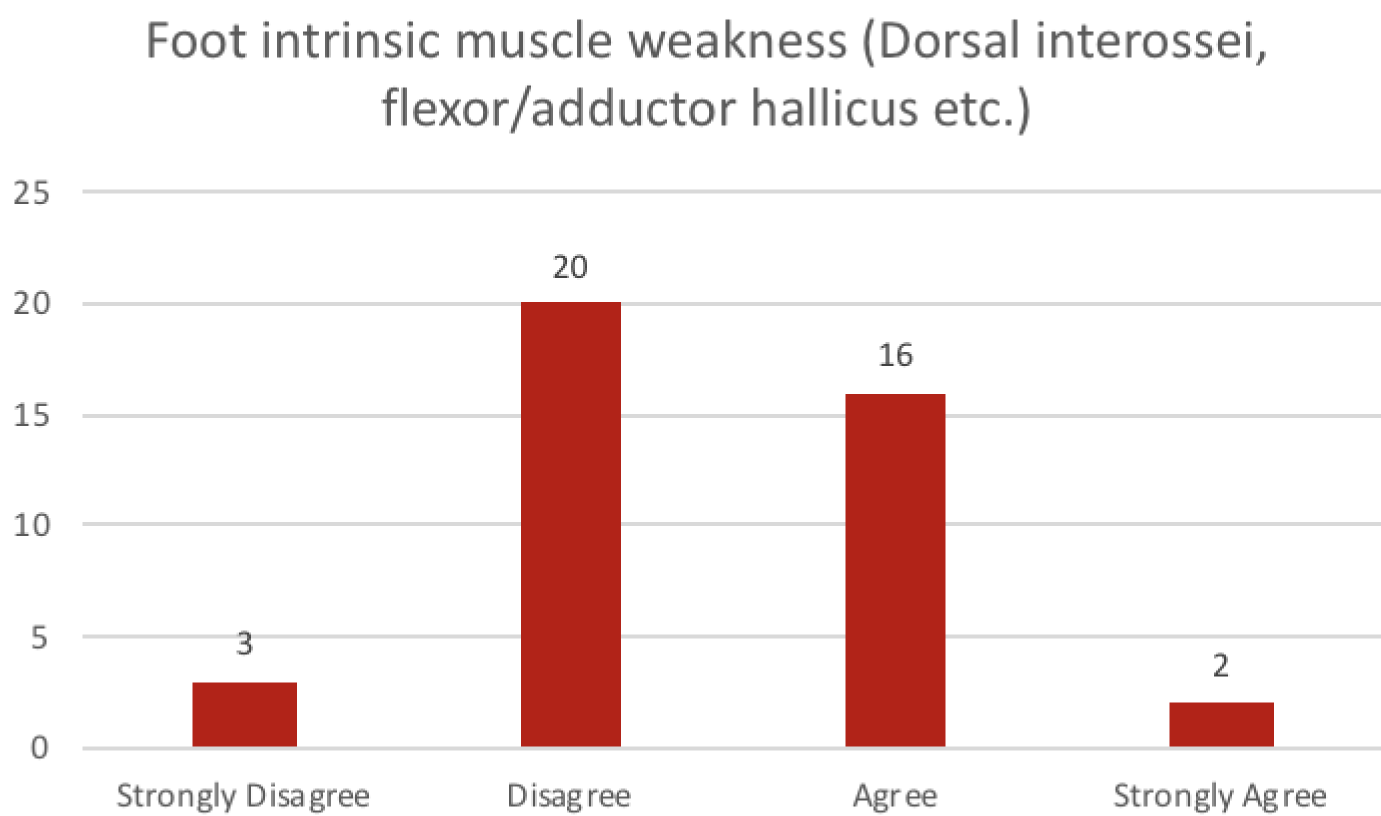
	Strongly disagree	Disagree	Agree	Strongly agree
Hip extensor weakness	○	○	○	○



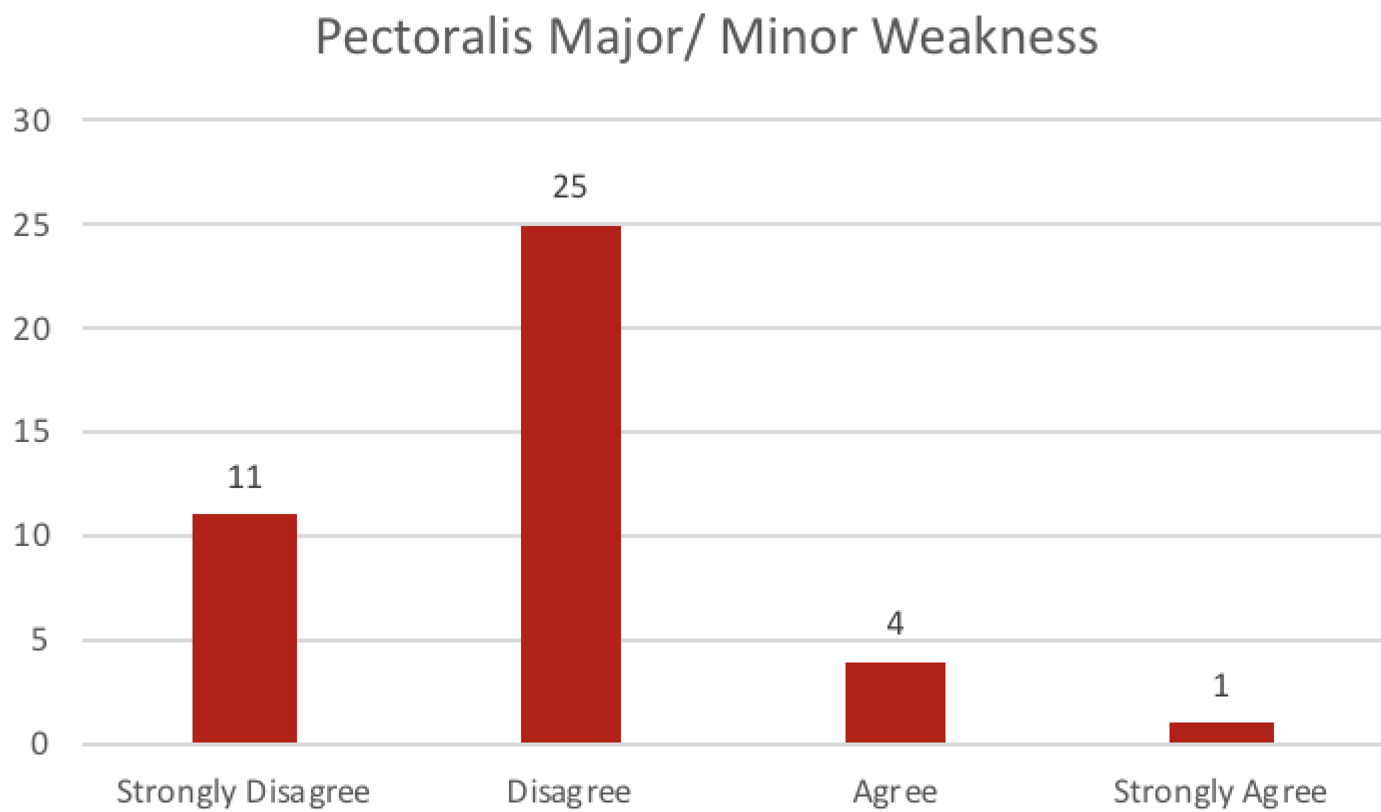
	Strongly disagree	Disagree	Agree	Strongly agree
Knee extensor weakness	O	O	O	O



	Strongly disagree	Disagree	Agree	Strongly agree
Scapular stabilizer weakness	O	O	O	O



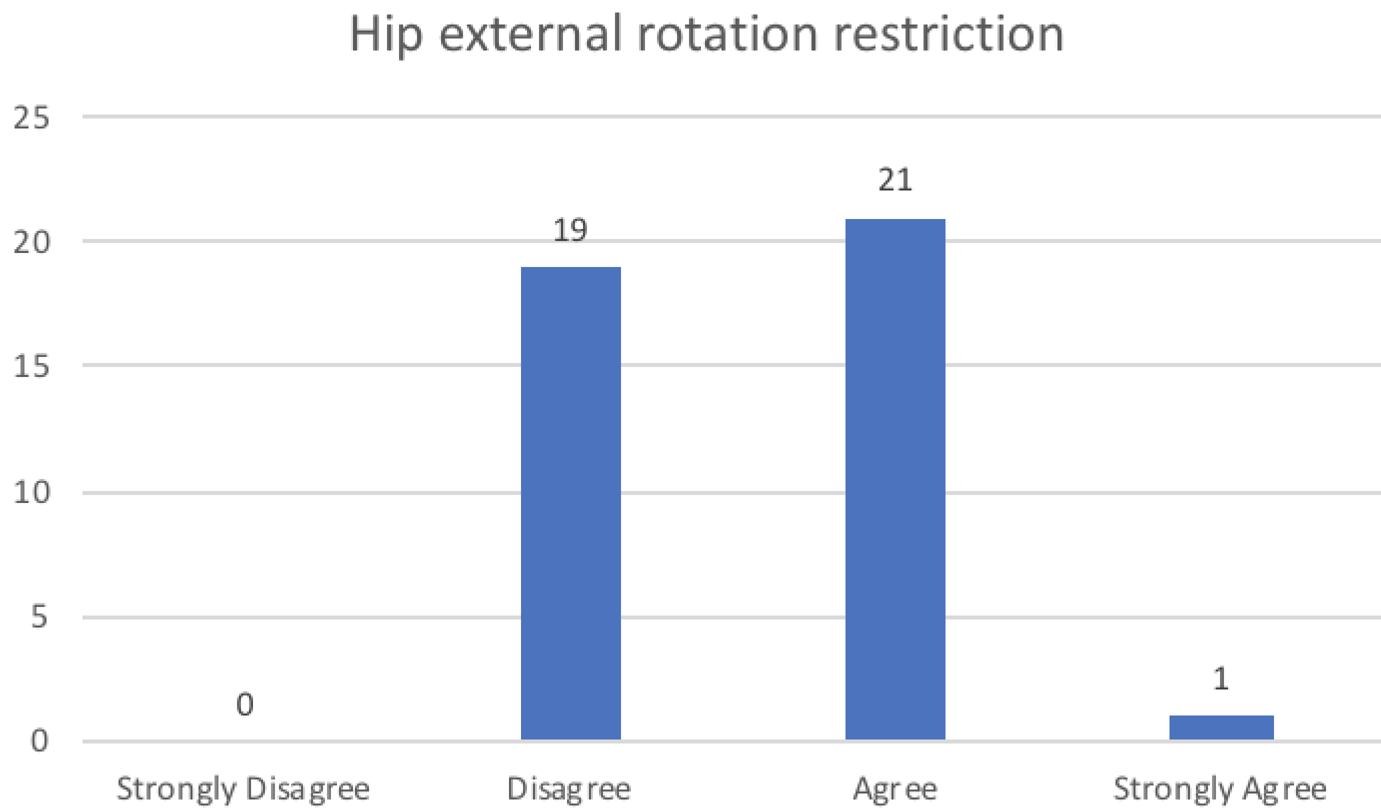
	Strongly disagree	Disagree	Agree	Strongly agree
Foot intrinsic muscle weakness	O	O	O	O



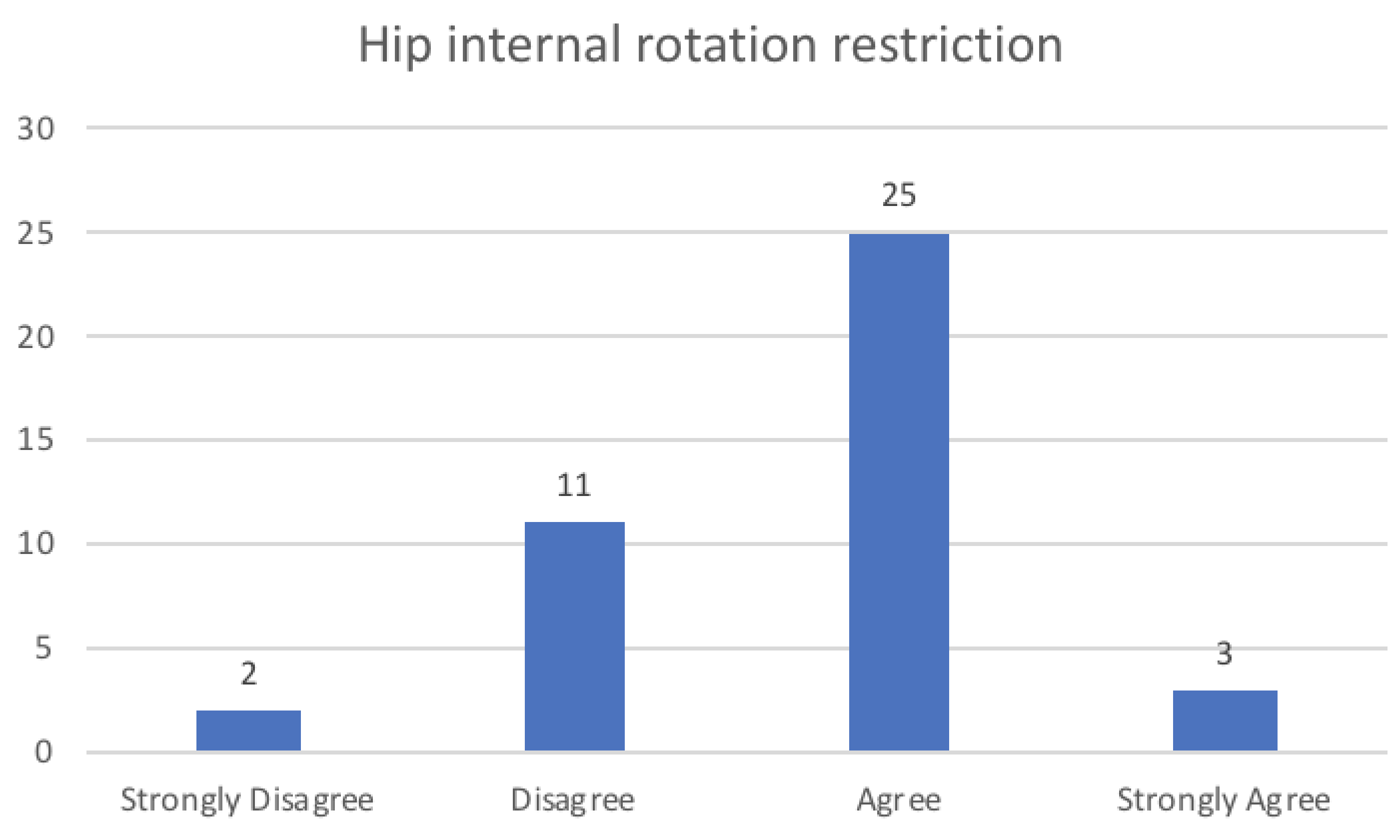
	Strongly Disagree	Disagree	Agree	Strongly agree
Pec Major/ Minor weakness	O	O	O	O

Comments:

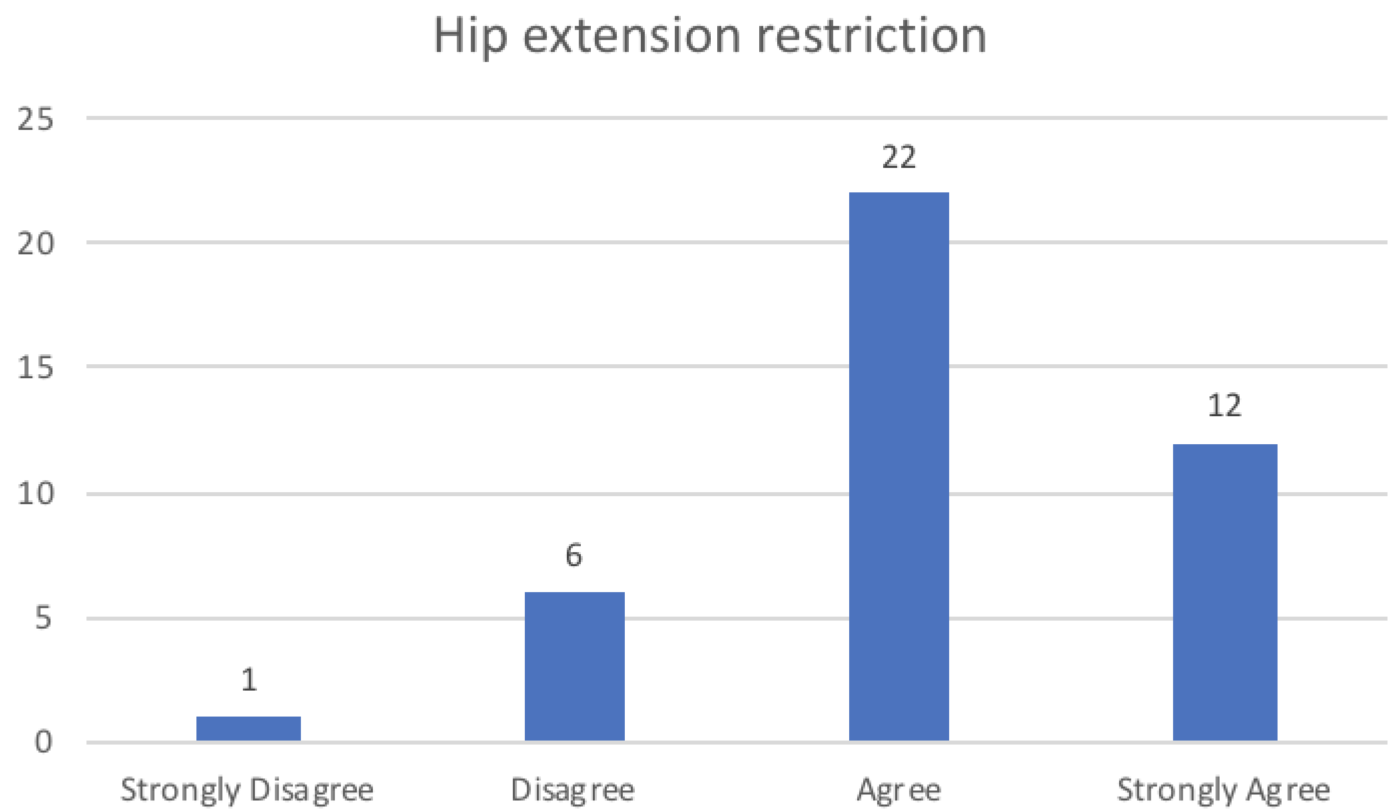
For each of the following range of motion impairments please indicate whether or not you agree that it contributes to pain in the postpartum runner.



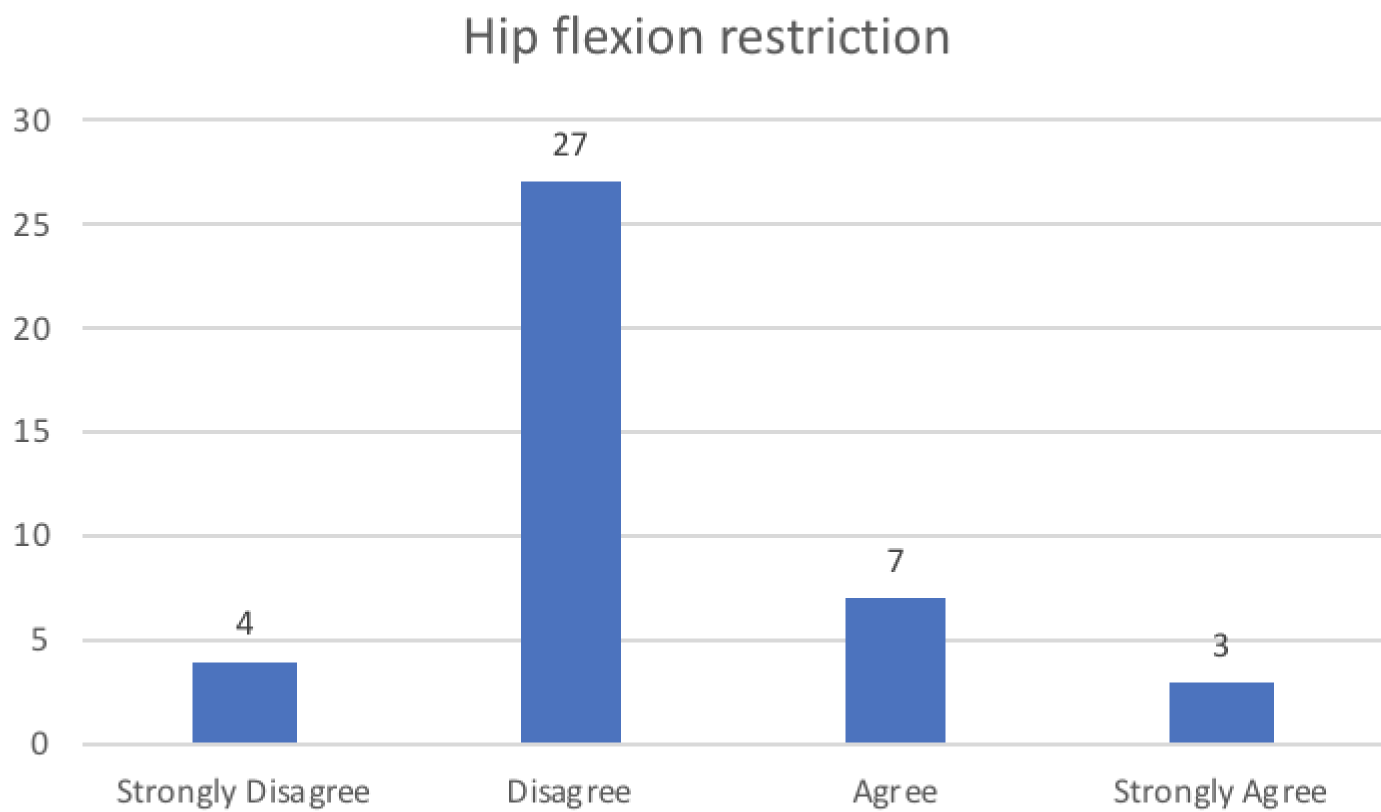
	Strongly disagree	Disagree	Agree	Strongly agree
Hip external rotation restriction				



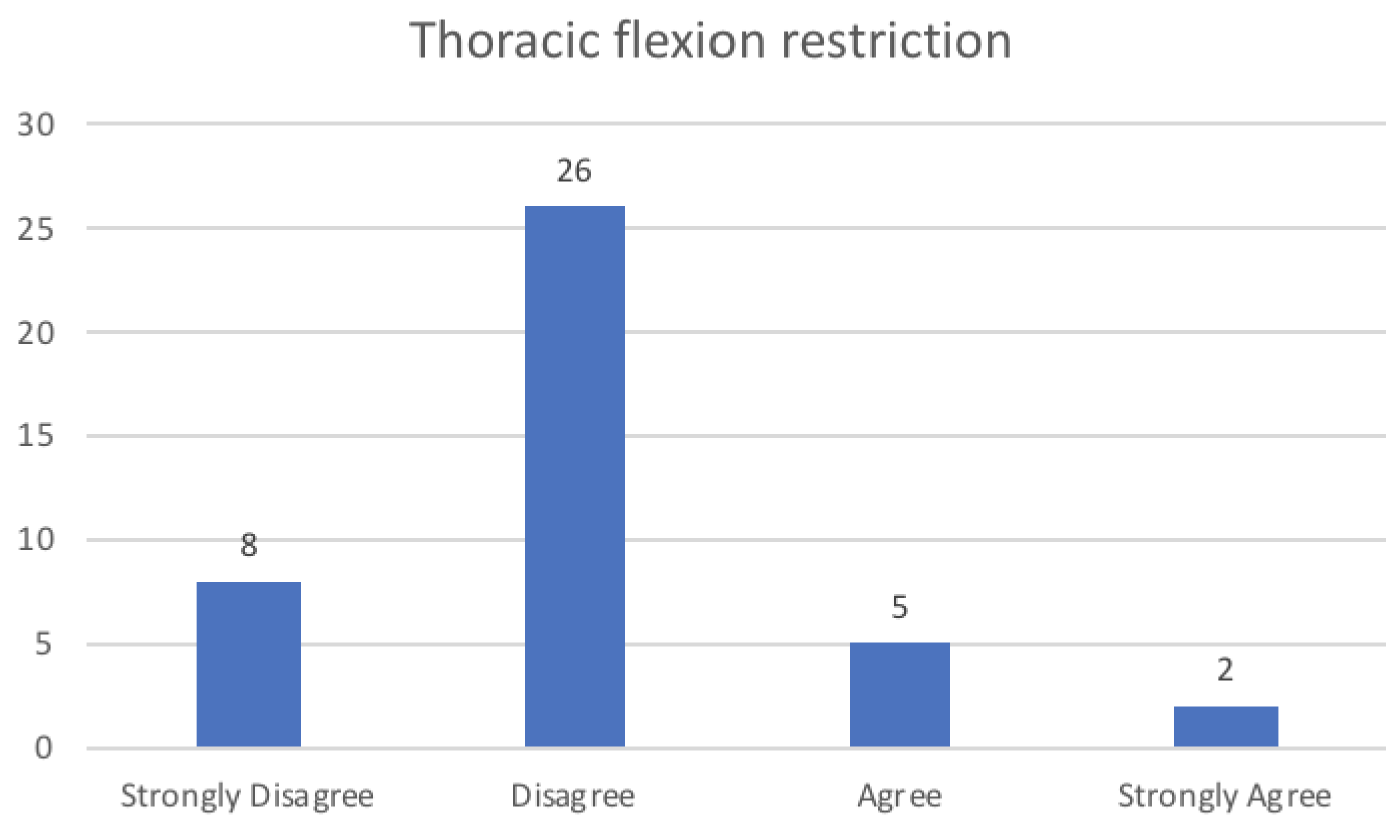
	Strongly disagree	Disagree	Agree	Strongly agree
Hip internal rotation restriction	O	O	O	O



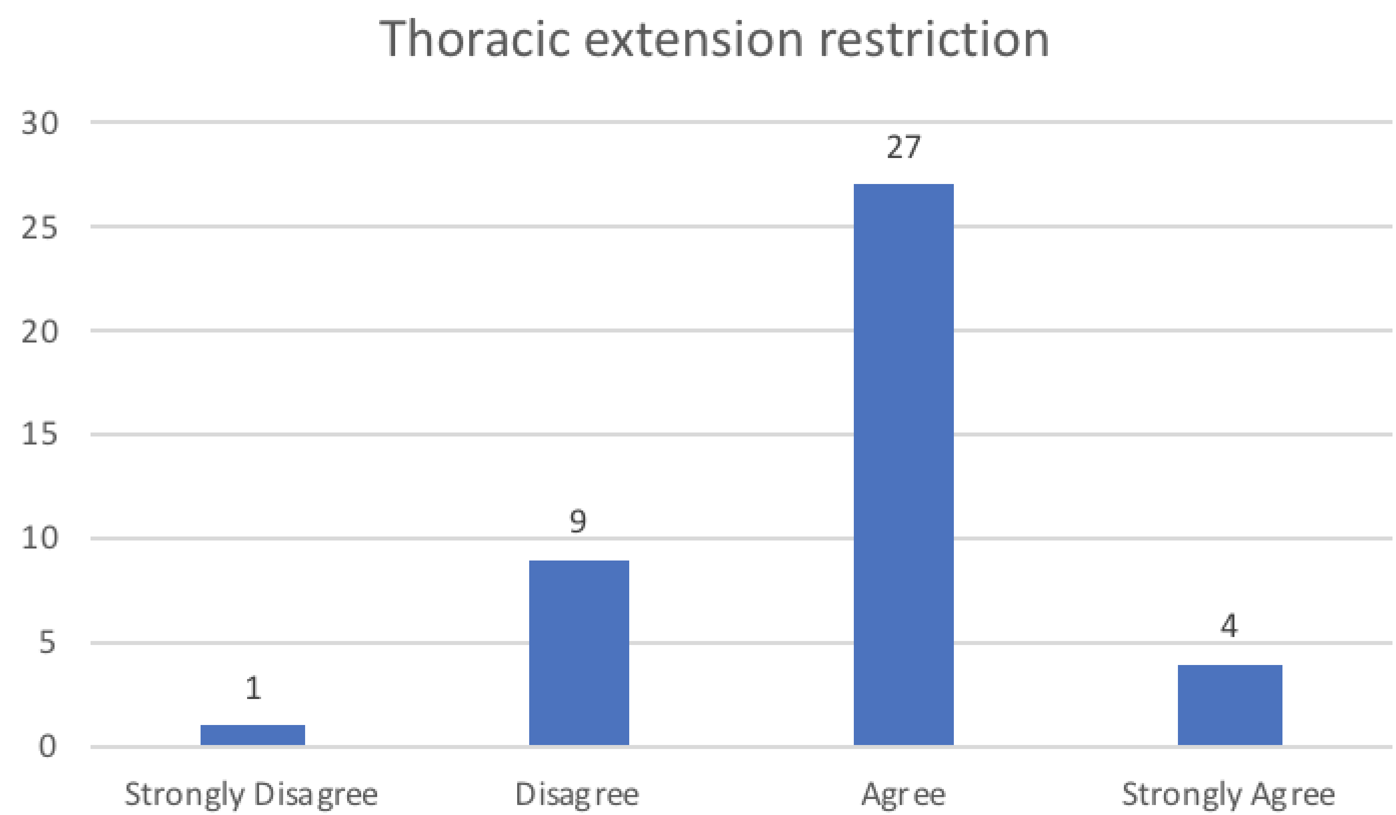
	Strongly disagree	Disagree	Agree	Strongly agree
Hip extension restriction	O	O	O	O



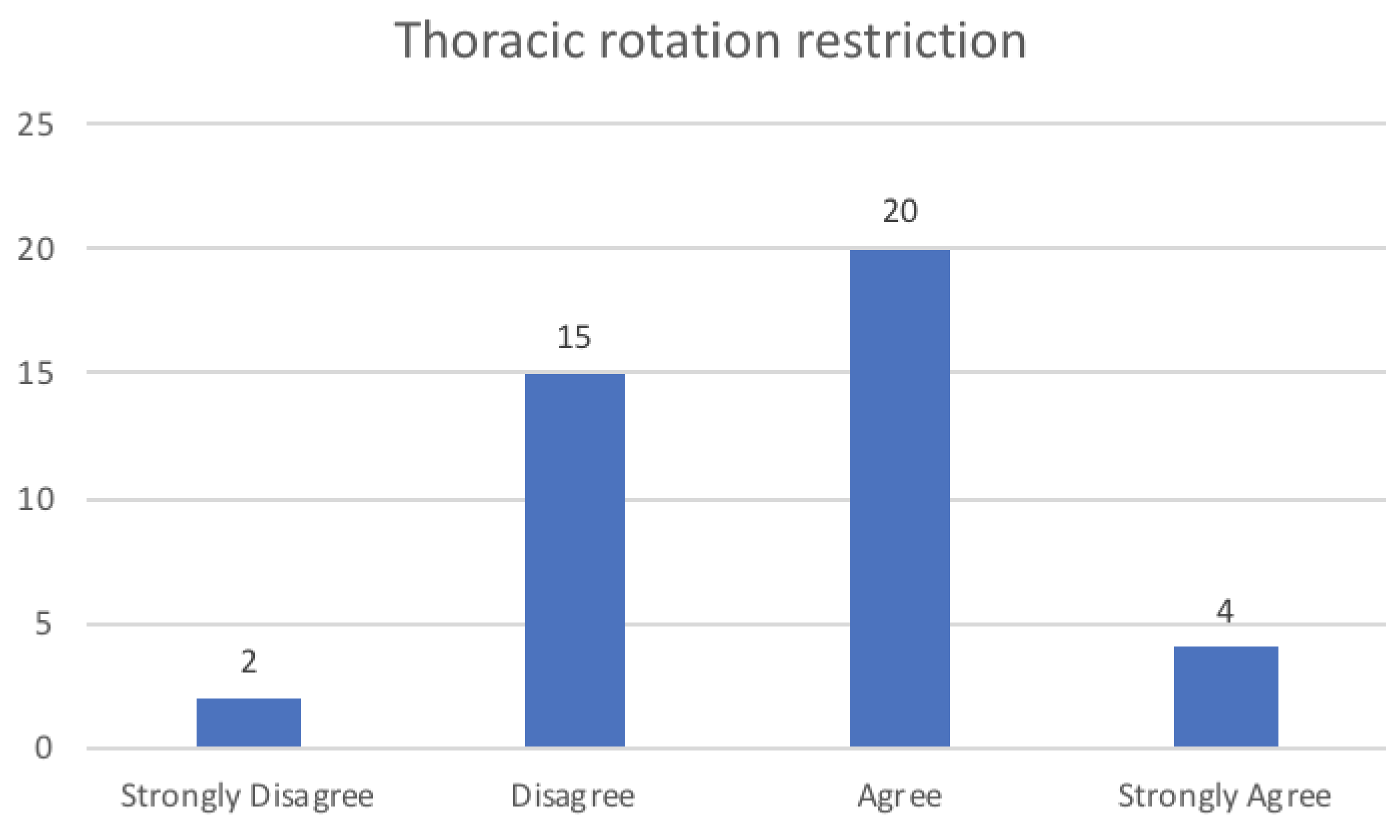
	Strongly disagree	Disagree	Agree	Strongly agree
Hip flexion restriction	○	○	○	○



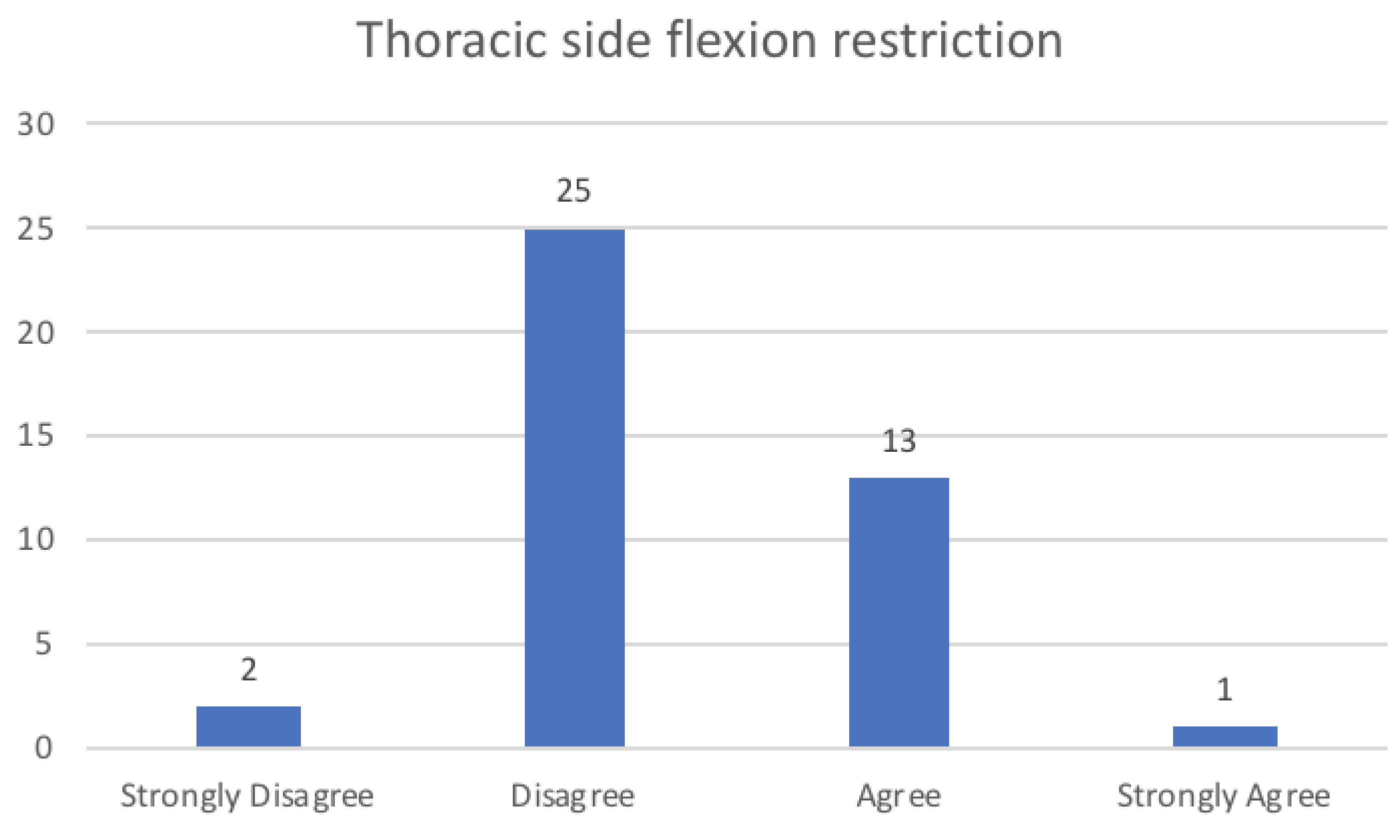
	Strongly disagree	Disagree	Agree	Strongly agree
Thoracic flexion restriction	O	O	O	O



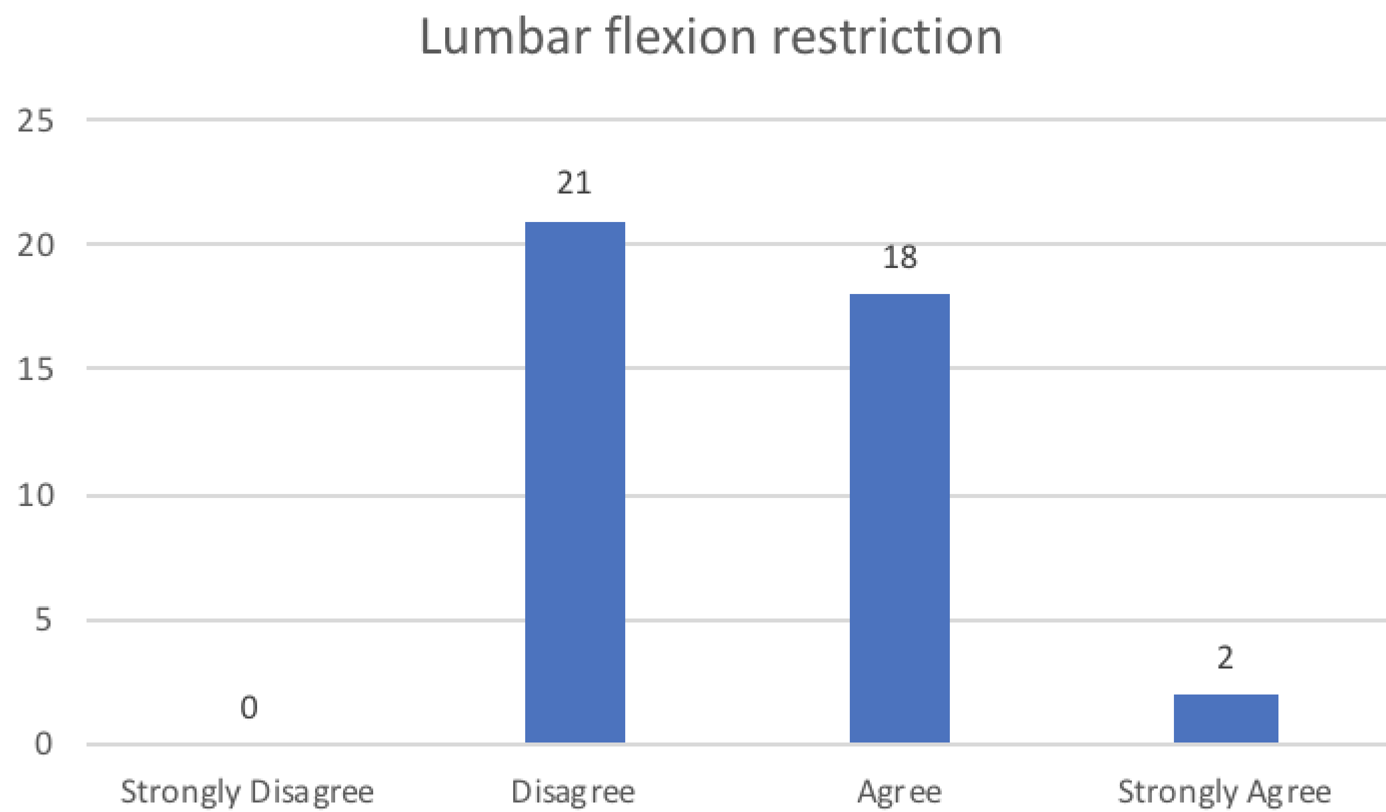
	Strongly disagree	Disagree	Agree	Strongly agree
Thoracic extension restriction	O	O	O	O



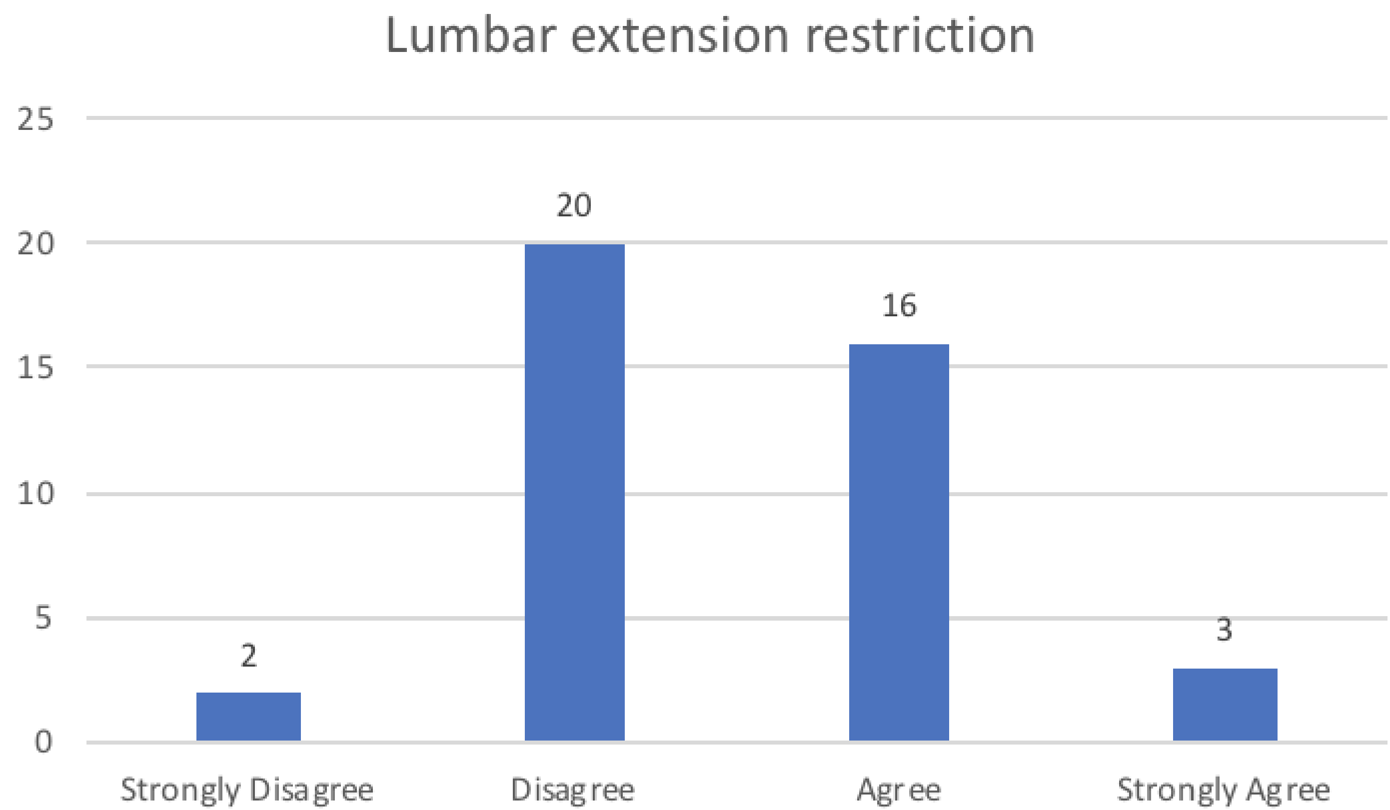
	Strongly disagree	Disagree	Agree	Strongly agree
Thoracic rotation restriction	○	○	○	○



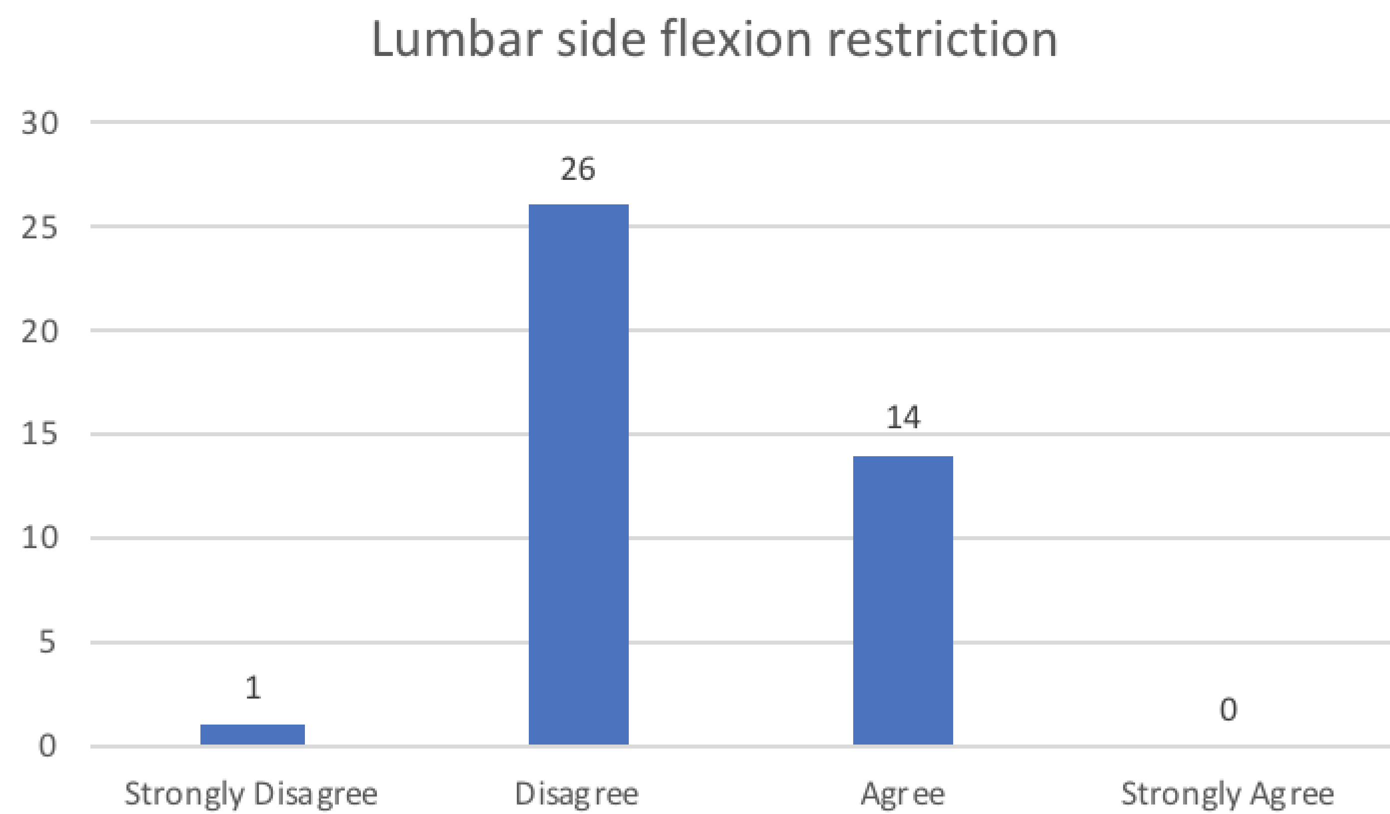
	Strongly disagree	Disagree	Agree	Strongly agree
Thoracic side flexion restriction	○	○	○	○



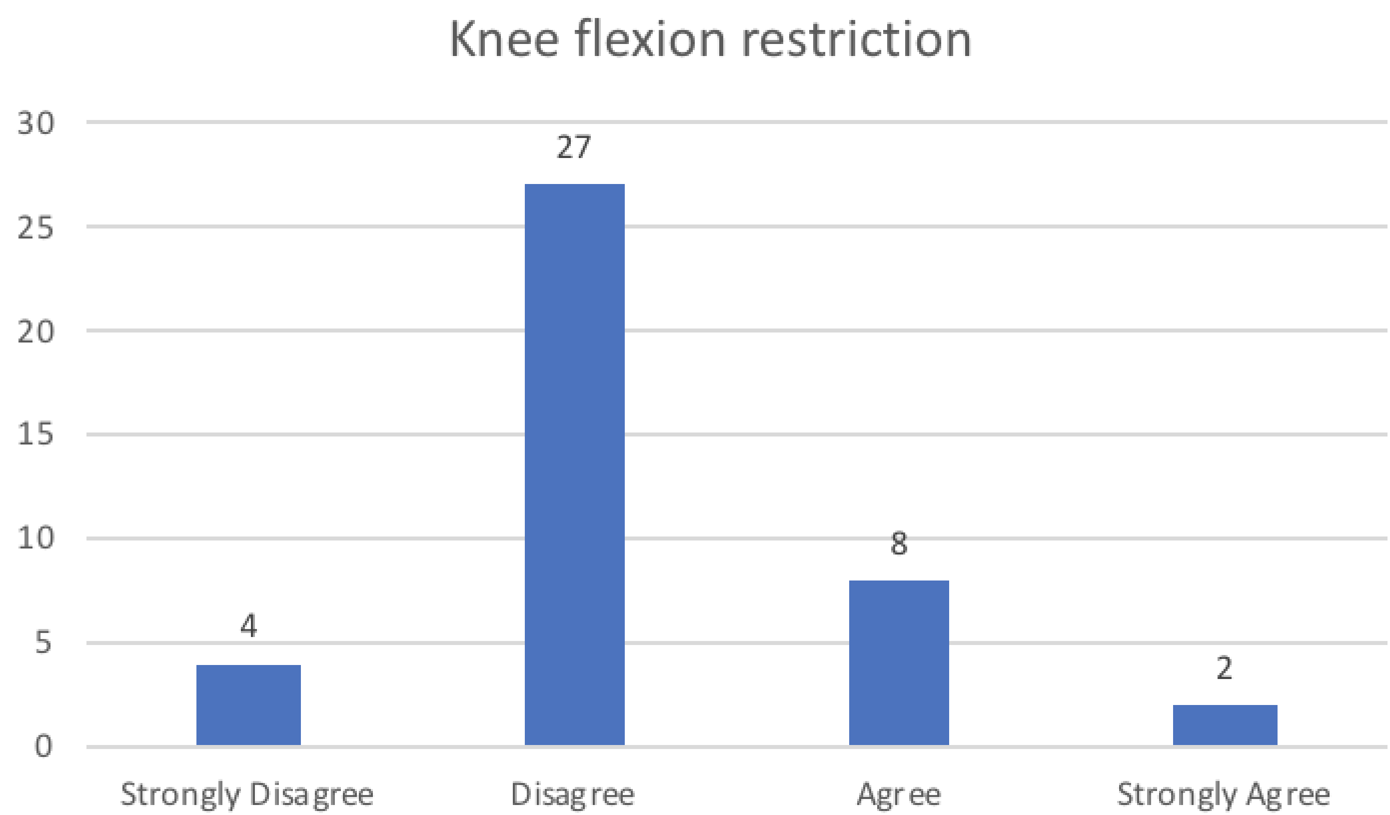
	Strongly disagree	Disagree	Agree	Strongly agree
Lumbar flexion restriction	O	O	O	O



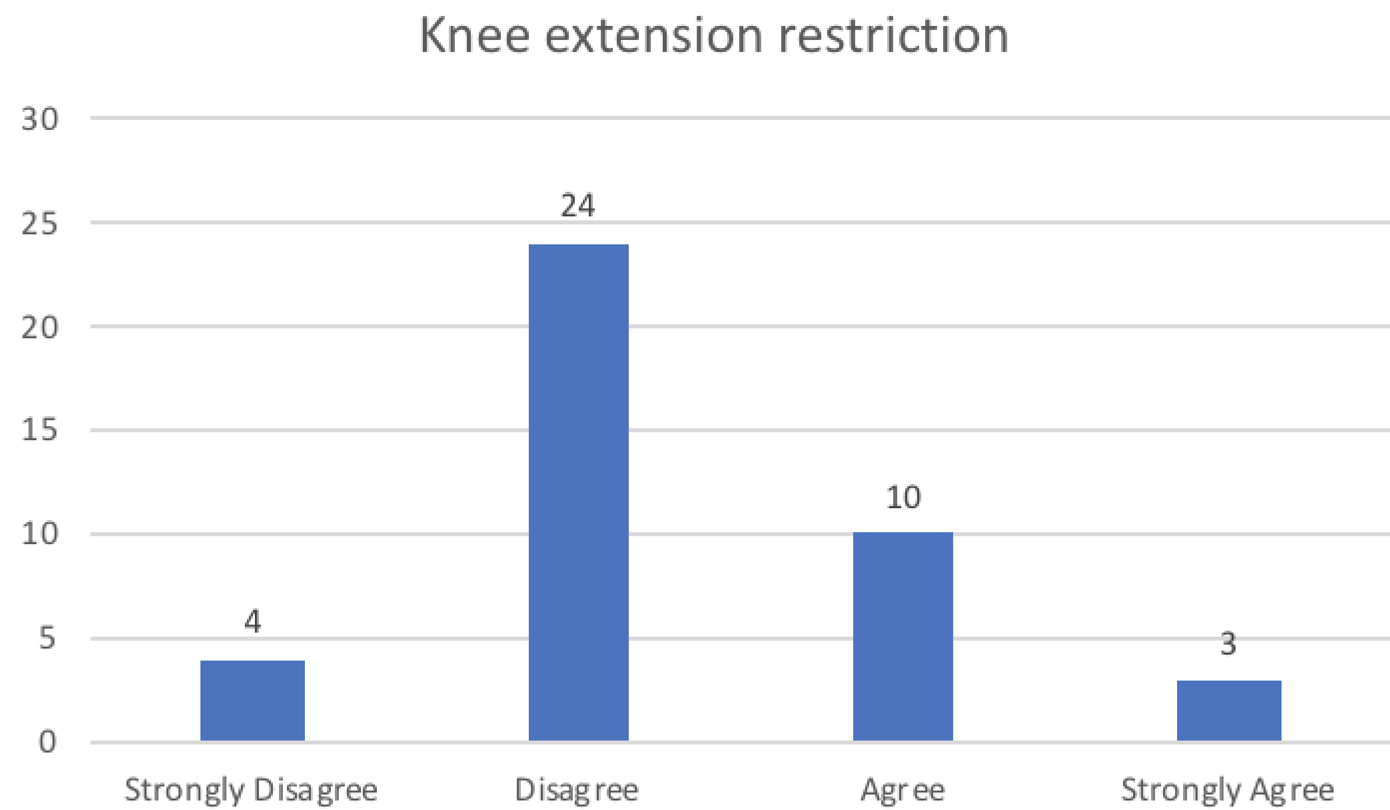
	Strongly disagree	Disagree	Agree	Strongly agree
Lumbar extension restriction	O	O	O	O



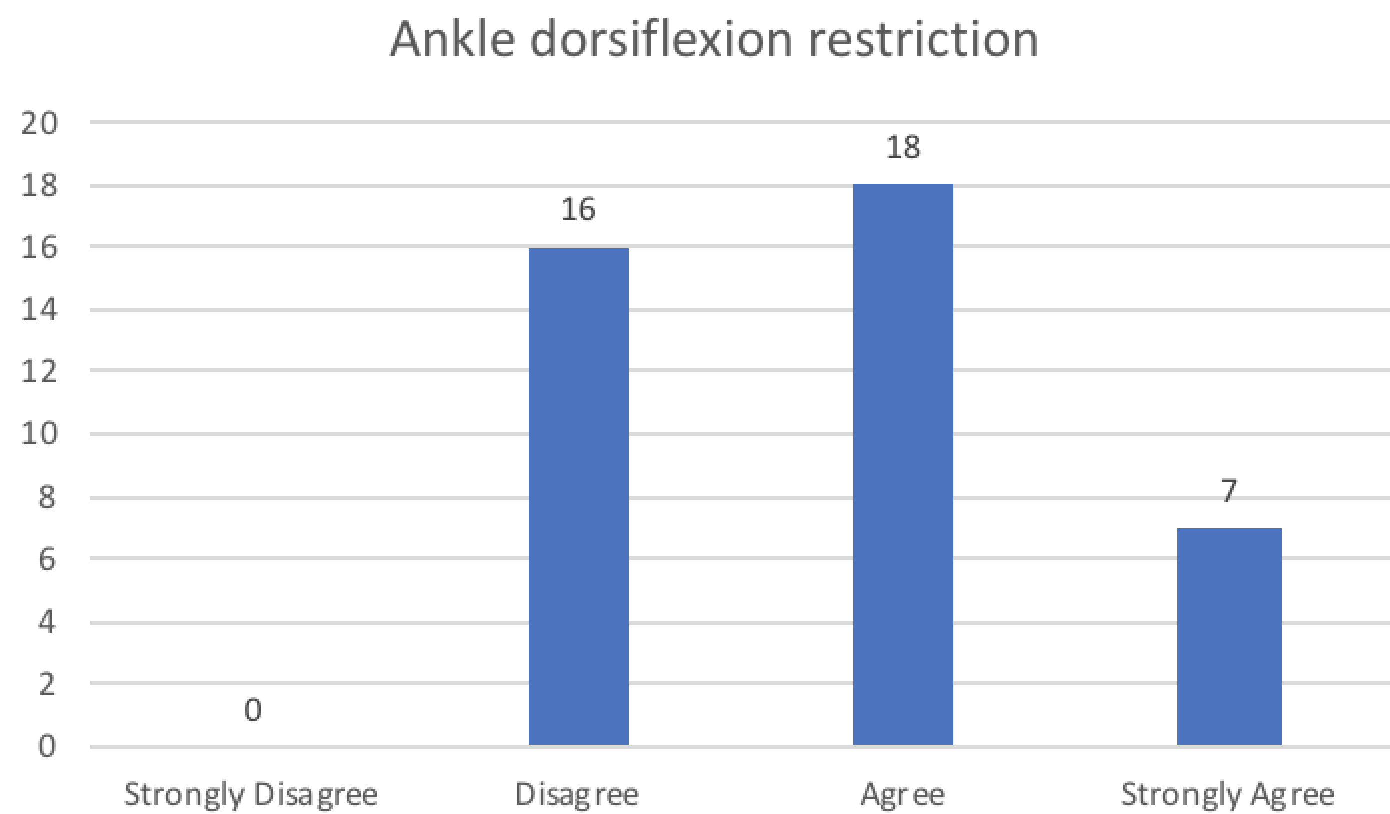
	Strongly disagree	Disagree	Agree	Strongly agree
Lumbar side flexion restriction	O	O	O	O



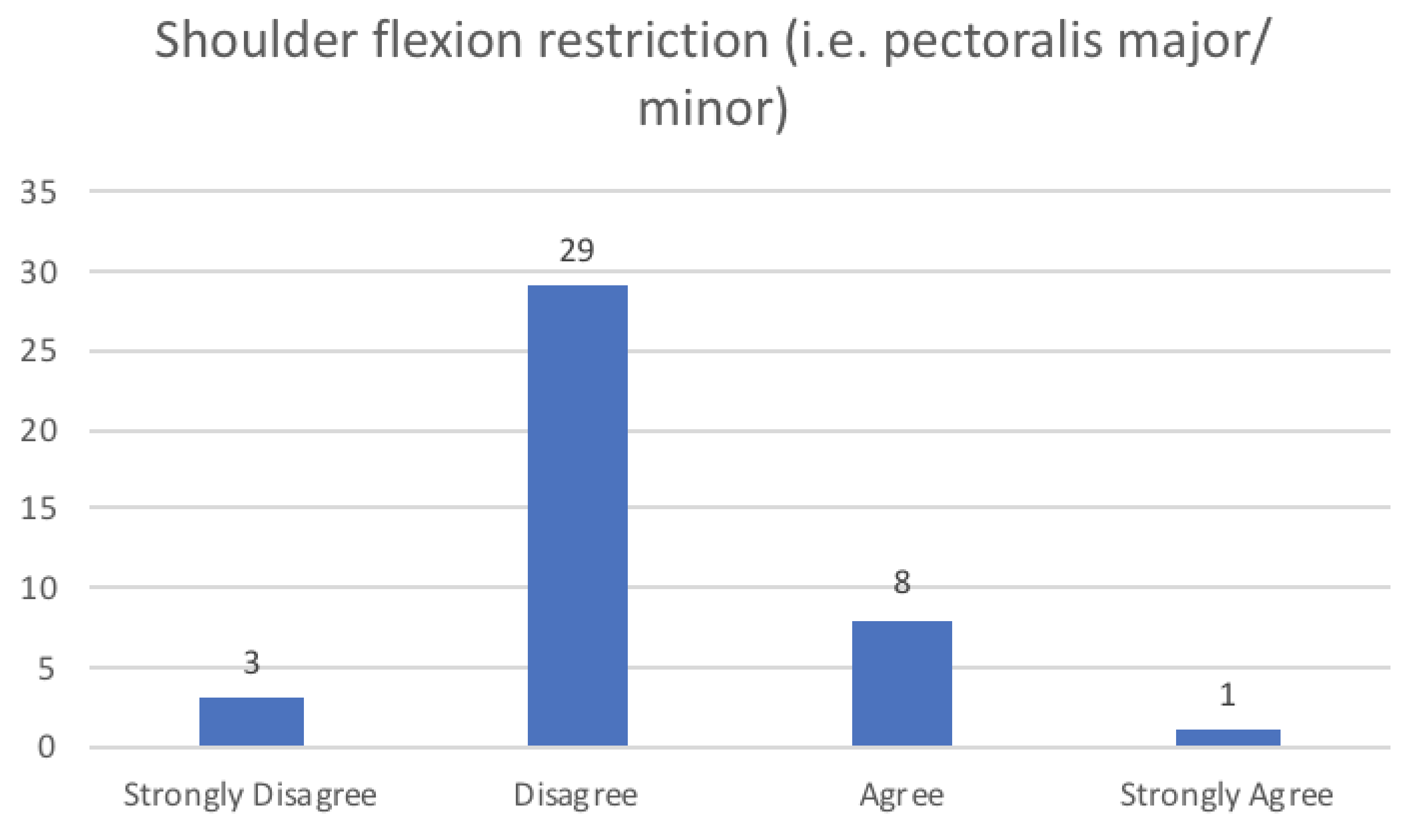
	Strongly disagree	Disagree	Agree	Strongly agree
Knee flexion restriction	O	O	O	O



	Strongly disagree	Disagree	Agree	Strongly agree
Knee extension restriction	O	O	O	O

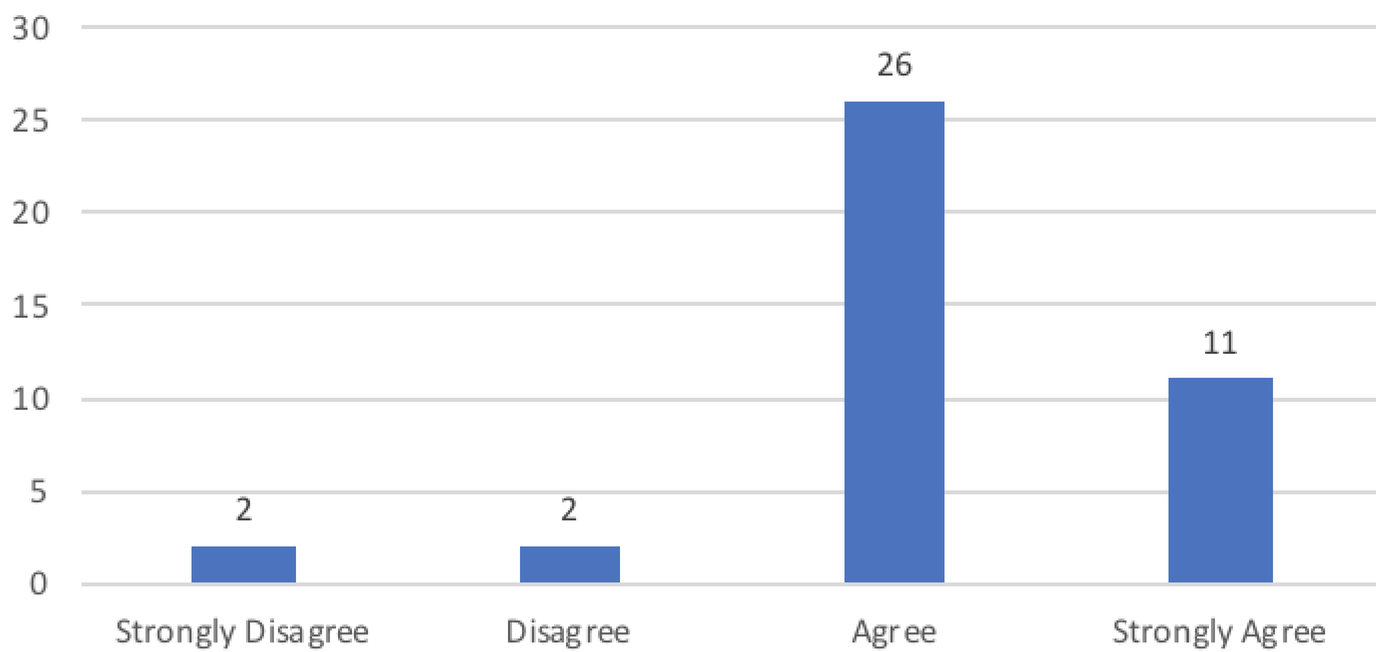


	Strongly disagree	Disagree	Agree	Strongly agree
Ankle dorsiflexion restriction	○	○	○	○

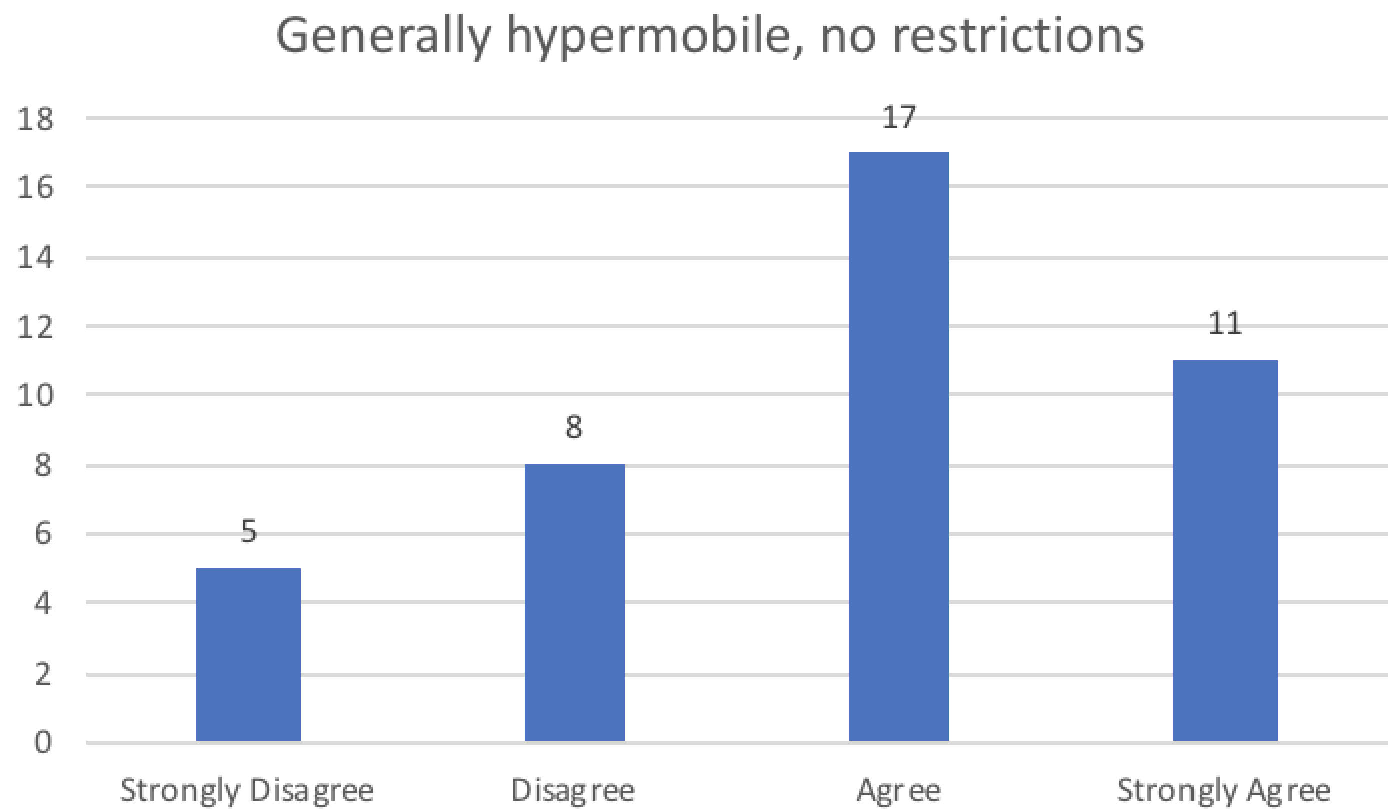


	Strongly disagree	Disagree	Agree	Strongly agree
Shoulder flexion restriction	○	○	○	○

Excessive counternutation relation to innominant
(i.e. Anterior pelvic tilt)



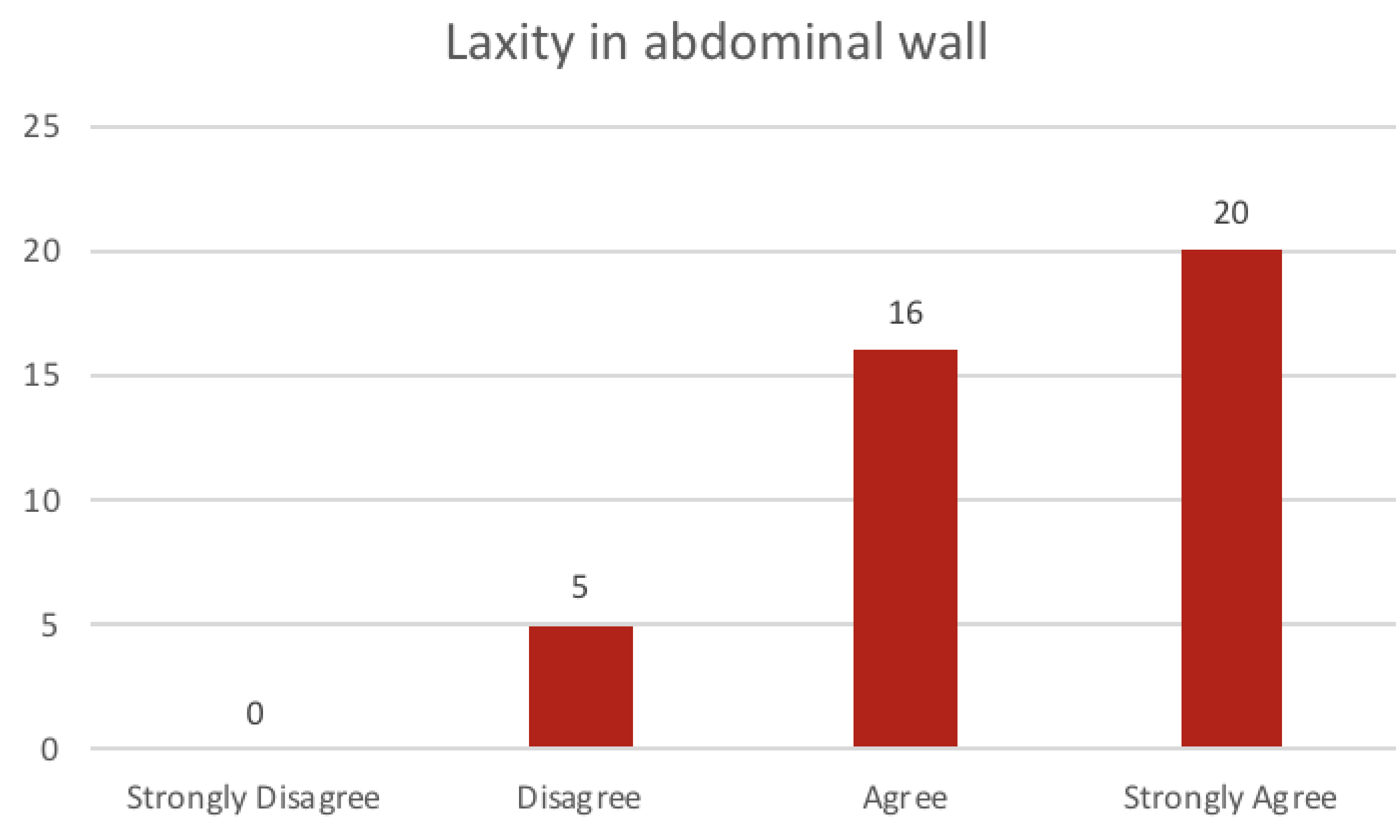
	Strongly disagree	Disagree	Agree	Strongly agree
Anterior pelvic tilt	O	O	O	O



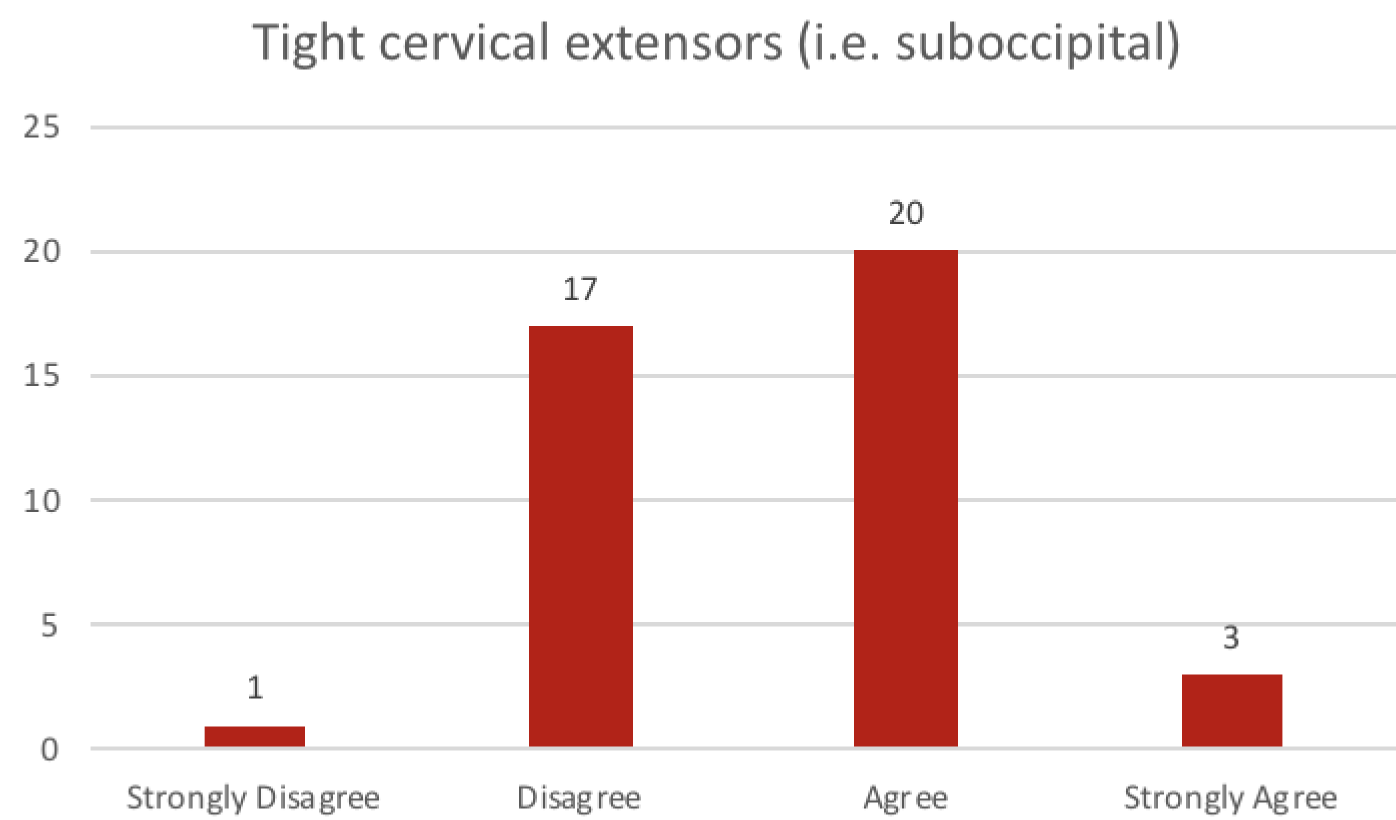
	Strongly disagree	Disagree	Agree	Strongly agree
Generally hypermobile	○	○	○	○

Comments:

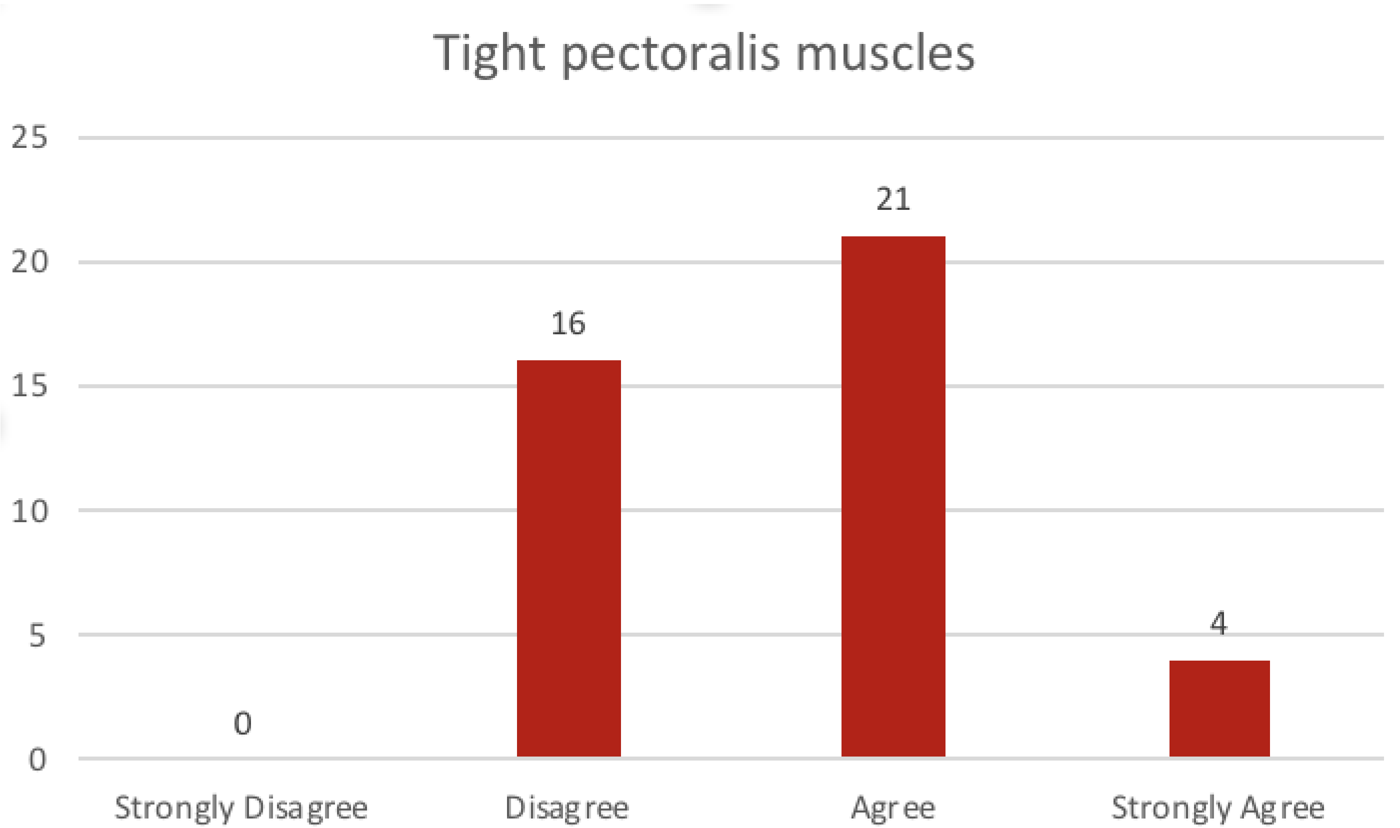
For each of the following flexibility impairments please indicate whether or not you agree that it contributes to pain in the postpartum runner.



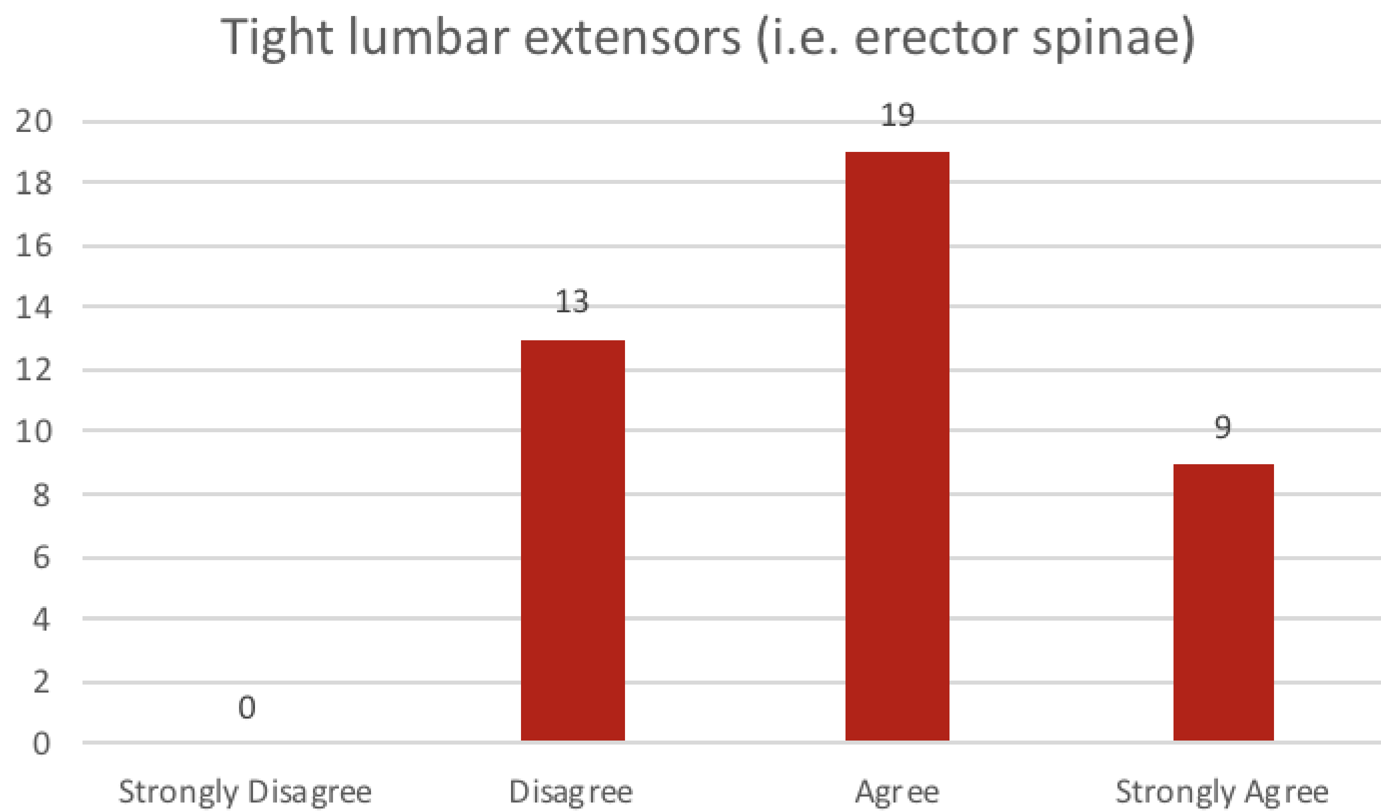
	Strongly disagree	Disagree	Agree	Strongly agree
Laxity in abdominal wall	O	O	O	O



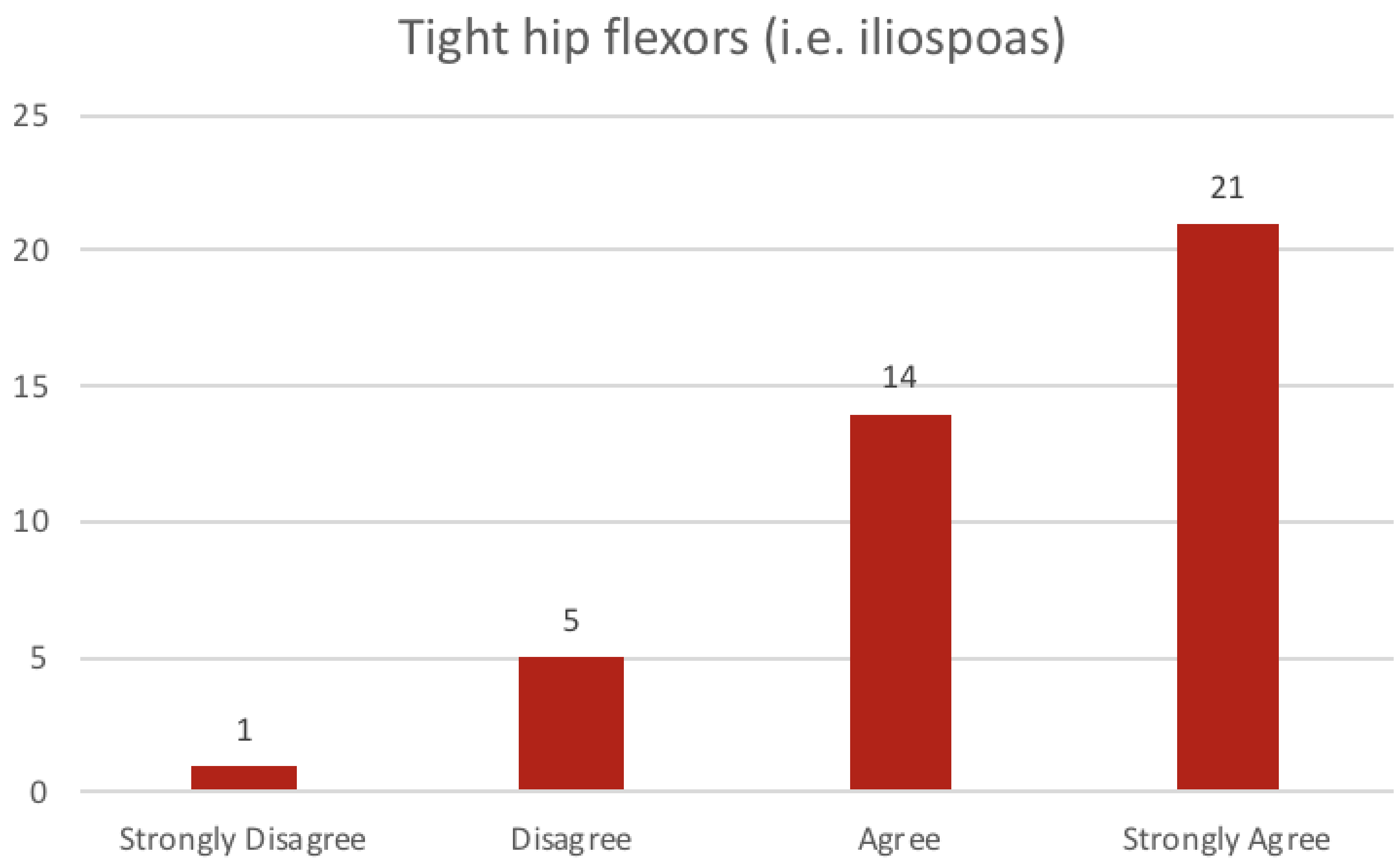
	Strongly disagree	Disagree	Agree	Strongly agree
Tight cervical extensors	O	O	O	O



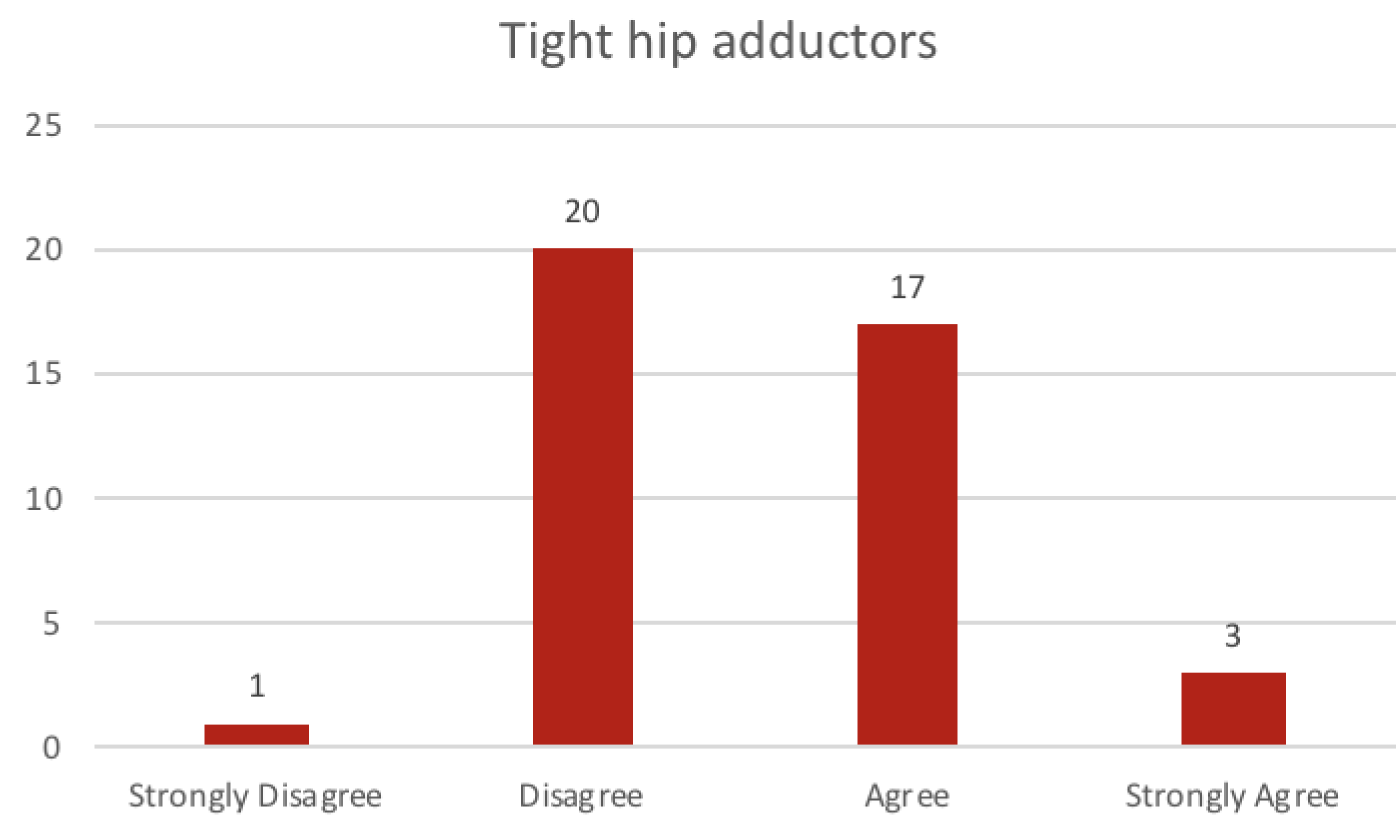
	Strongly disagree	Disagree	Agree	Strongly agree
Tight pectoralis muscles	O	O	O	O



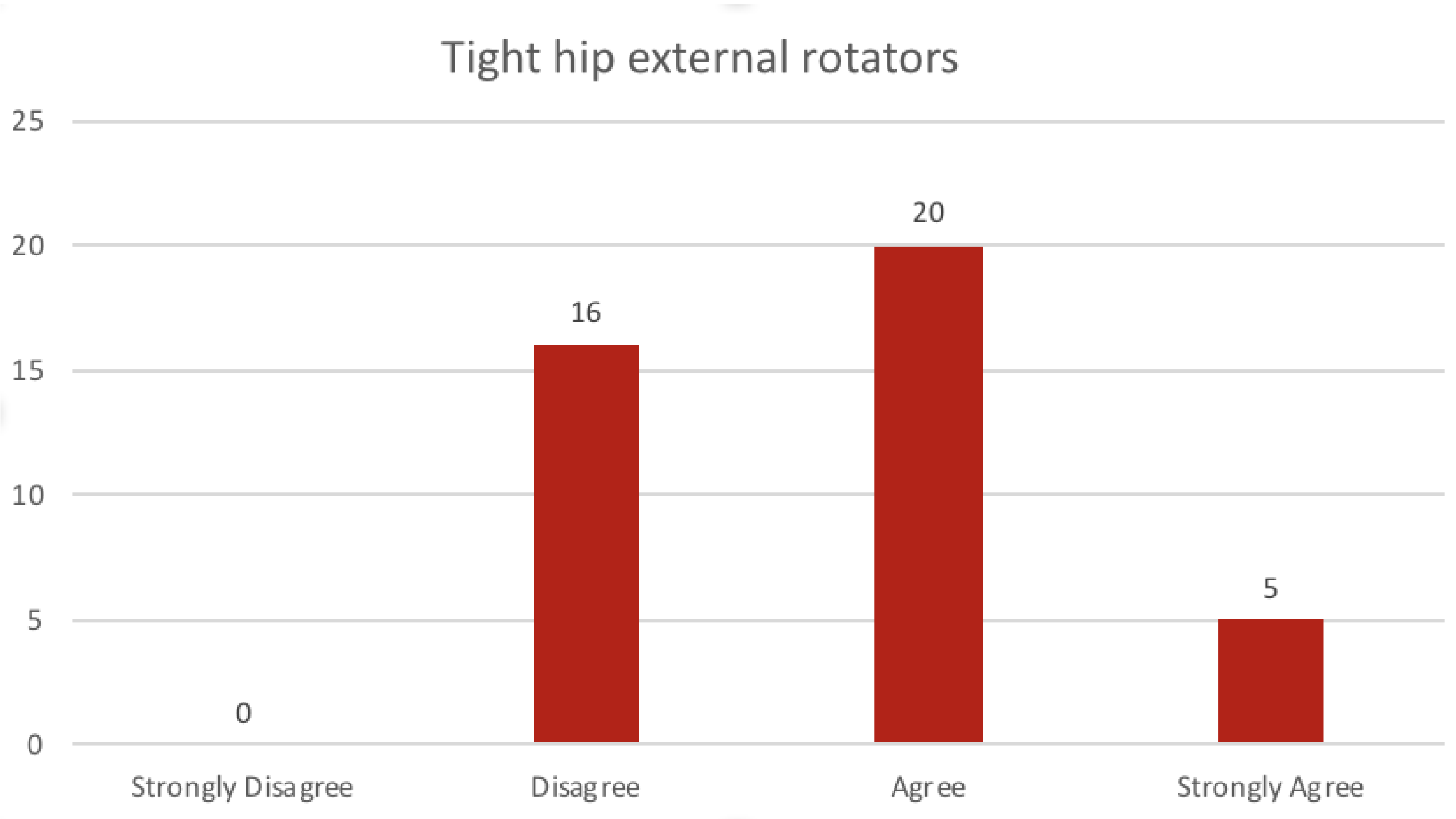
	Strongly disagree	Disagree	Agree	Strongly agree
Tight lumbar extensors	○	○	○	○



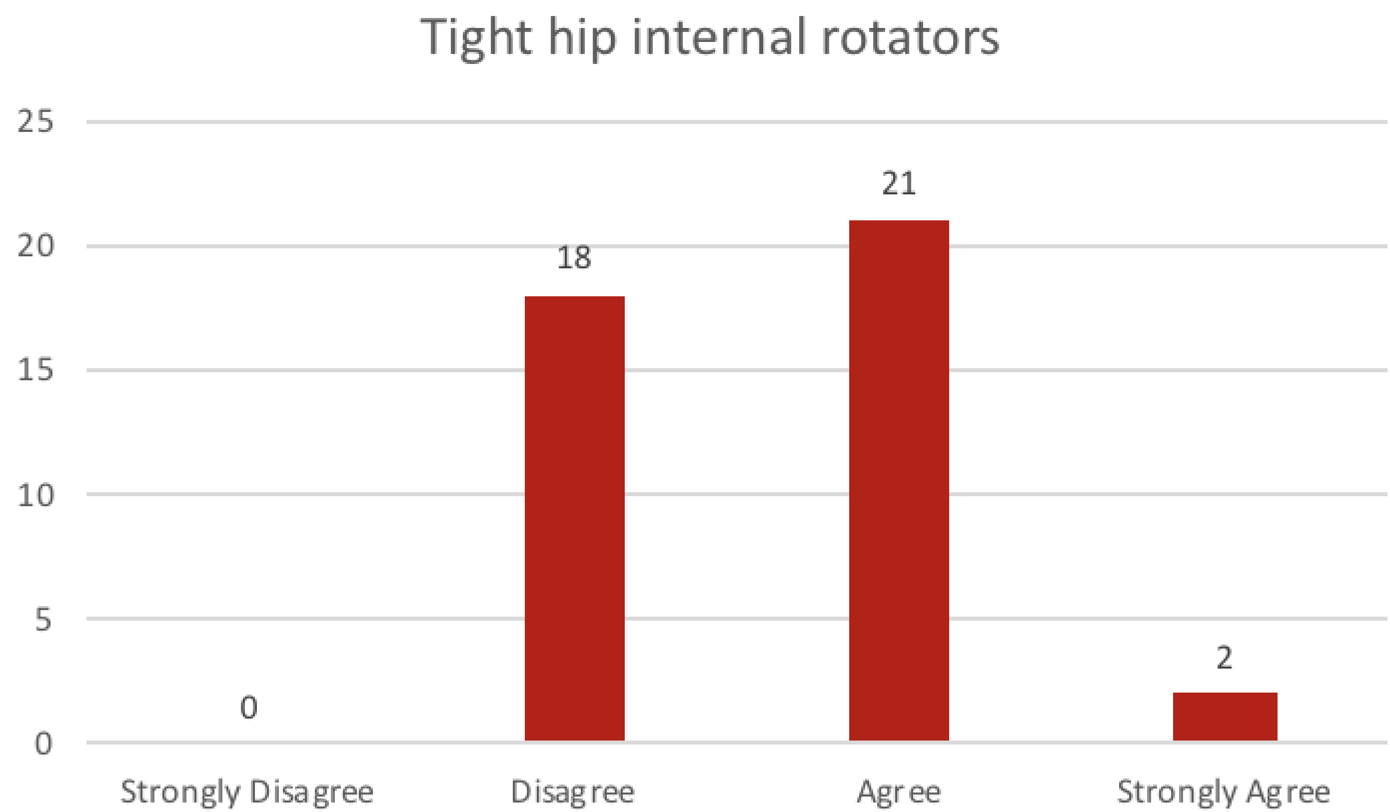
	Strongly disagree	Disagree	Agree	Strongly agree
Tight hip flexors	○	○	○	○



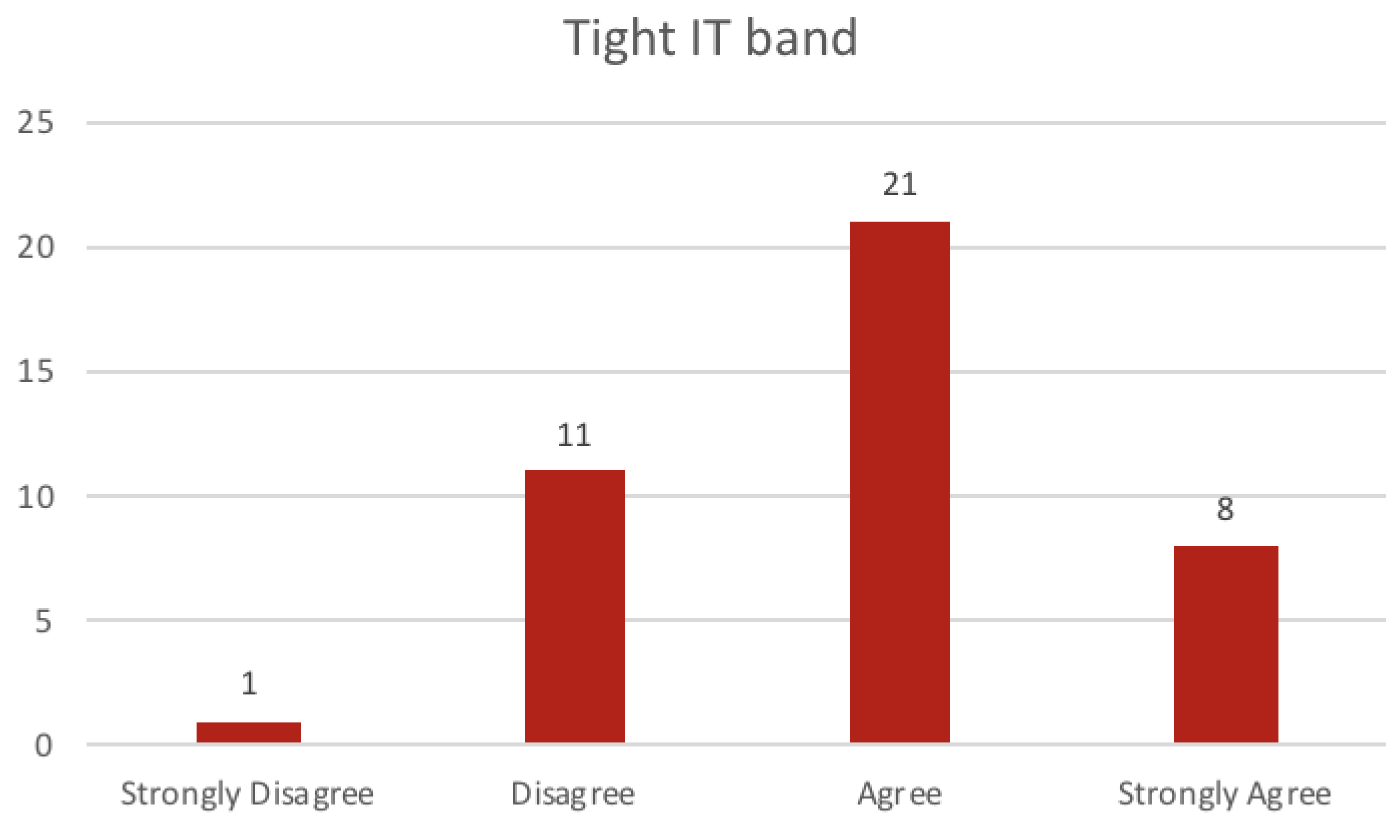
	Strongly disagree	Disagree	Agree	Strongly agree
Tight hip adductors				



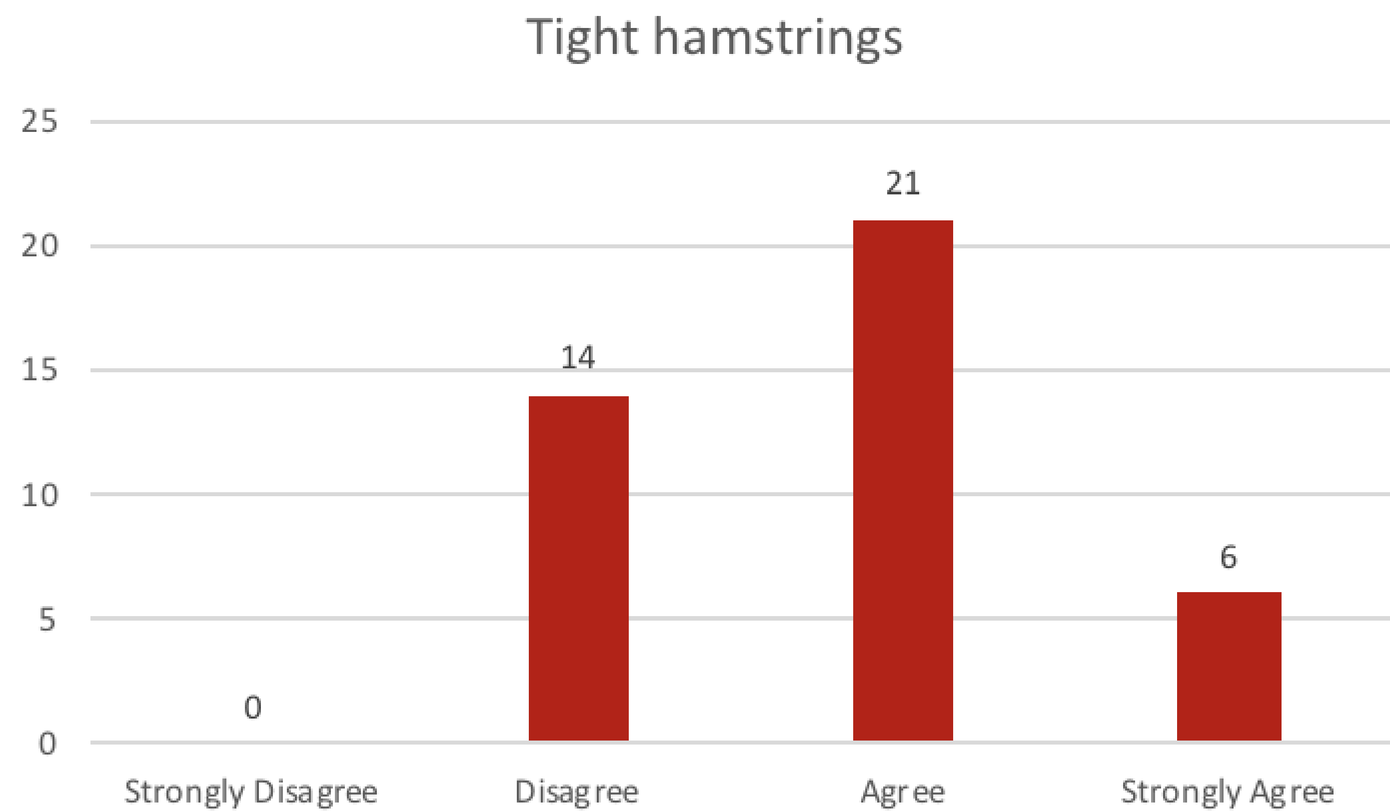
	Strongly disagree	Disagree	Agree	Strongly agree
Tight hip external rotators	○	○	○	○



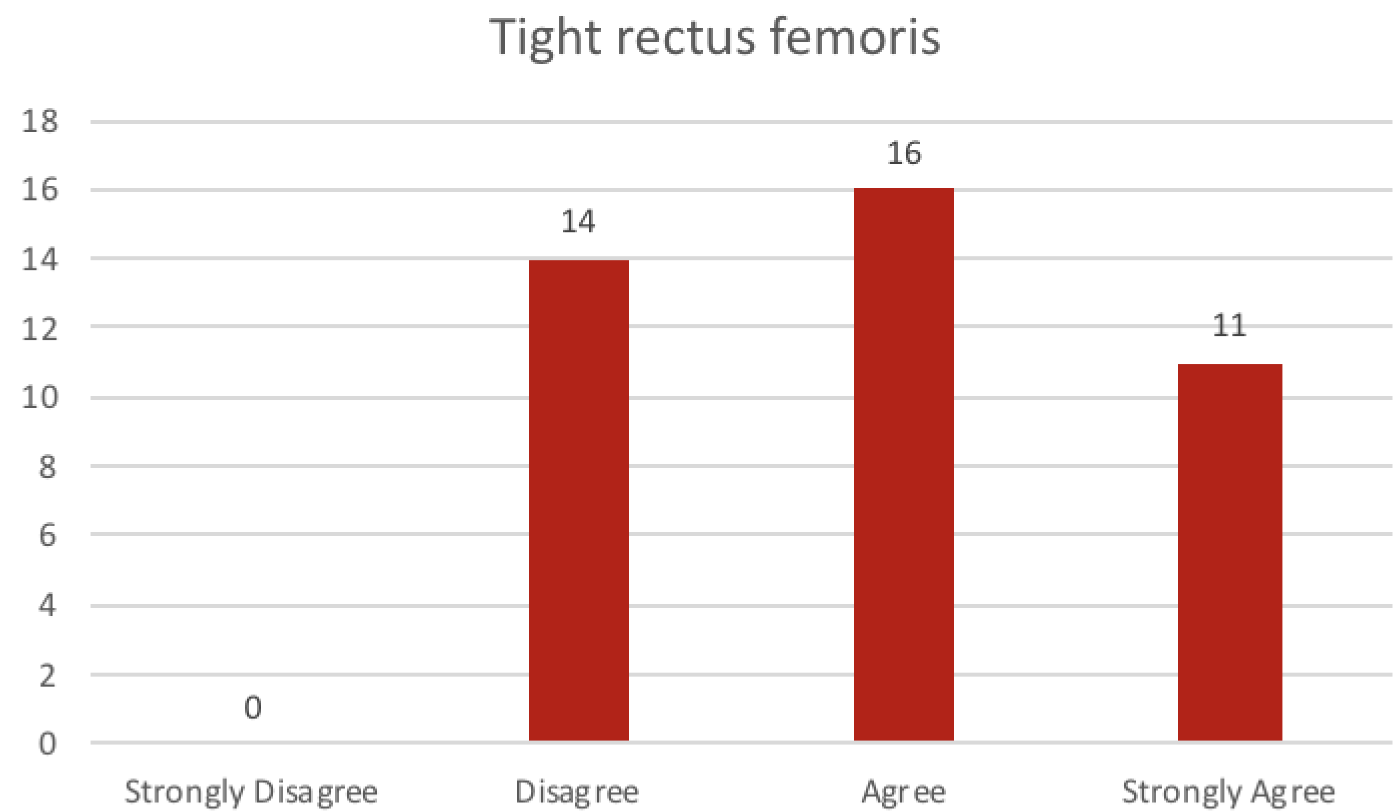
	Strongly disagree	Disagree	Agree	Strongly agree
Tight hip internal rotators	○	○	○	○



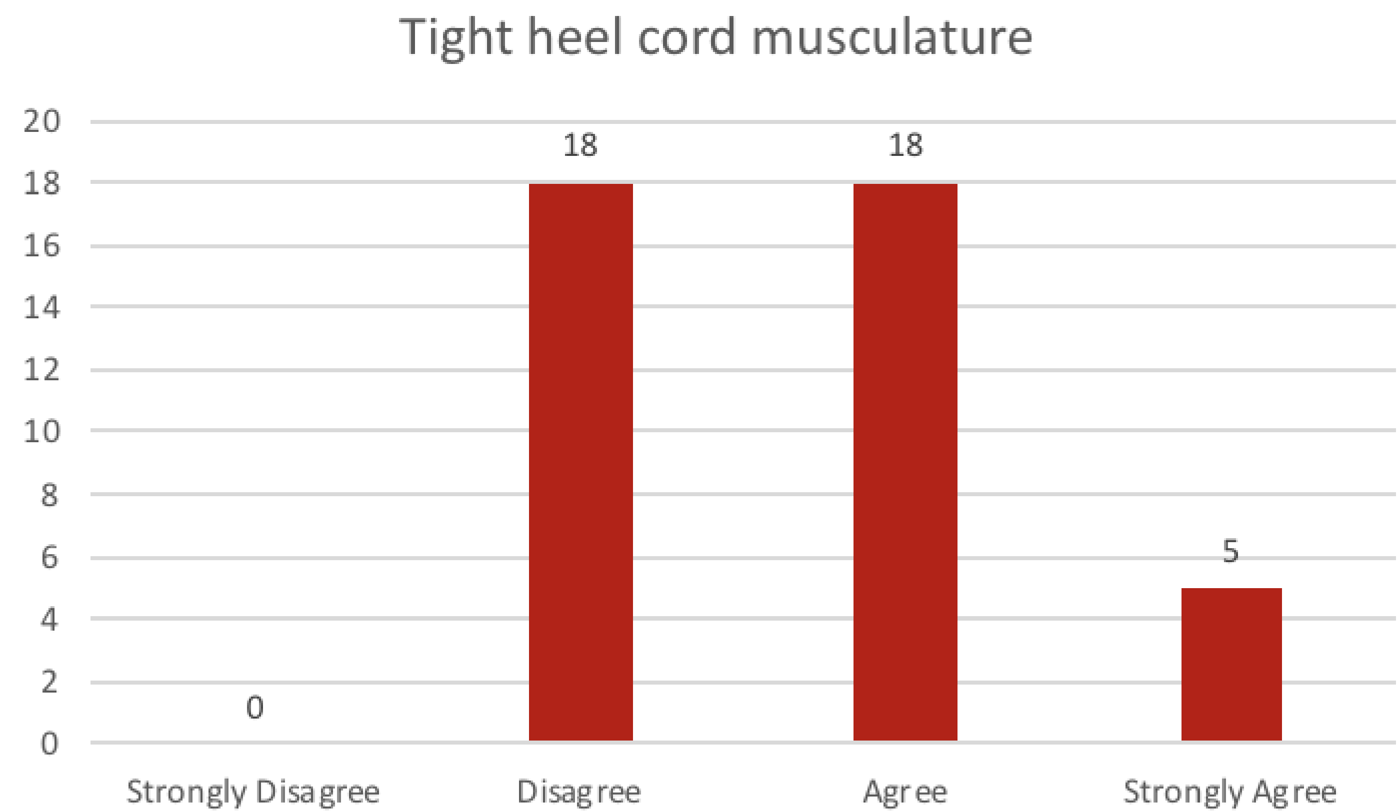
	Strongly disagree	Disagree	Agree	Strongly agree
Tight IT band	○	○	○	○



	Strongly disagree	Disagree	Agree	Strongly agree
Tight hamstrings	O	O	O	O



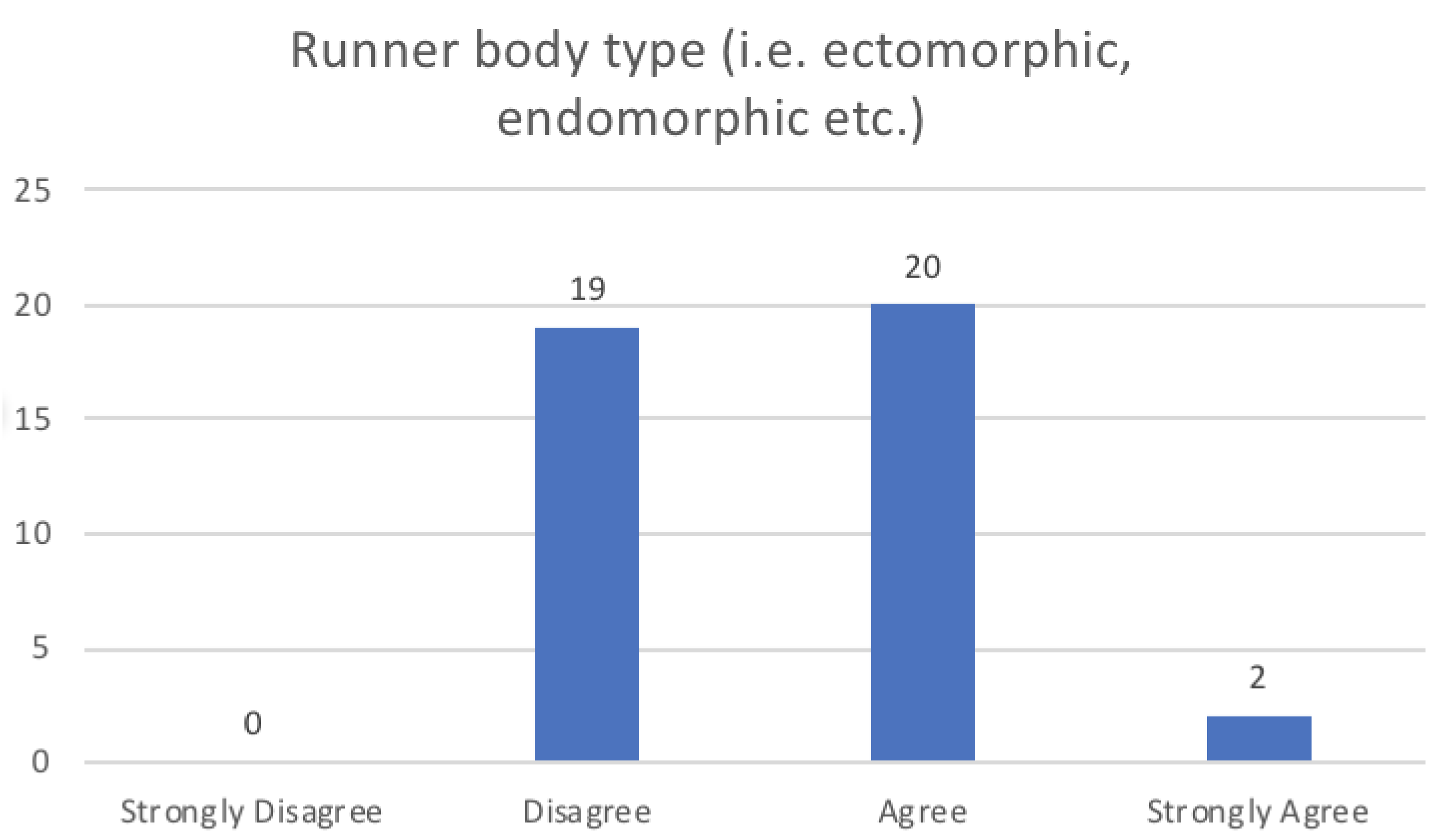
	Strongly disagree	Disagree	Agree	Strongly agree
Tight rectus femoris	O	O	O	O



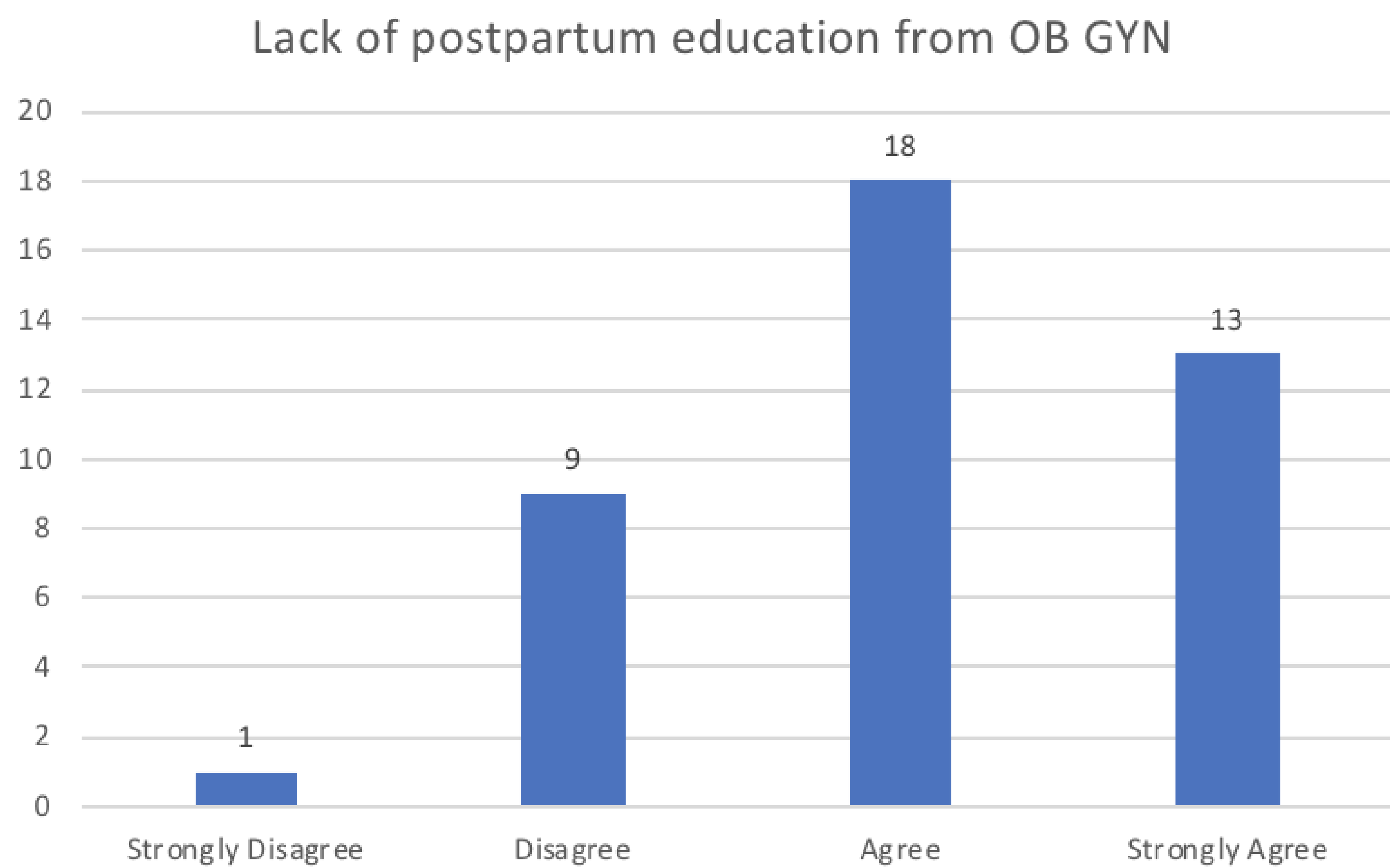
	Strongly disagree	Disagree	Agree	Strongly agree
Tight heel cord musculature	O	O	O	O

Comments:

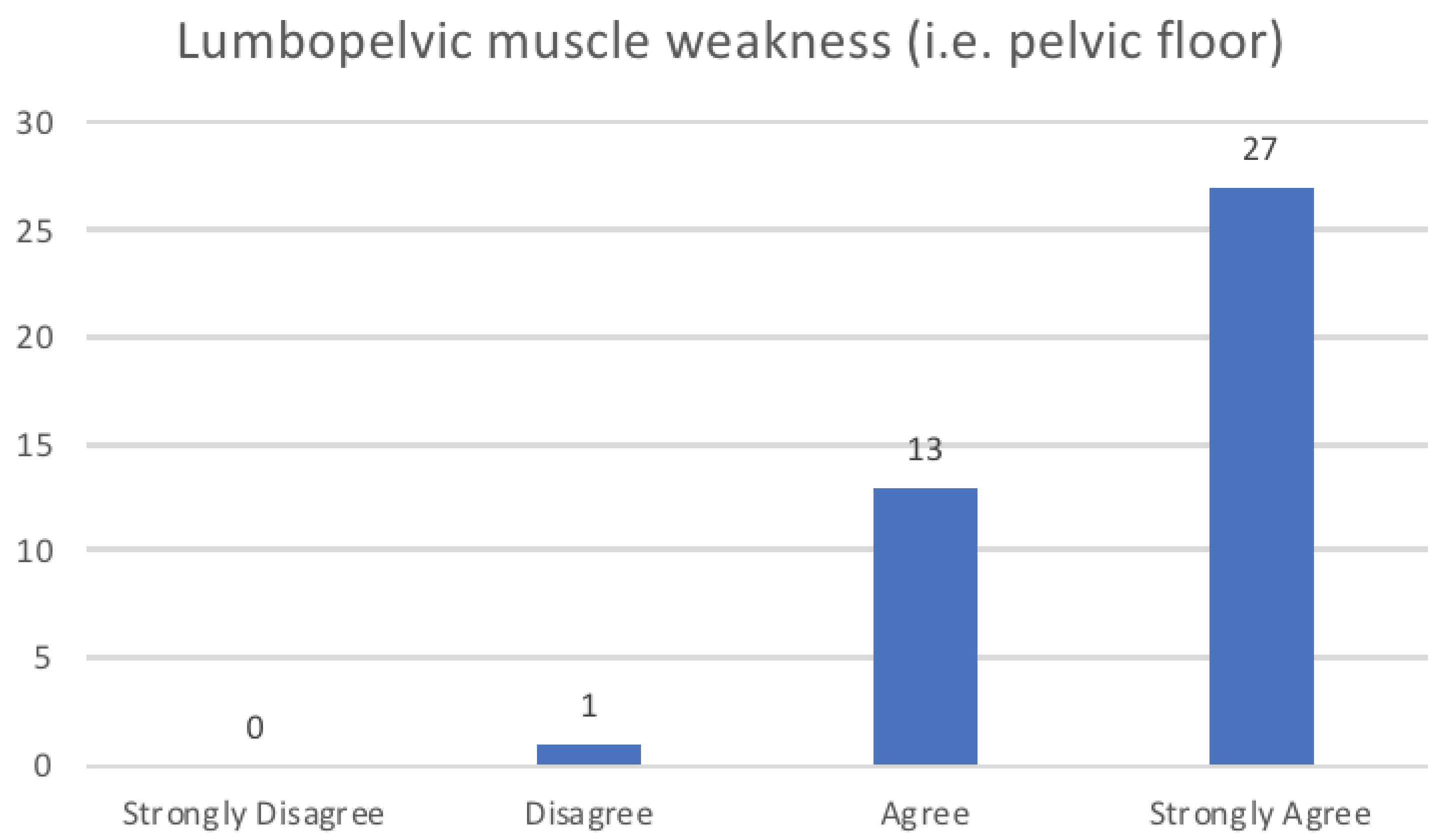
For each of the following risk factors please indicate whether or not you agree that it contributes to pain in the postpartum runner.



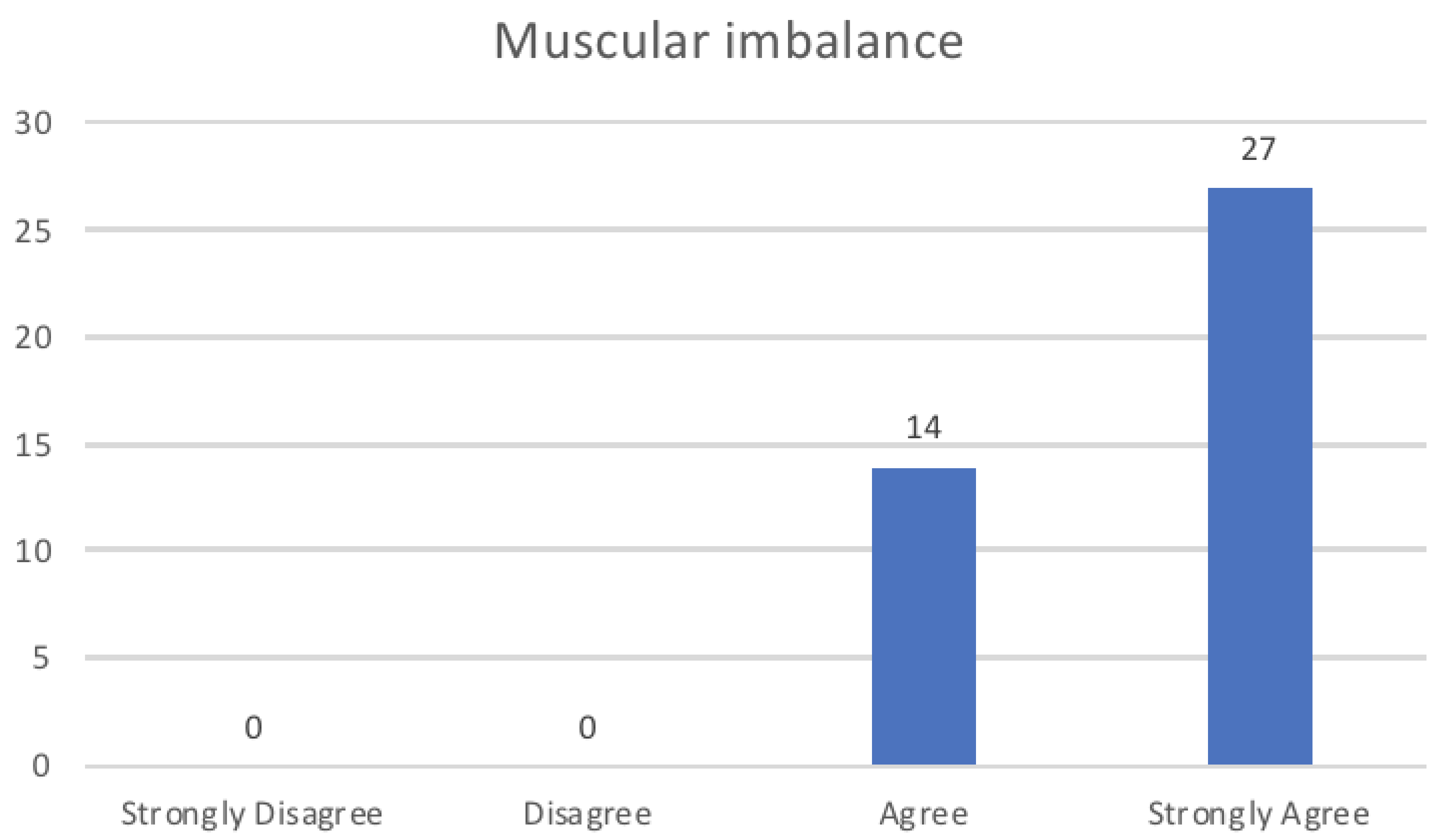
	Strongly disagree	Disagree	Agree	Strongly agree
Runner body type	○	○	○	○



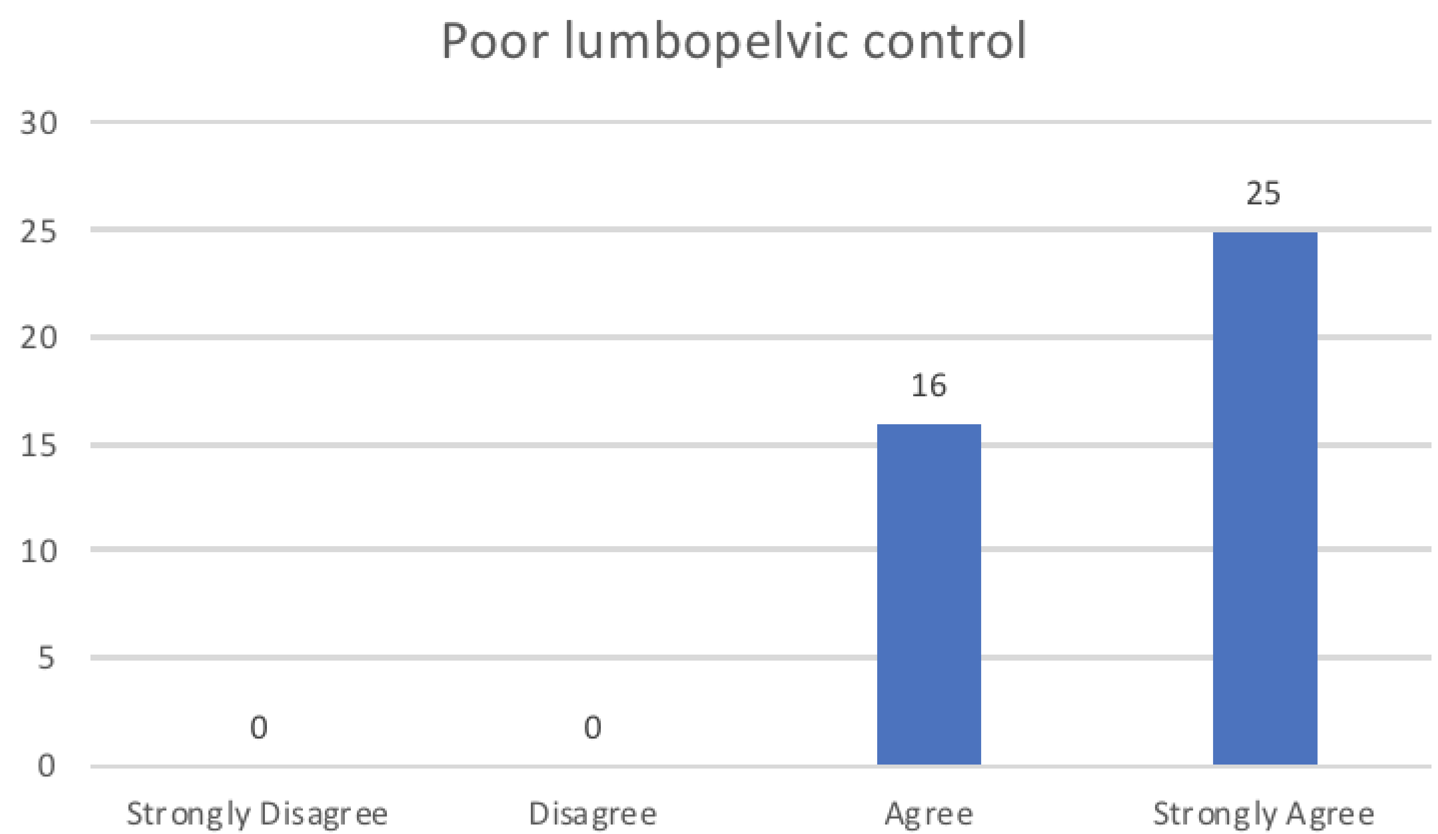
	Strongly Disagree	Disagree	Agree	Strongly agree
Lack of postpartum education from OB GYN	O	O	O	O



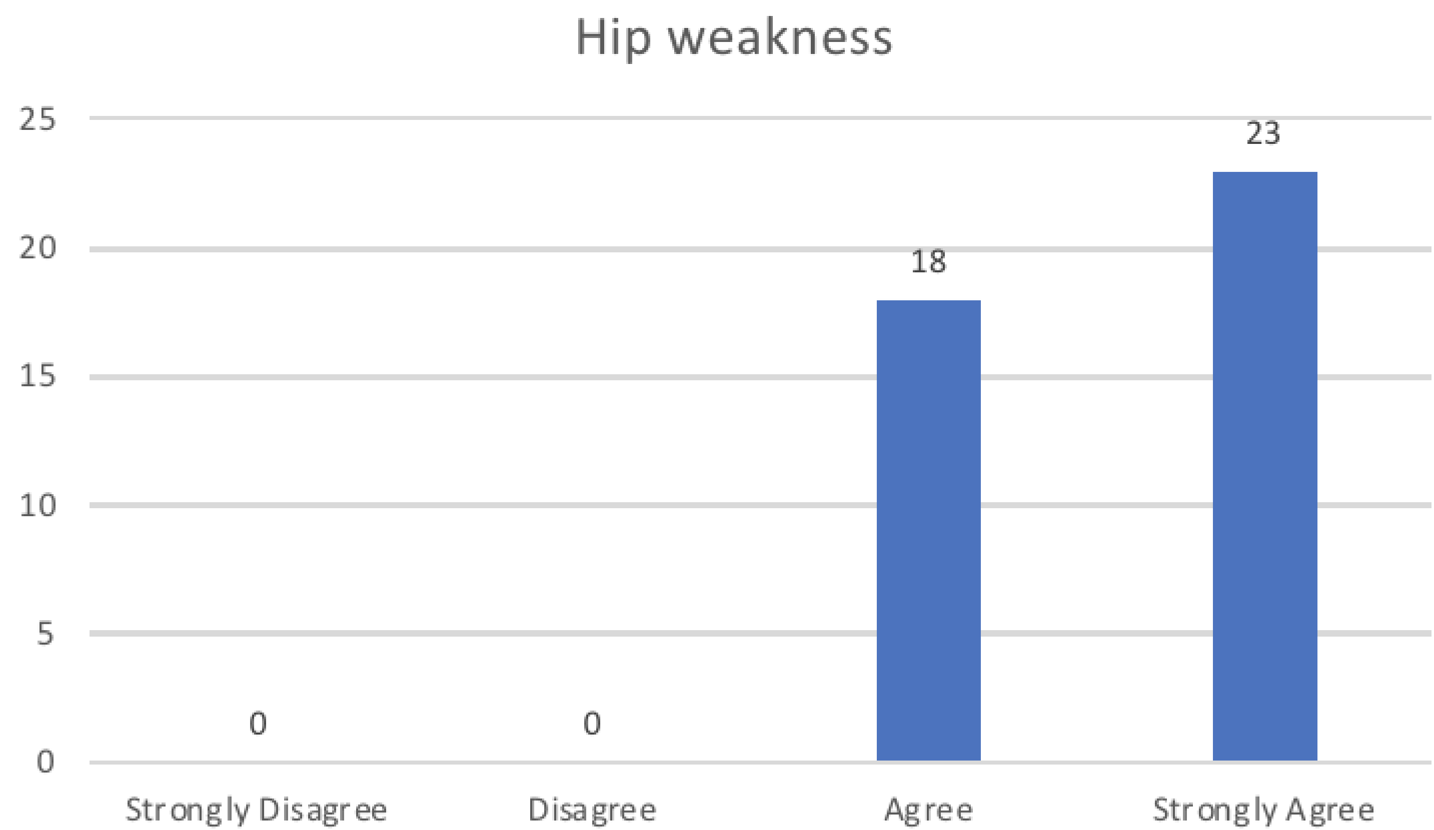
	Strongly disagree	Disagree	Agree	Strongly agree
Lumbopelvic muscle weakness	O	O	O	O



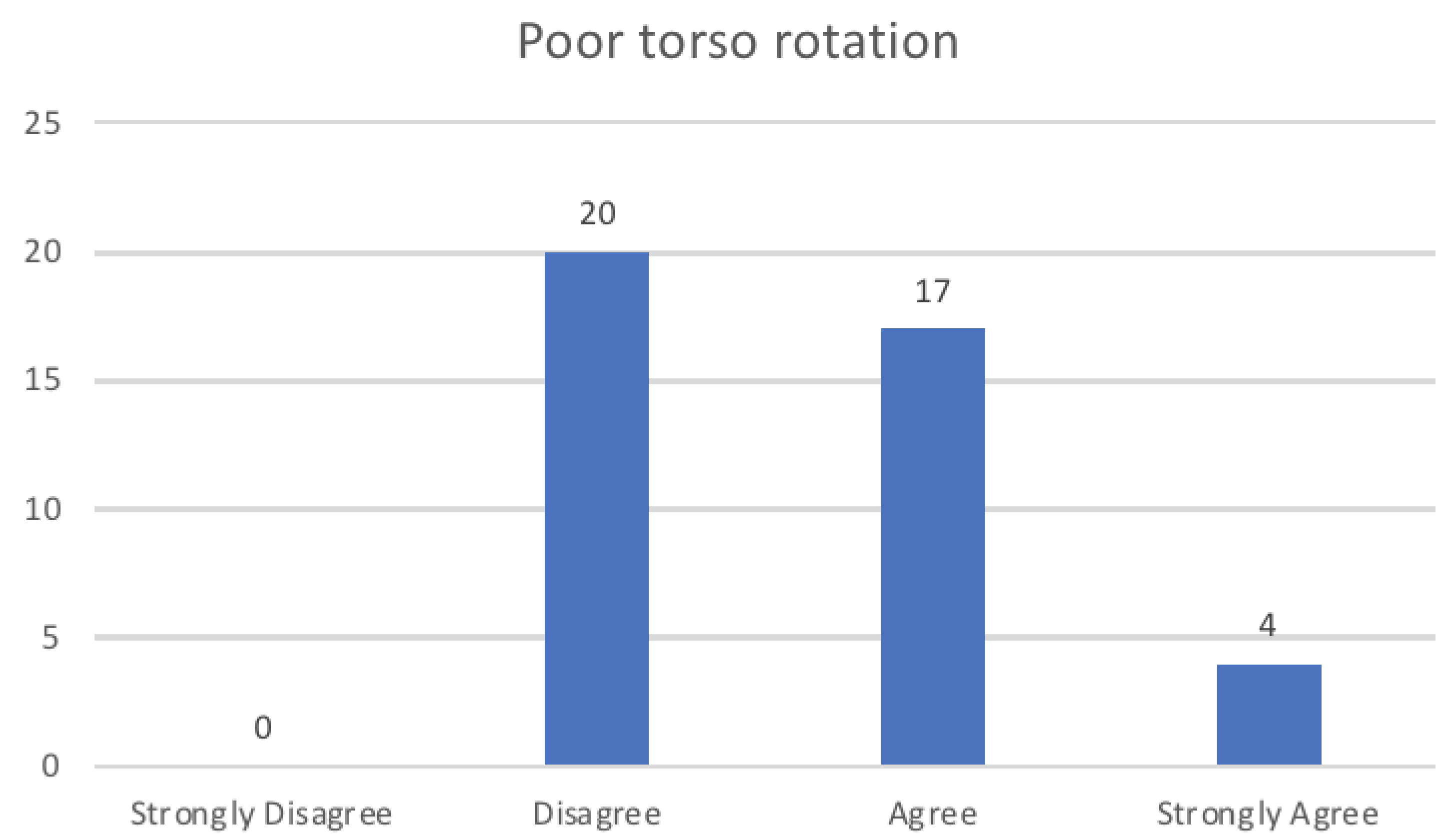
	Strongly Disagree	Disagree	Agree	Strongly agree
Muscular imbalance	O	O	O	O



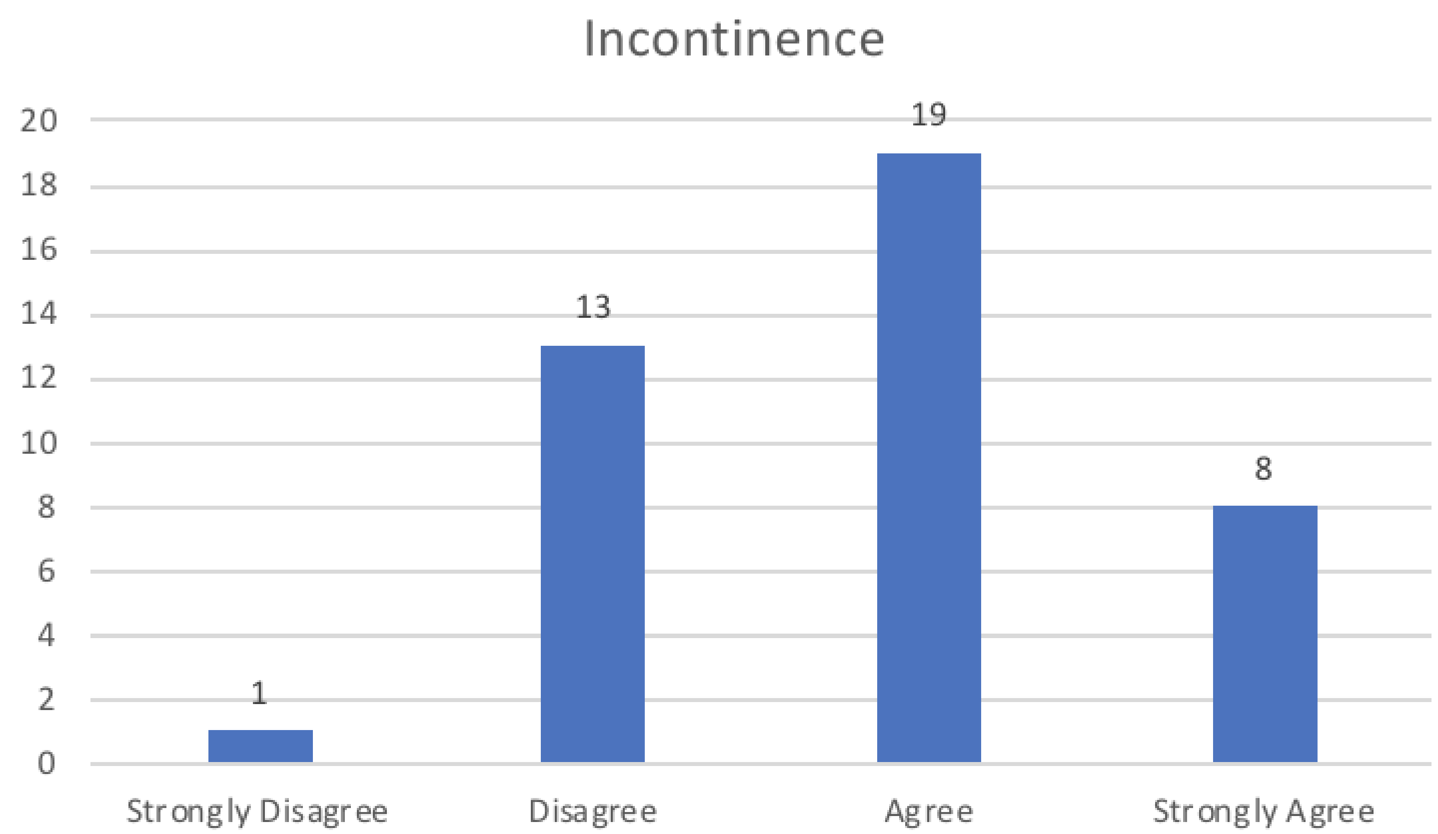
	Strongly disagree	Disagree	Agree	Strongly agree
Poor lumbopelvic control	O	O	O	O



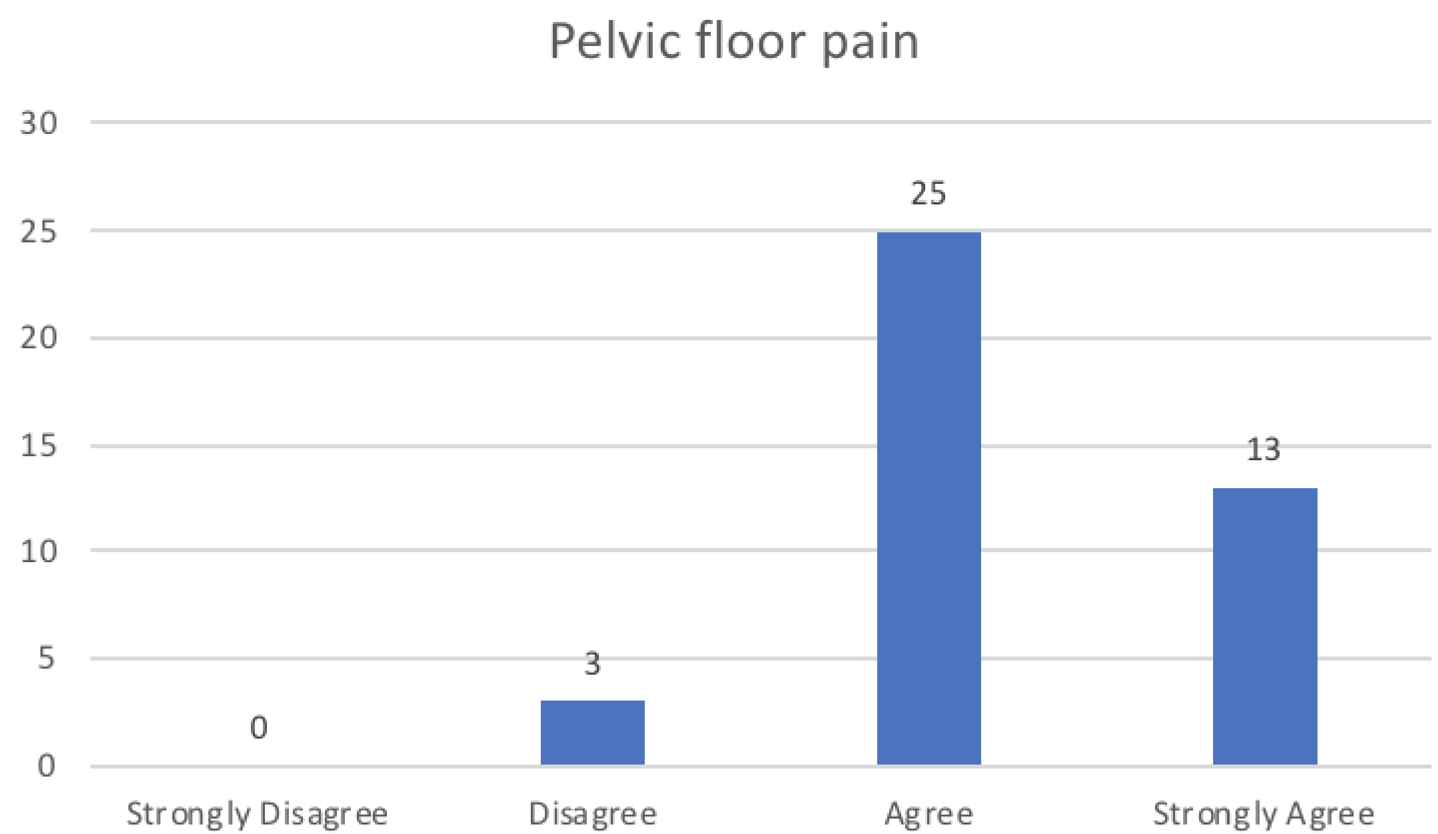
	Strongly disagree	Disagree	Agree	Strongly agree
Hip Weakness	O	O	O	O



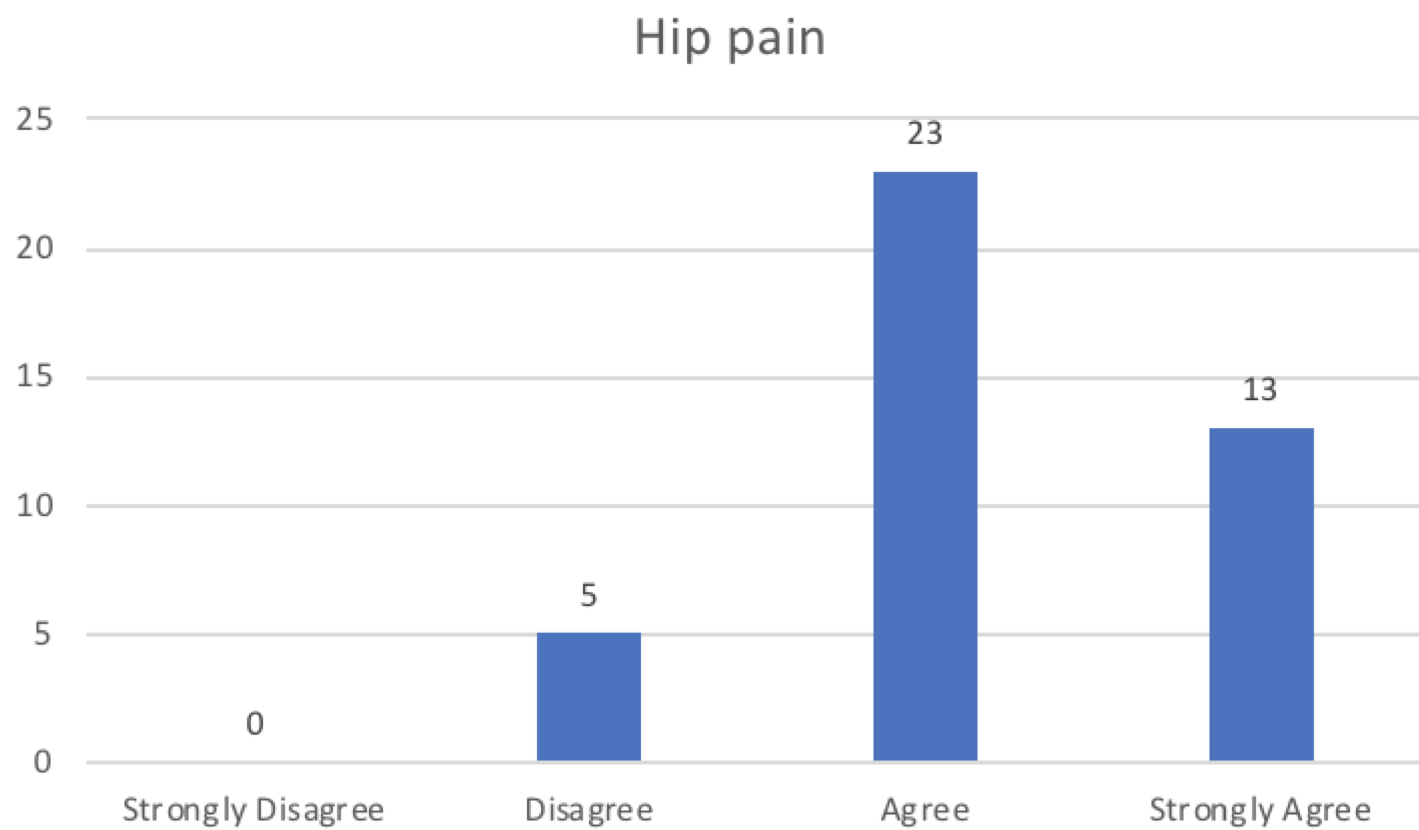
	Strongly disagree	Disagree	Agree	Strongly agree
Poor torso rotation	○	○	○	○



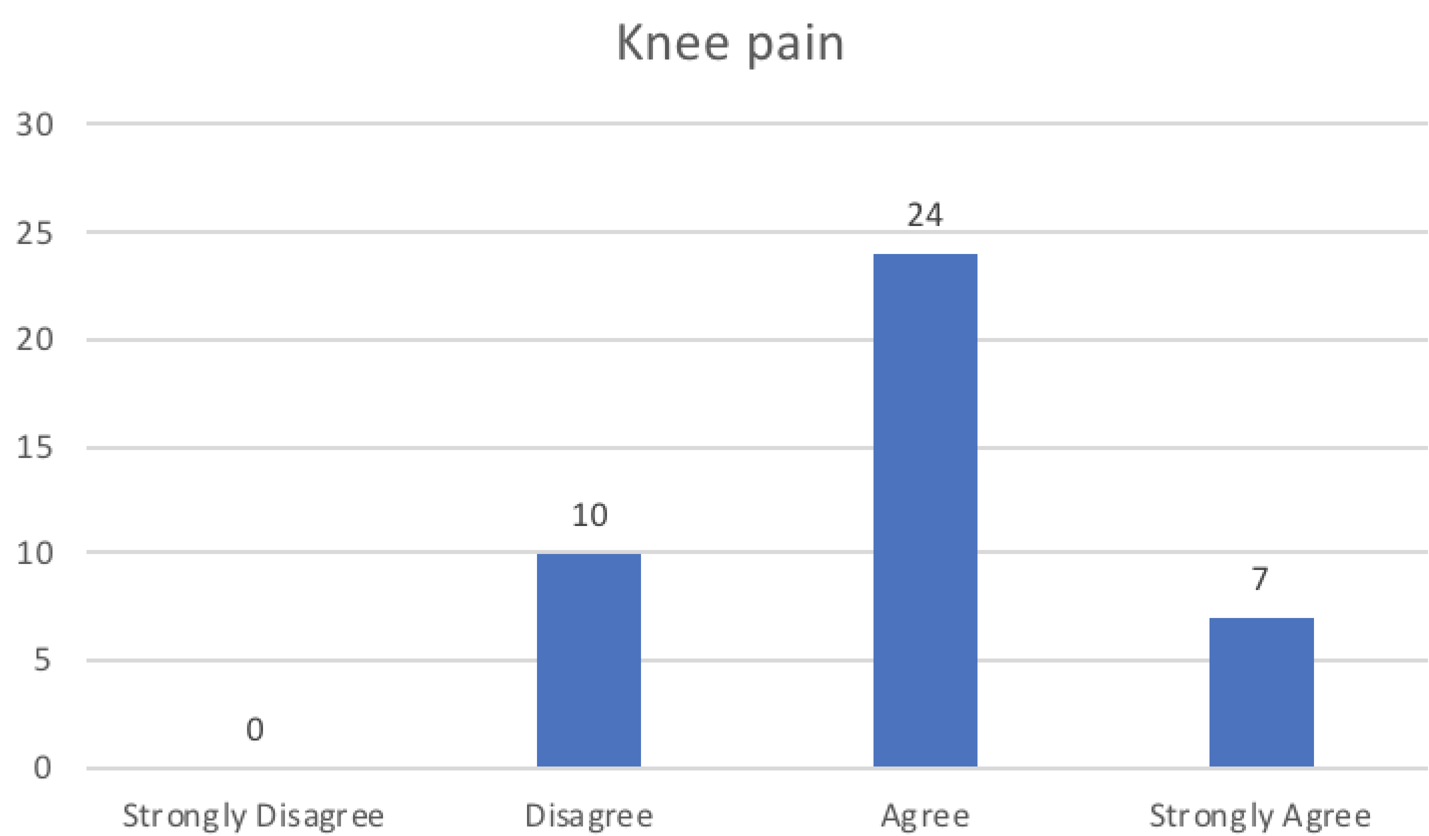
	Strongly disagree	Disagree	Agree	Strongly agree
Incontinence	O	O	O	O



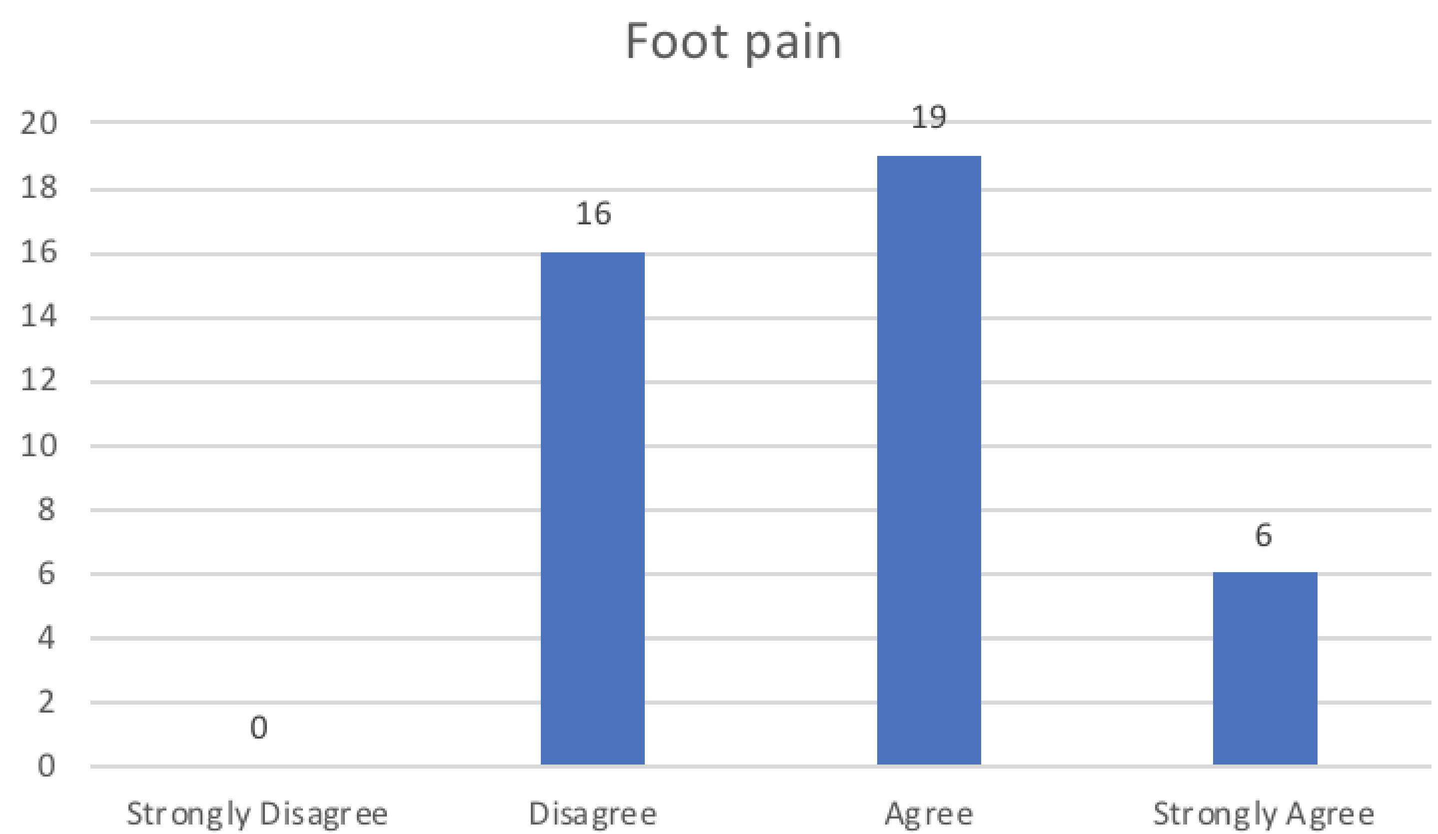
	Strongly disagree	Disagree	Agree	Strongly agree
Pelvic floor pain	○	○	○	○



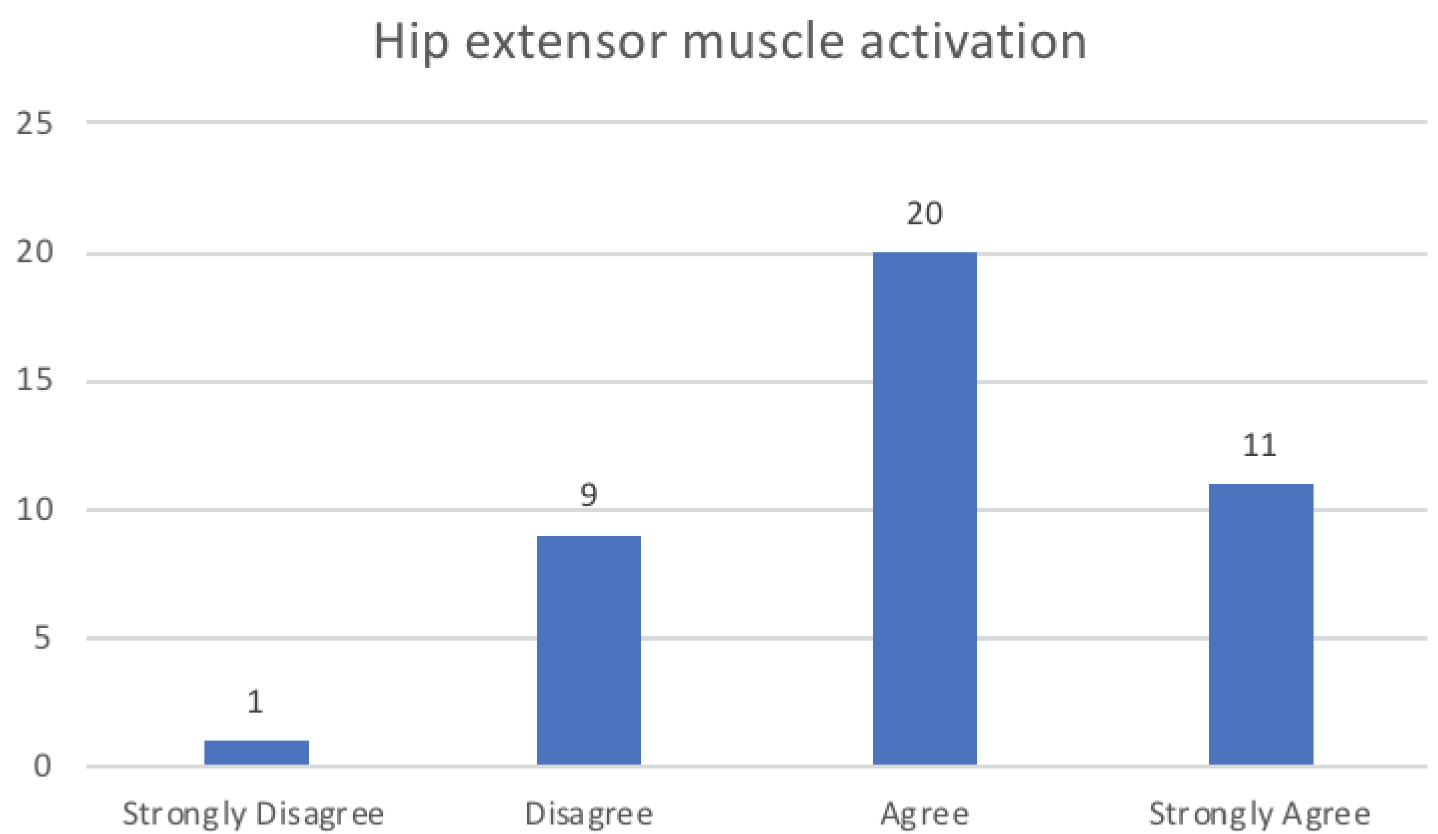
	Strongly disagree	Disagree	Agree	Strongly agree
Hip pain	○	○	○	○



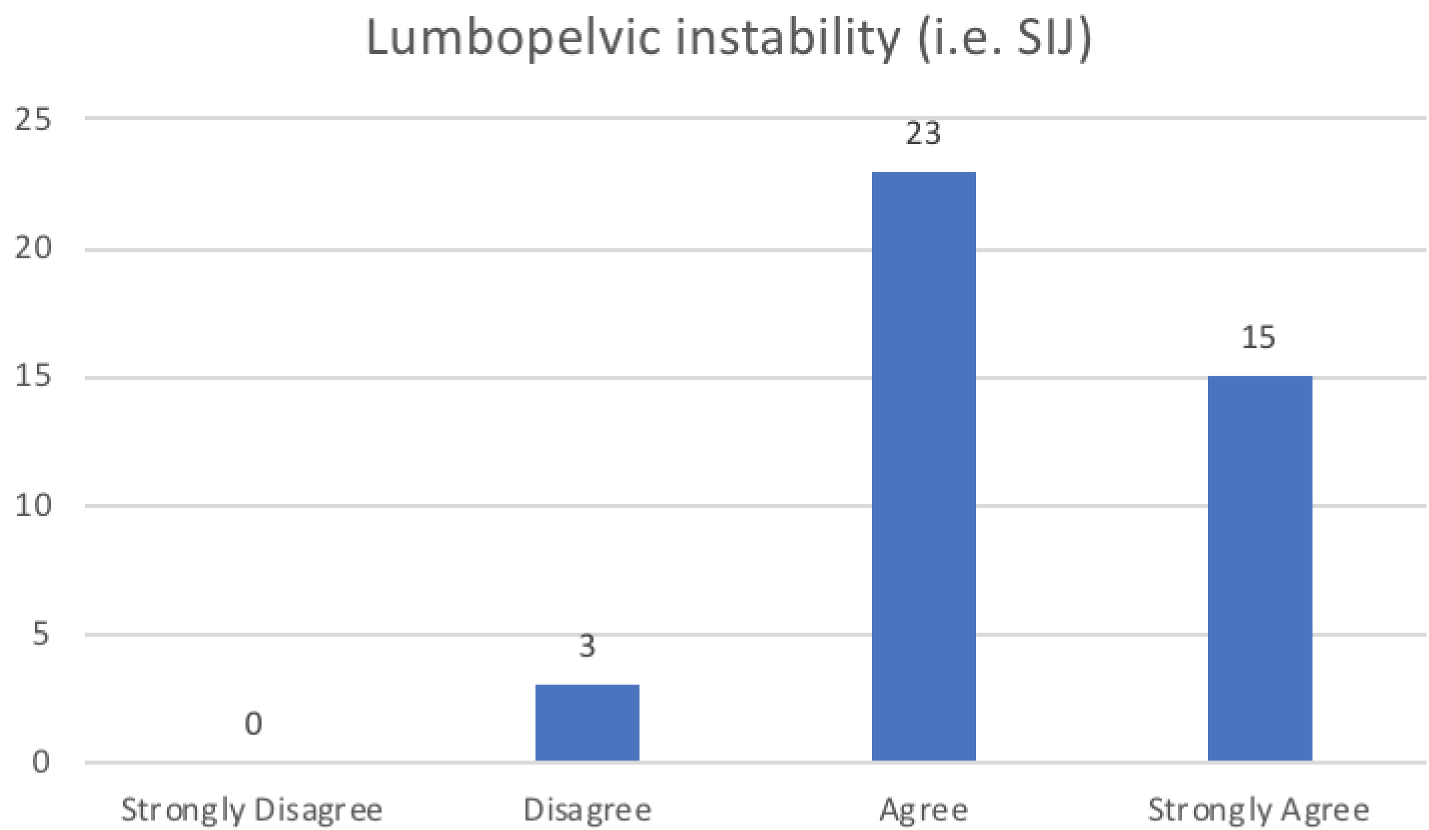
	Strongly disagree	Disagree	Agree	Strongly agree
Knee pain	○	○	○	○



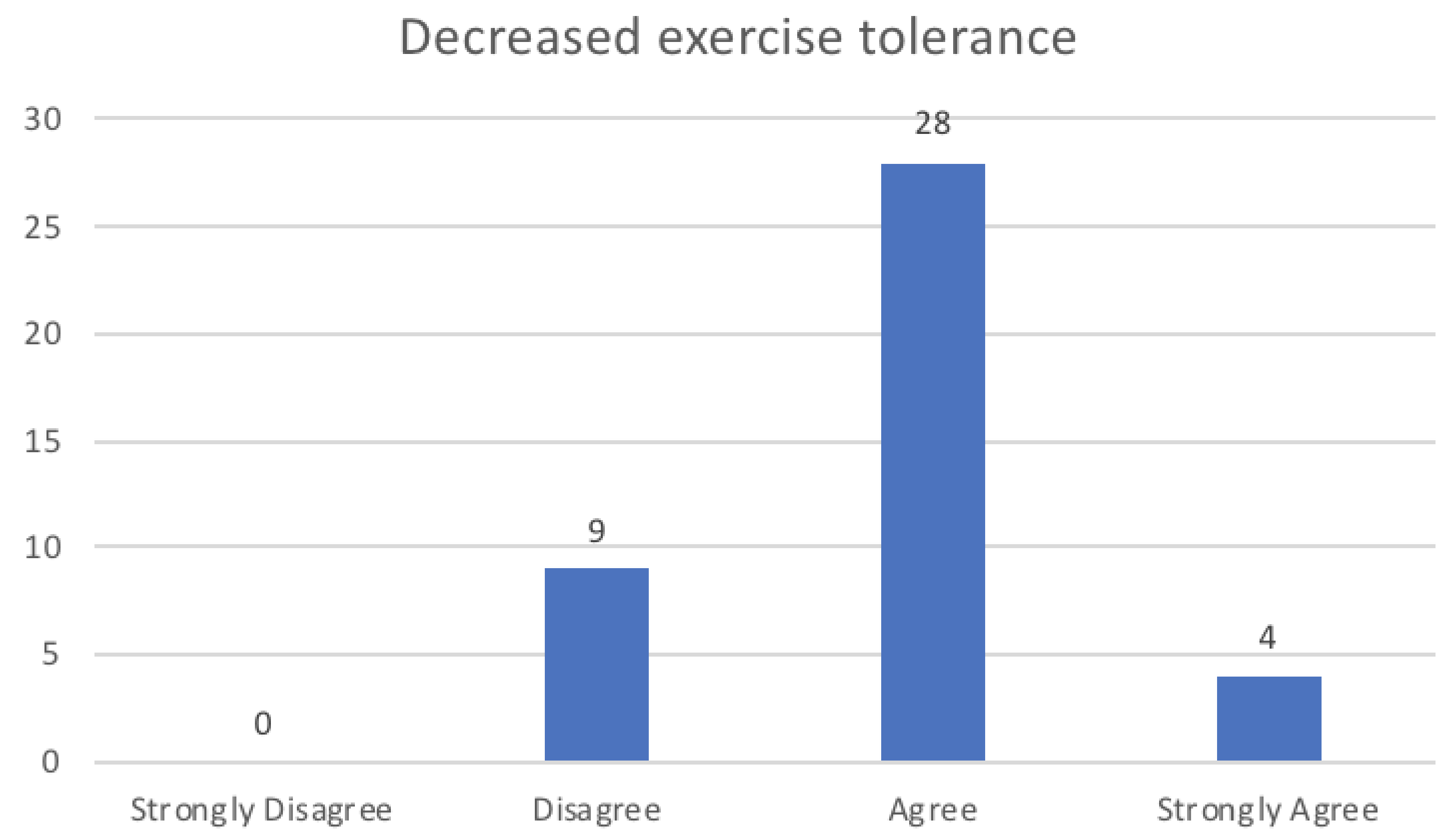
	Strongly disagree	Disagree	Agree	Strongly agree
Foot pain	○	○	○	○



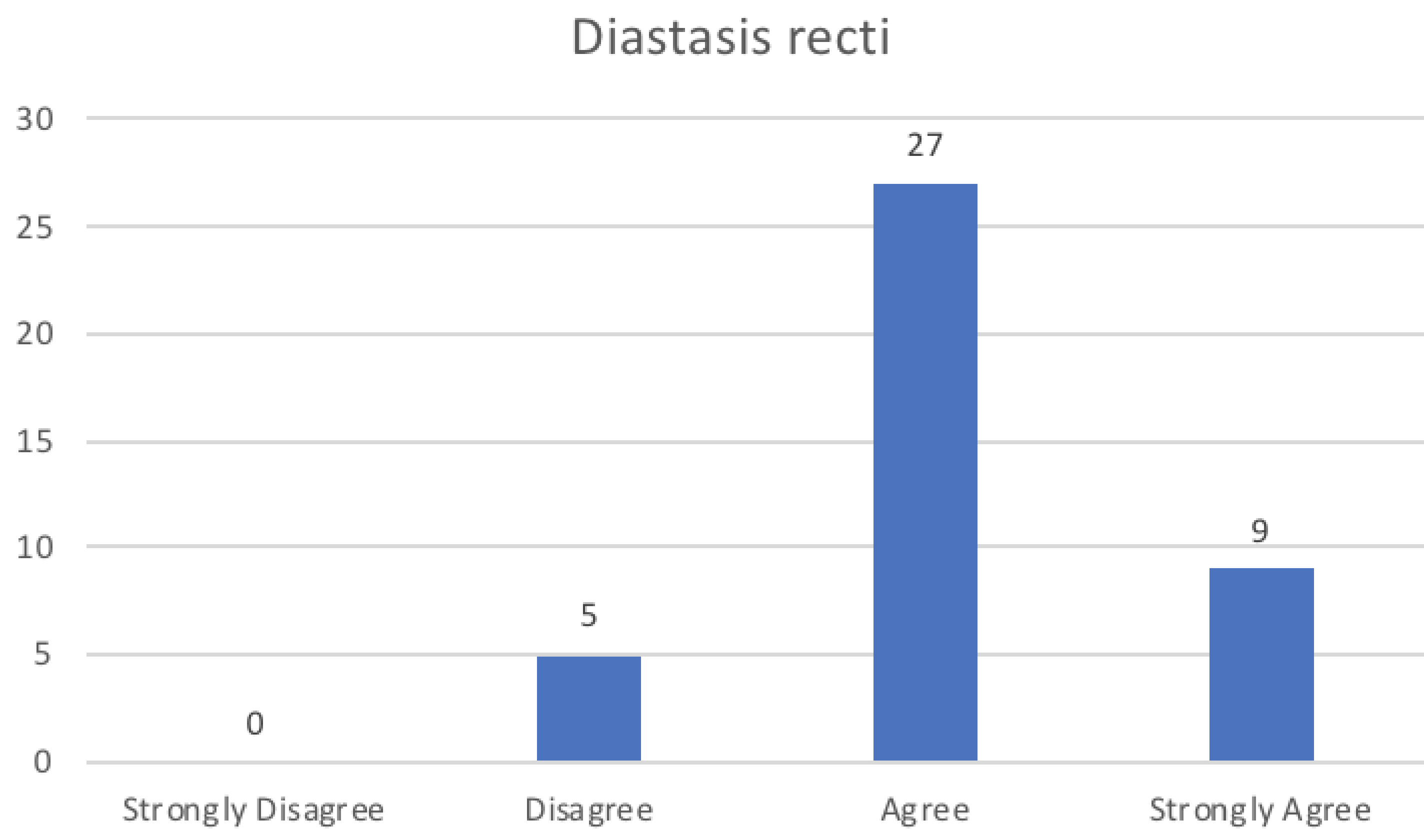
	Strongly disagree	Disagree	Agree	Strongly agree
Hip extensor muscle activation	O	O	O	O



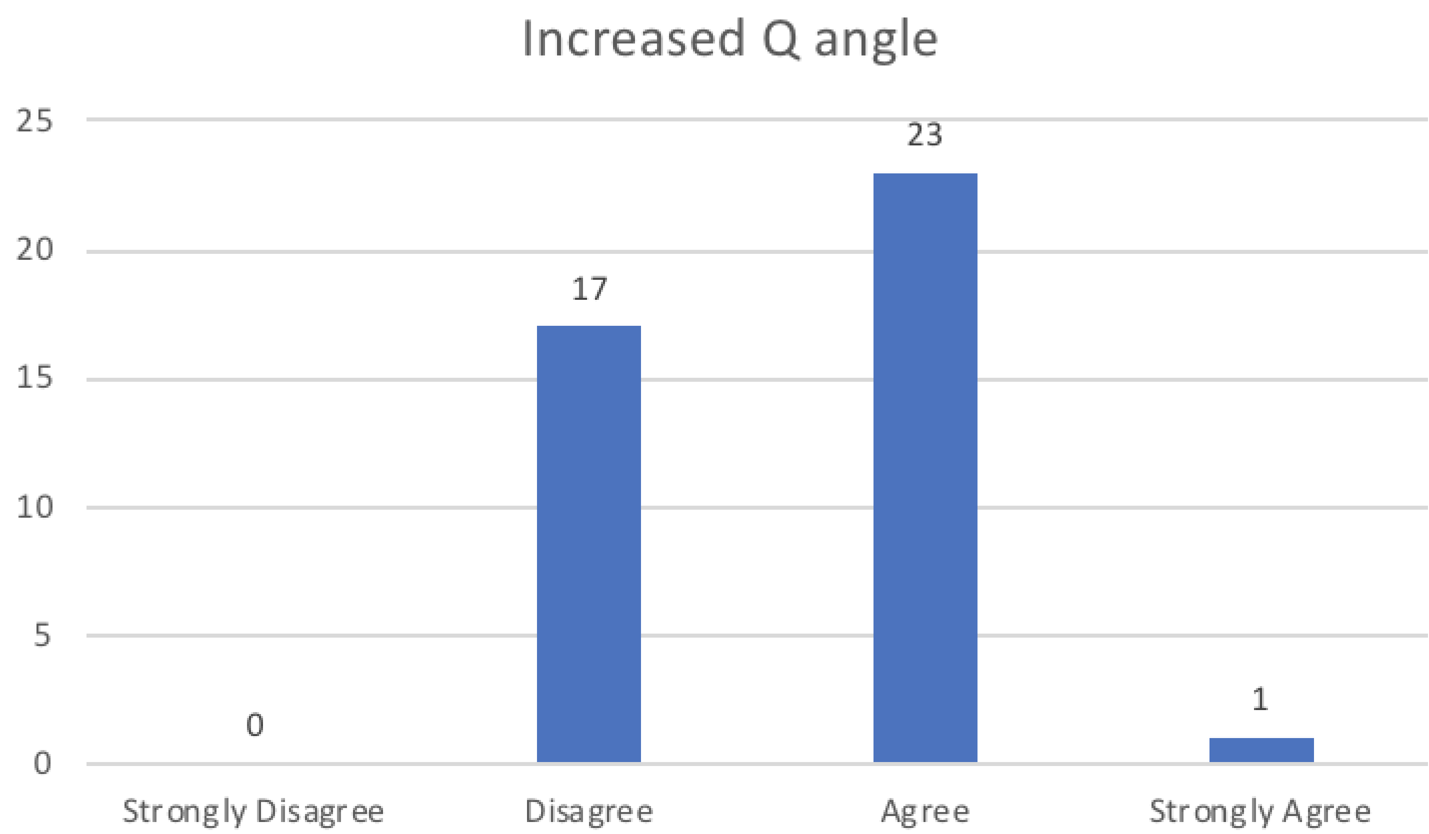
	Strongly disagree	Disagree	Agree	Strongly agree
Lumbopelvic instability	○	○	○	○



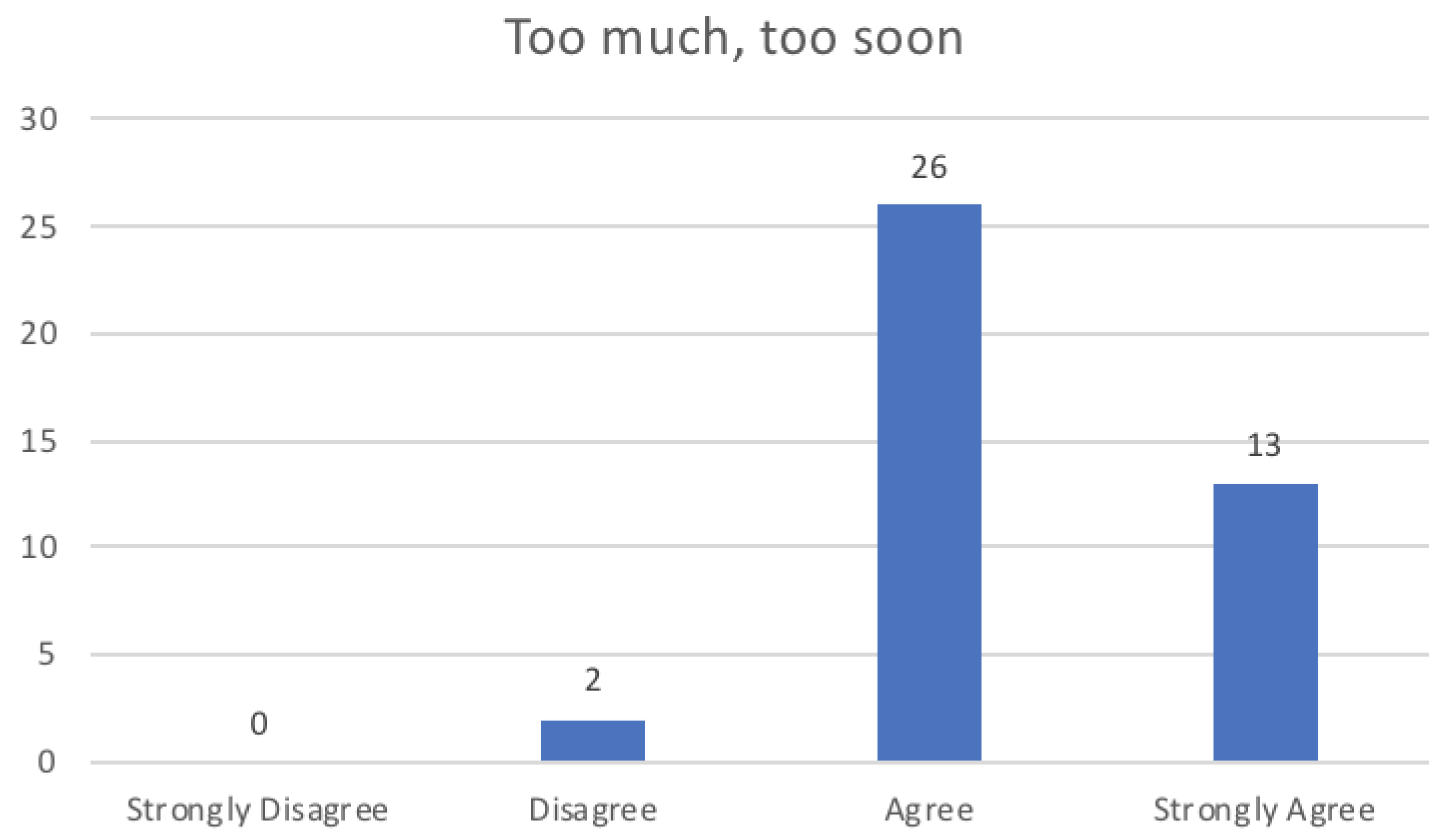
	Strongly disagree	Disagree	Agree	Strongly agree
Decreased exercise tolerance	○	○	○	○



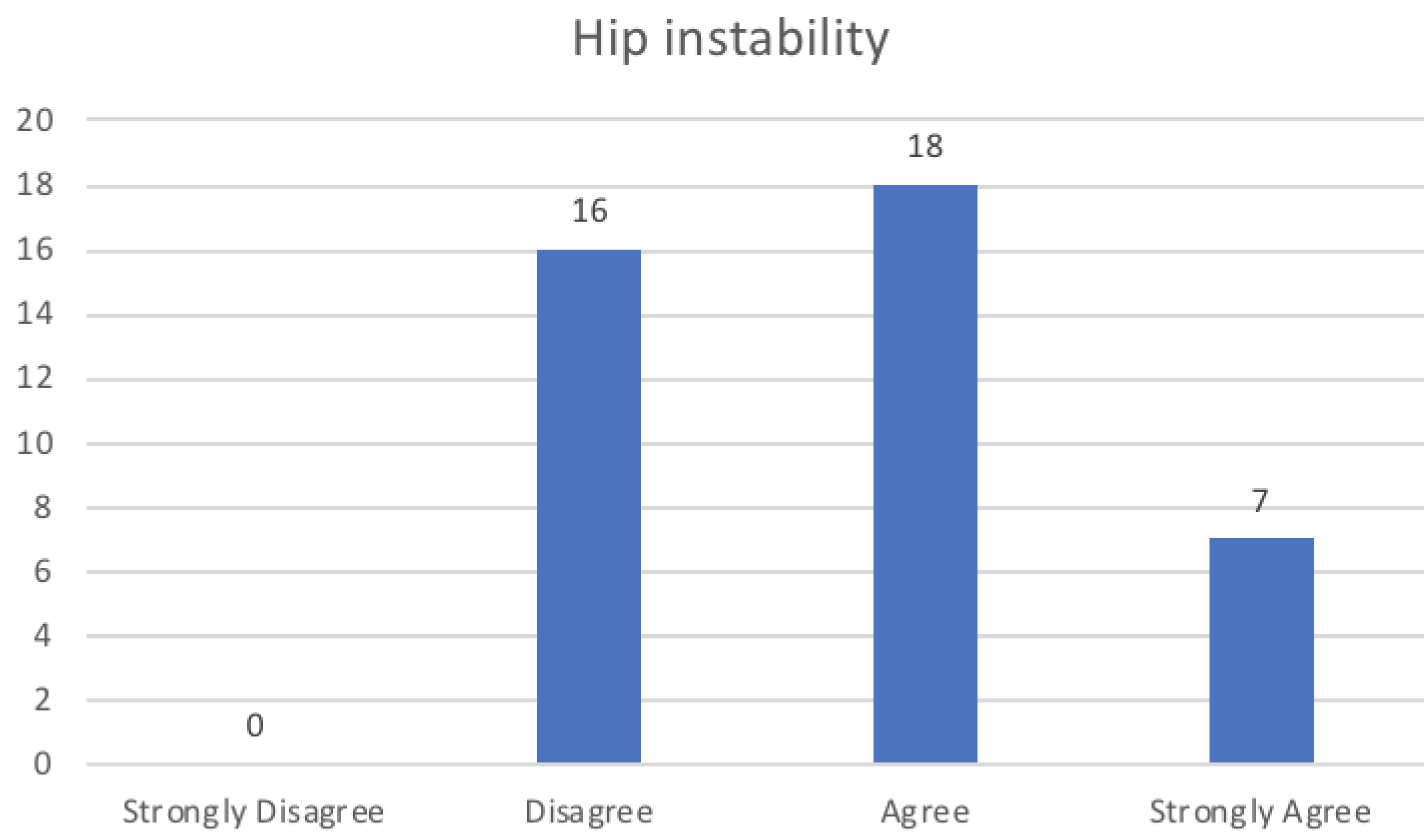
	Strongly disagree	Disagree	Agree	Strongly agree
Diastasis Recti	O	O	O	O



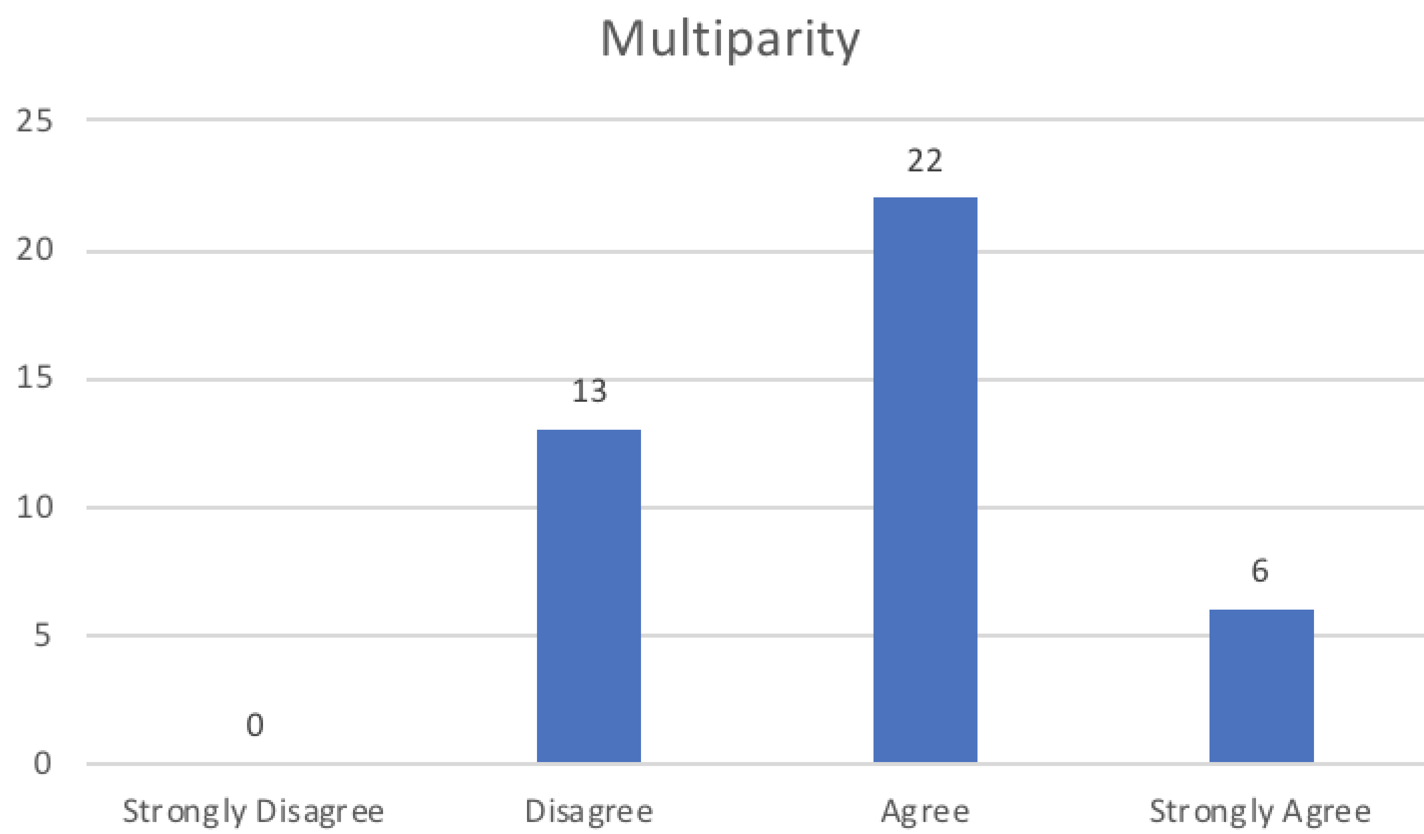
	Strongly disagree	Disagree	Agree	Strongly agree
Increased Q angle	○	○	○	○



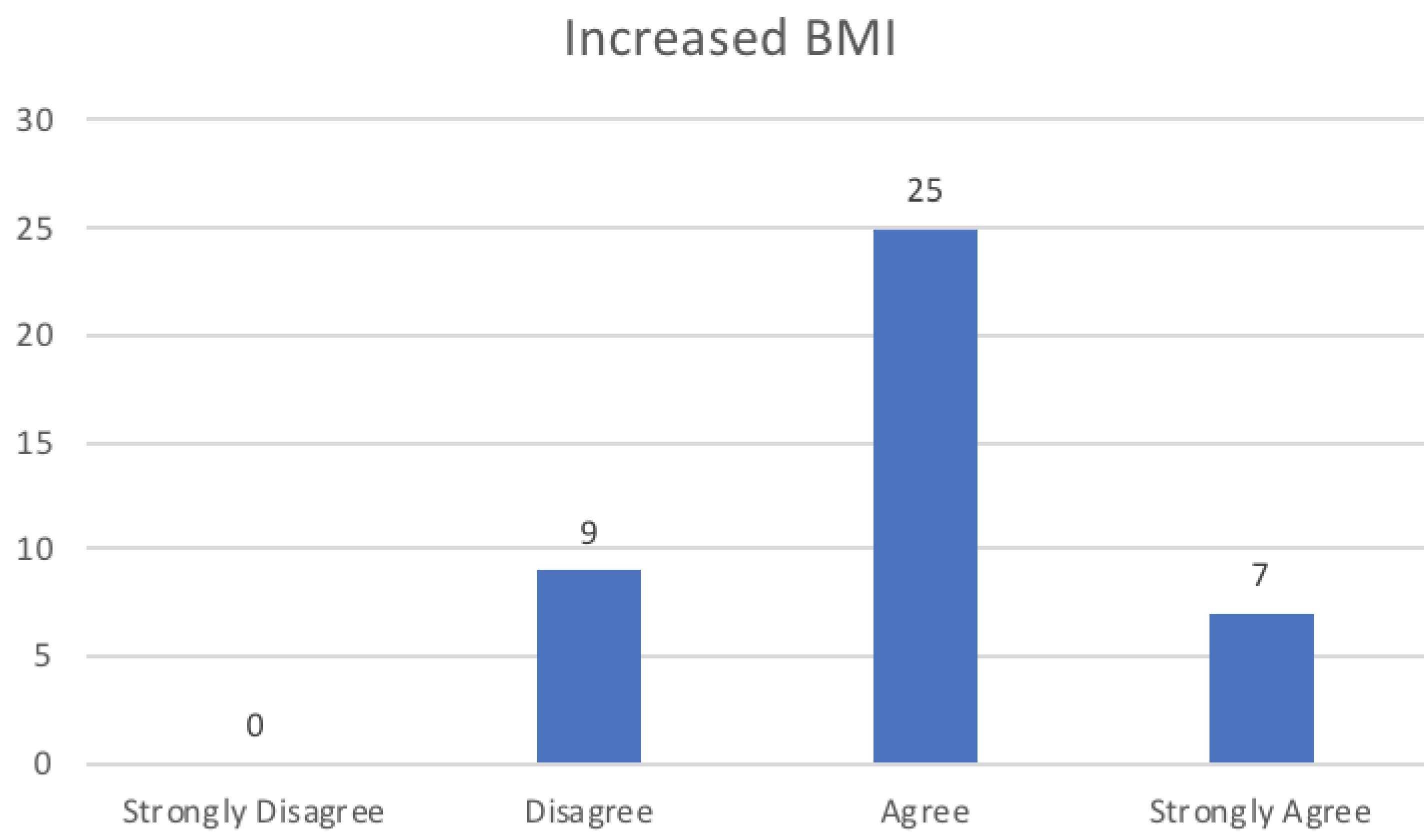
	Strongly disagree	Disagree	Agree	Strongly agree
Too much too soon	○	○	○	○



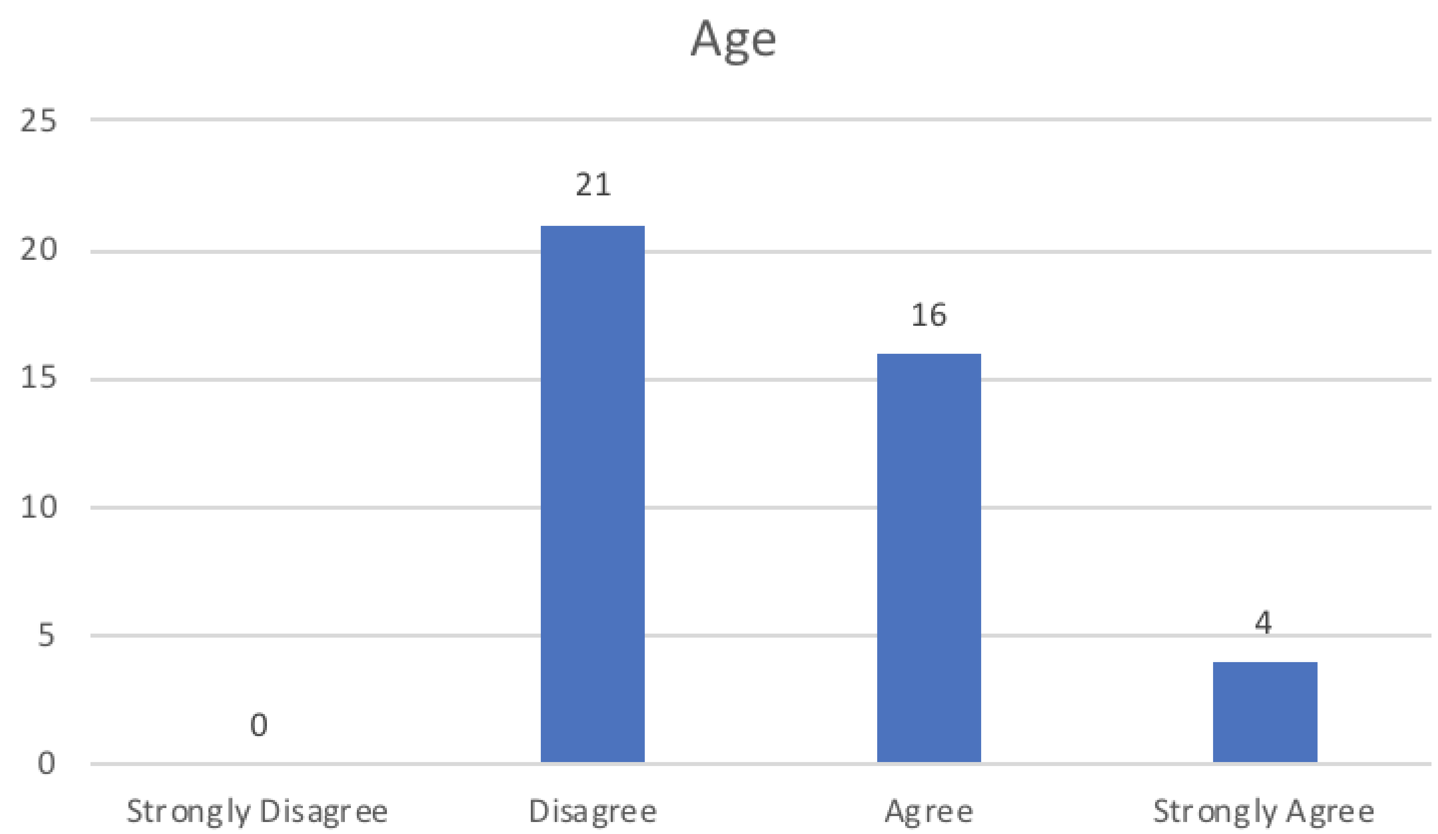
	Strongly disagree	Disagree	Agree	Strongly agree
Hip instability	O	O	O	O



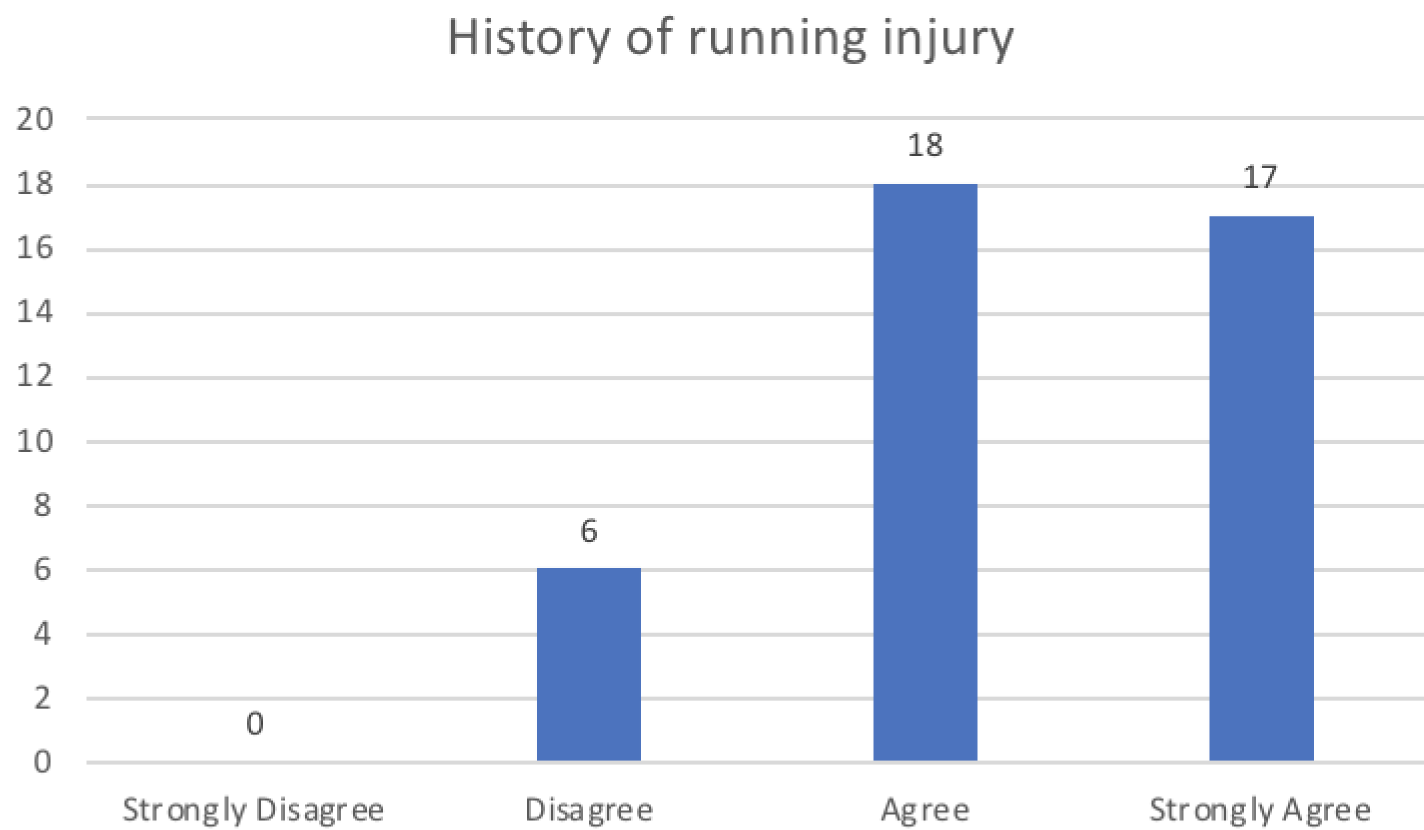
	Strongly disagree	Disagree	Agree	Strongly agree
Multiparity	O	O	O	O



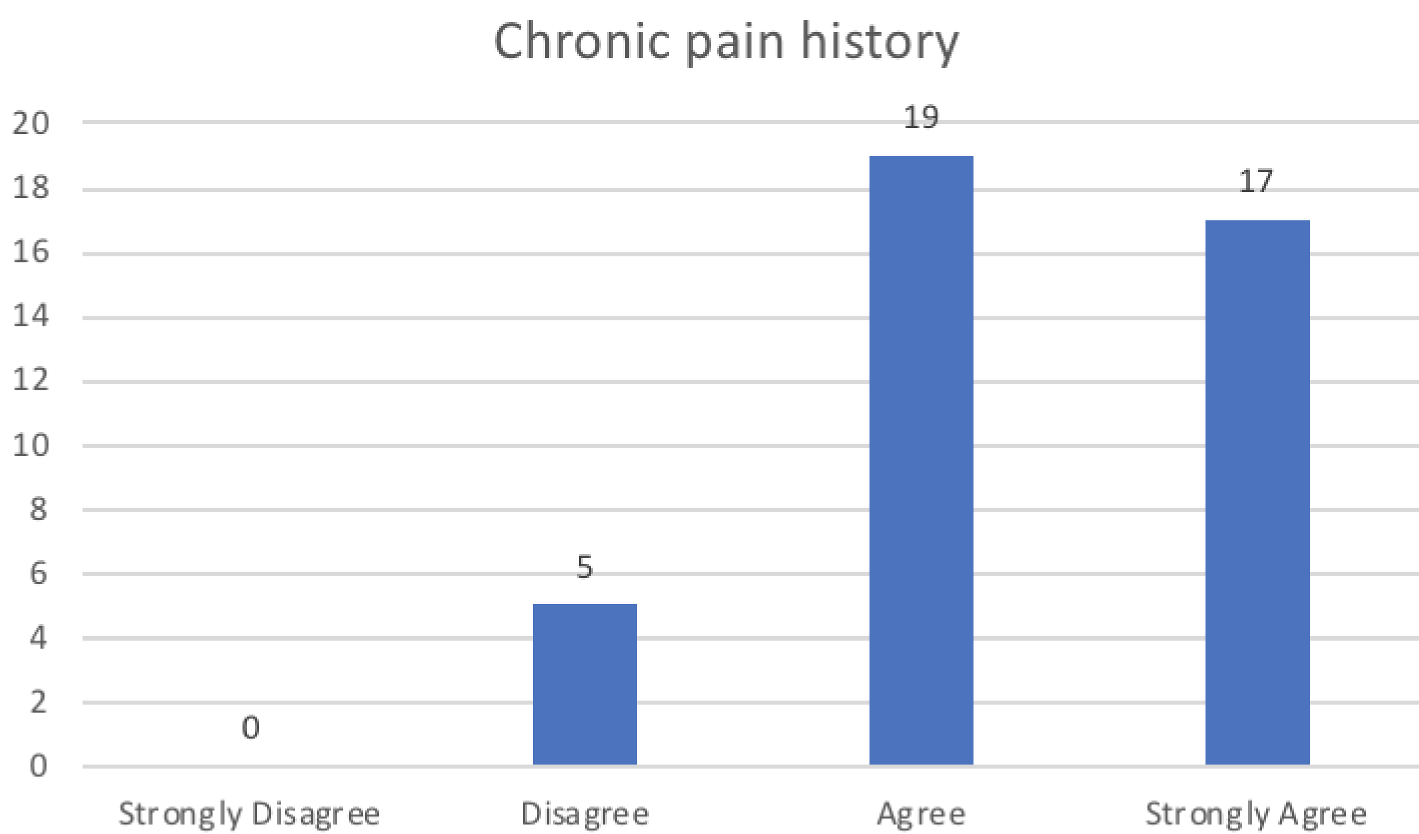
	Strongly disagree	Disagree	Agree	Strongly agree
Increased BMI	O	O	O	O



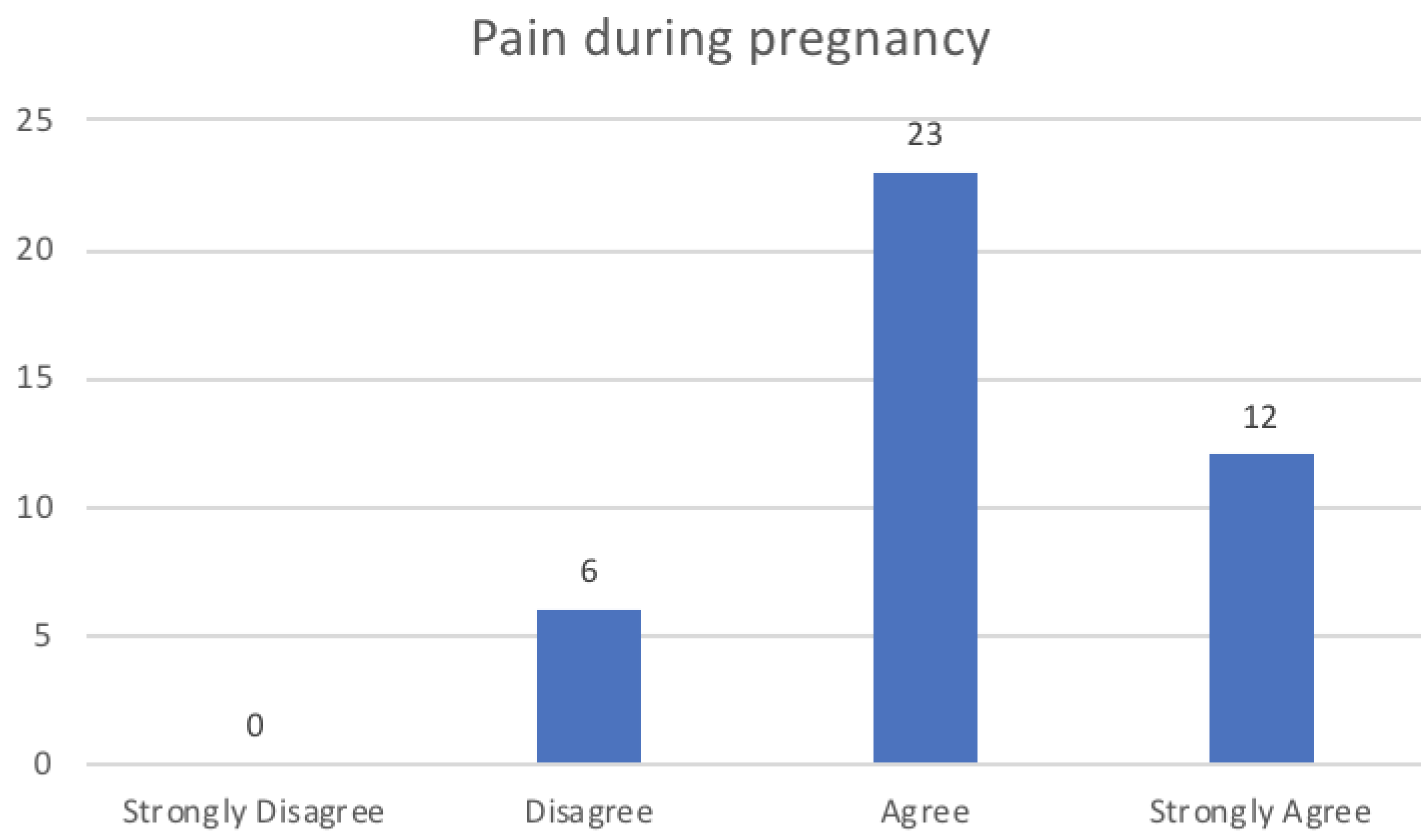
	Strongly disagree	Disagree	Agree	Strongly agree
Age	○	○	○	○



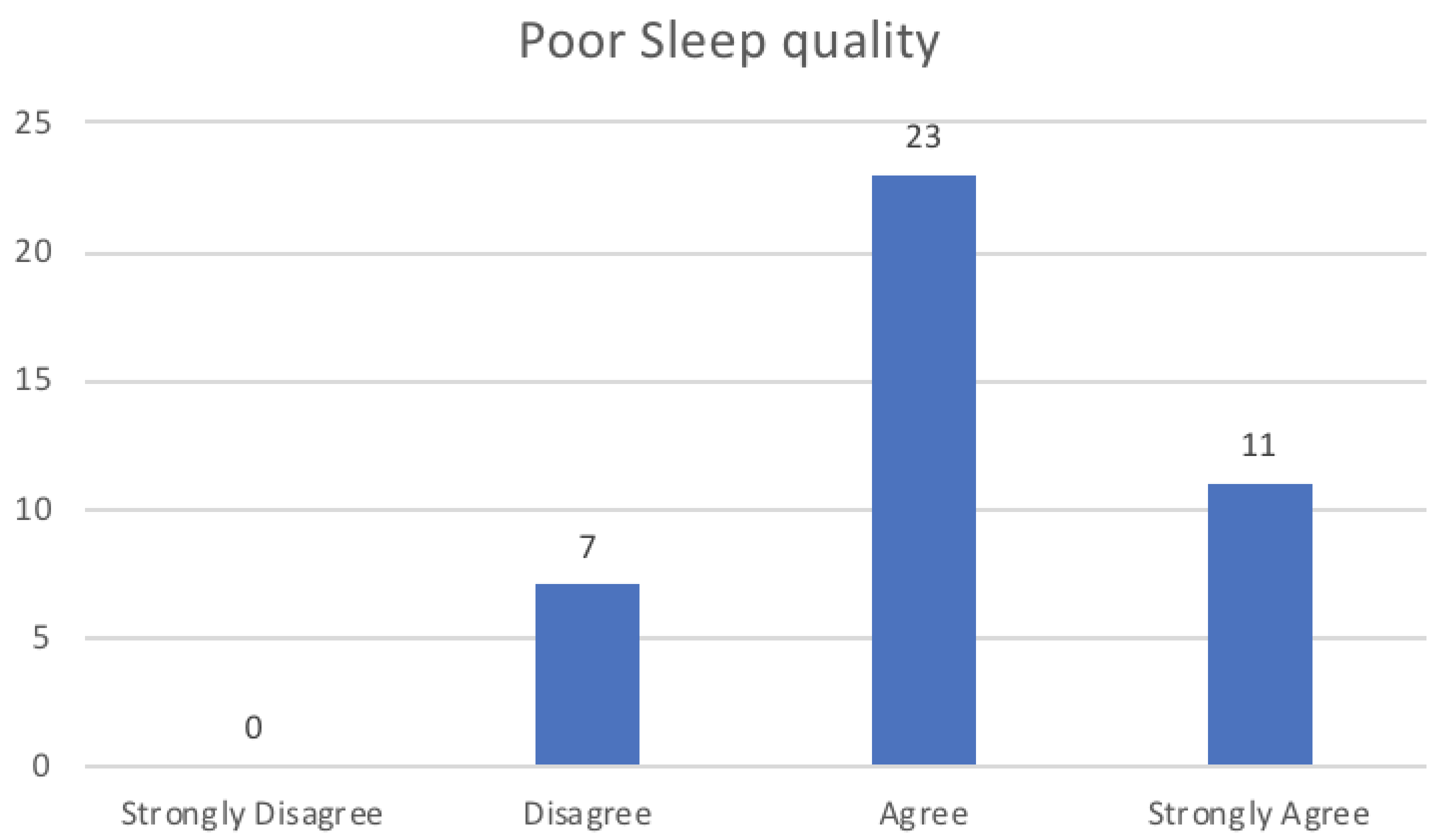
	Strongly disagree	Disagree	Agree	Strongly agree
History of running injury				



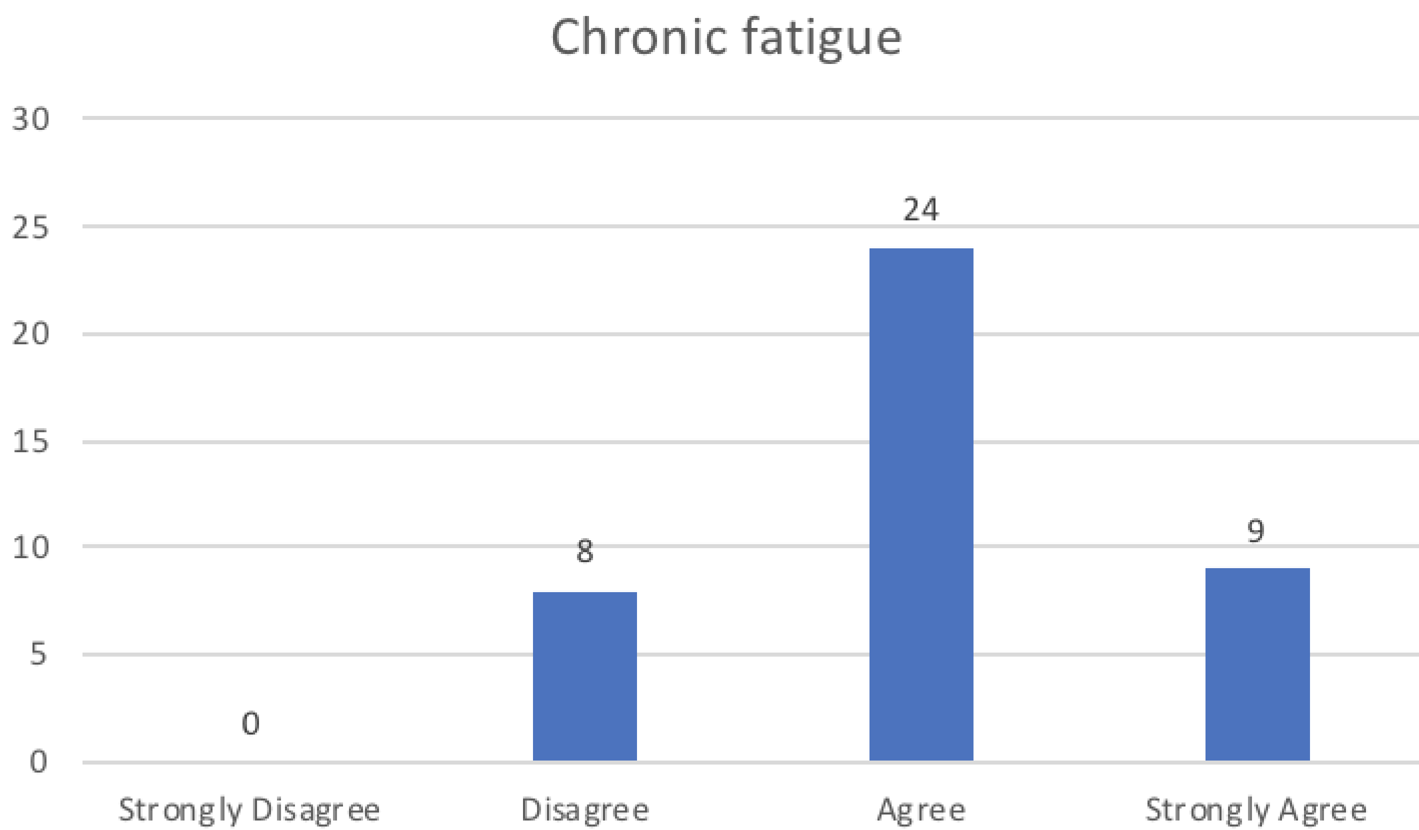
	Strongly disagree	Disagree	Agree	Strongly agree
Chronic pain history	O	O	O	O



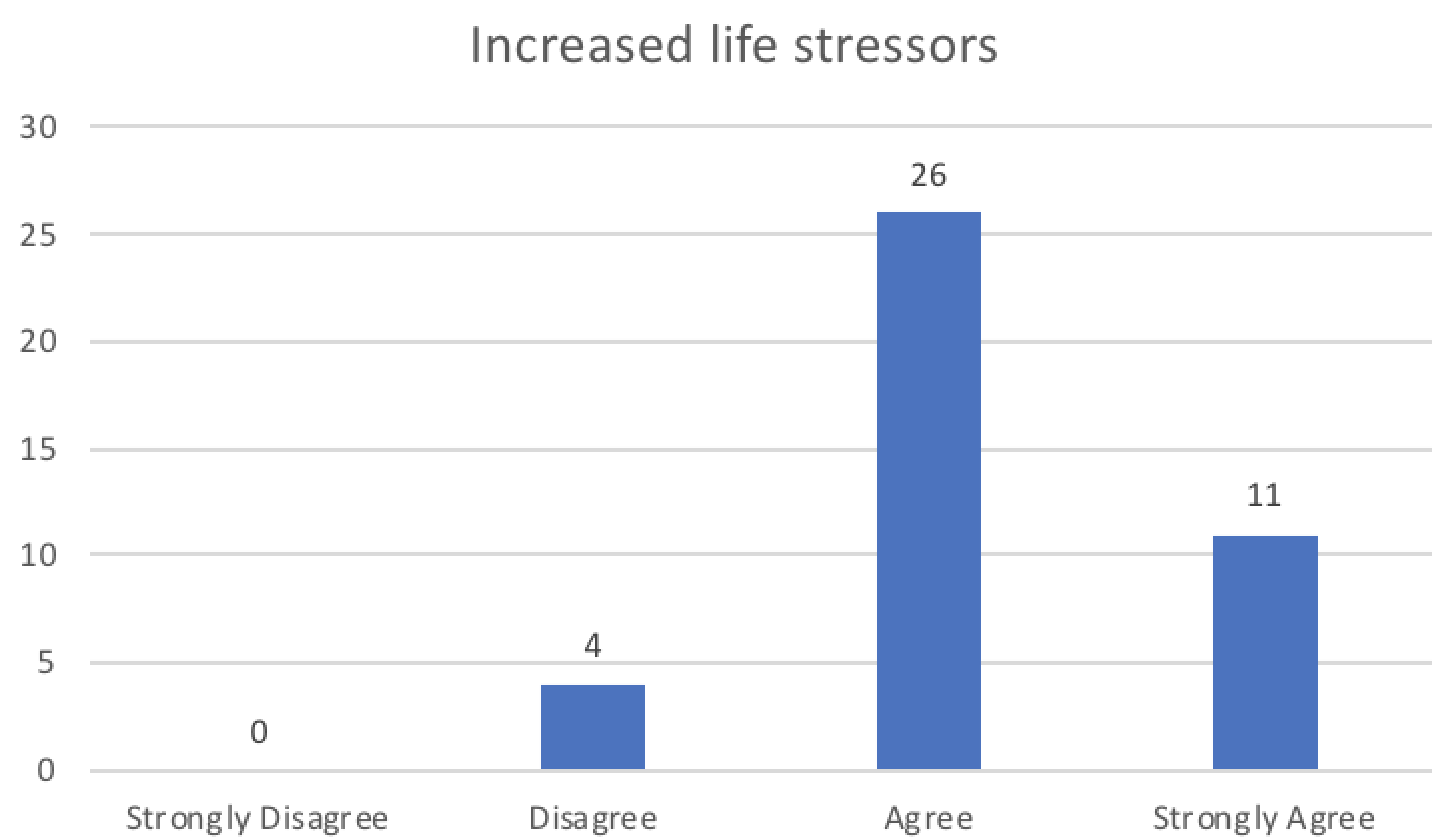
	Strongly disagree	Disagree	Agree	Strongly agree
Pain during pregnancy	O	O	O	O



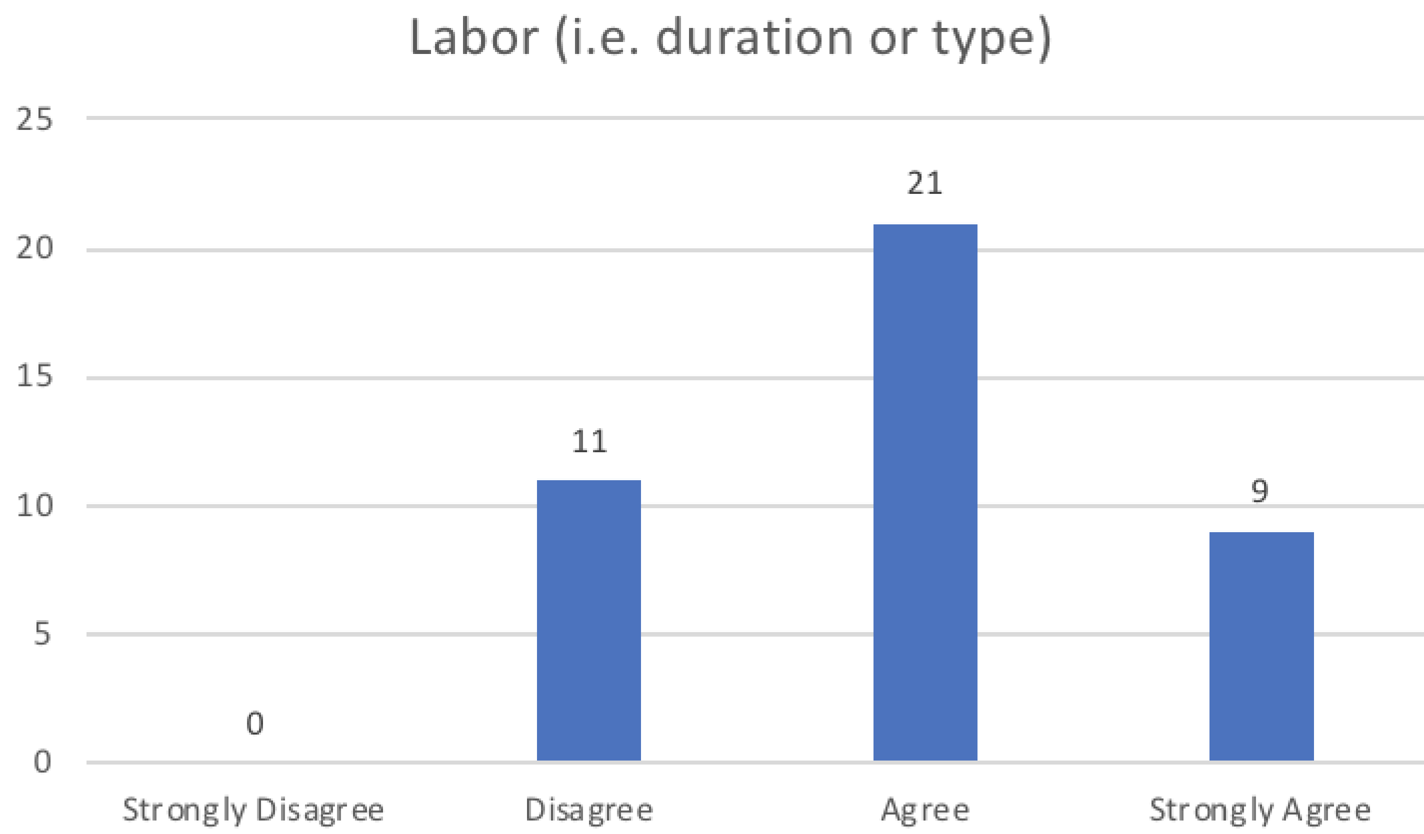
	Strongly disagree	Disagree	Agree	Strongly agree
Poor sleep quality	○	○	○	○



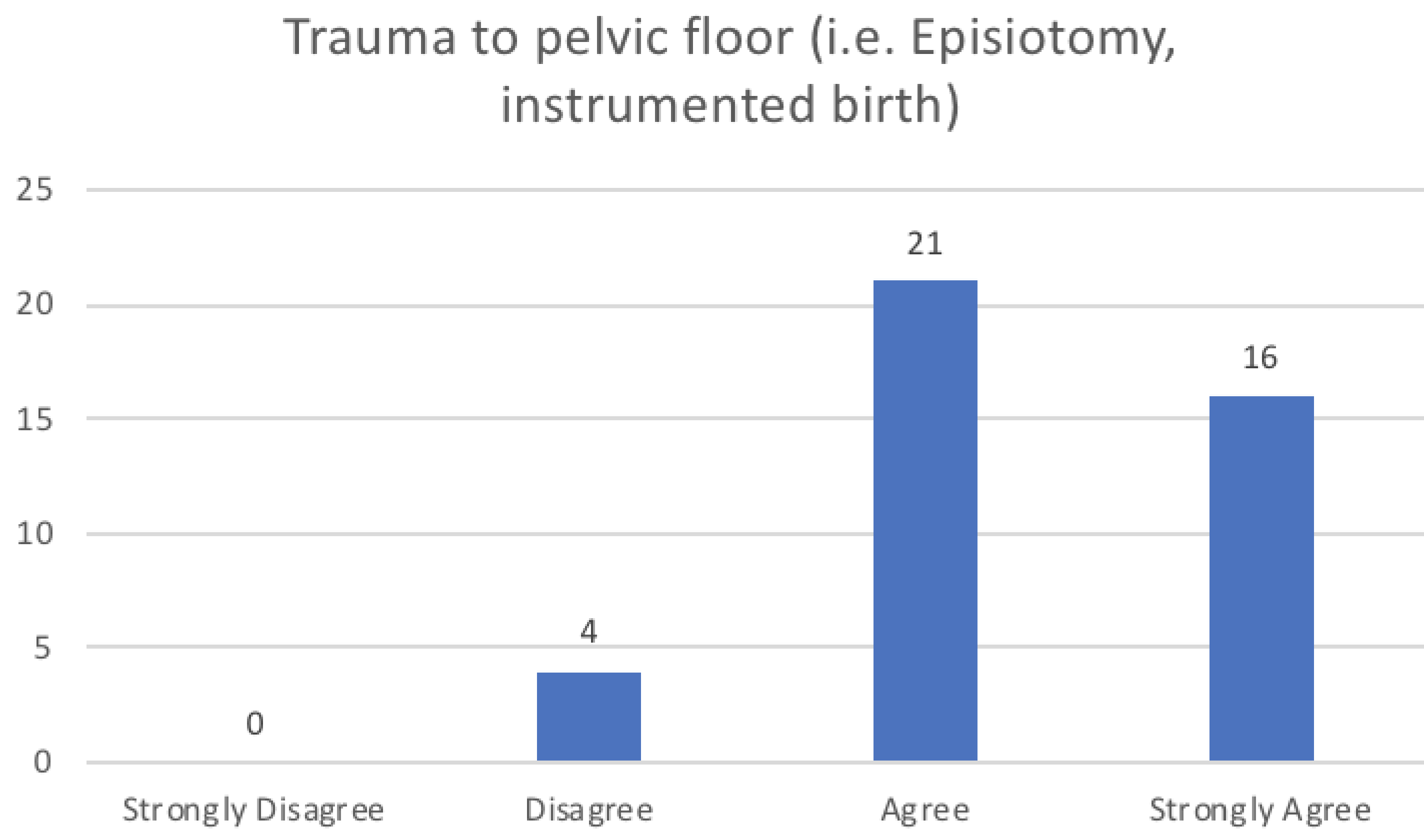
	Strongly disagree	Disagree	Agree	Strongly agree
Chronic fatigue	O	O	O	O



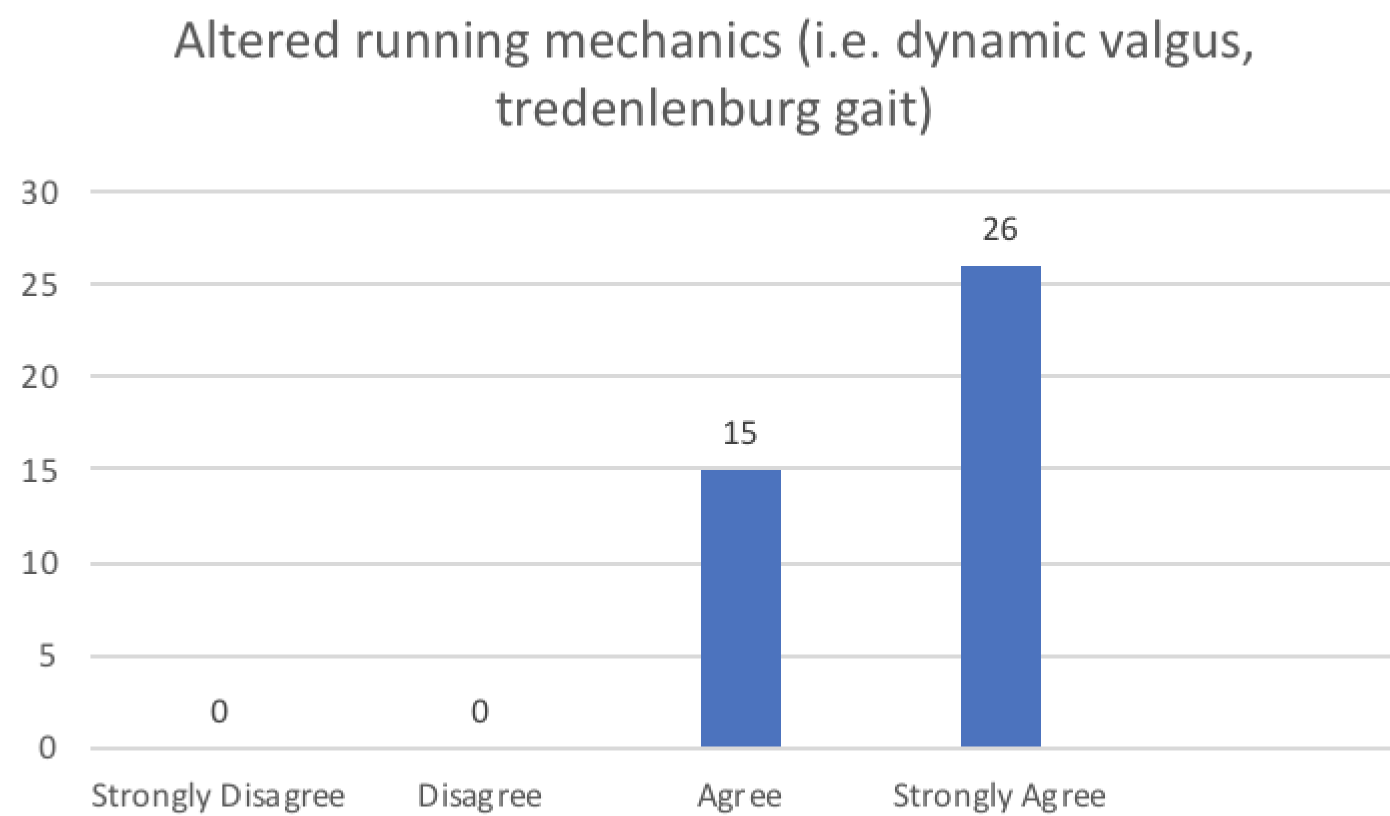
	Strongly disagree	Disagree	Agree	Strongly agree
Increased life stressors	○	○	○	○



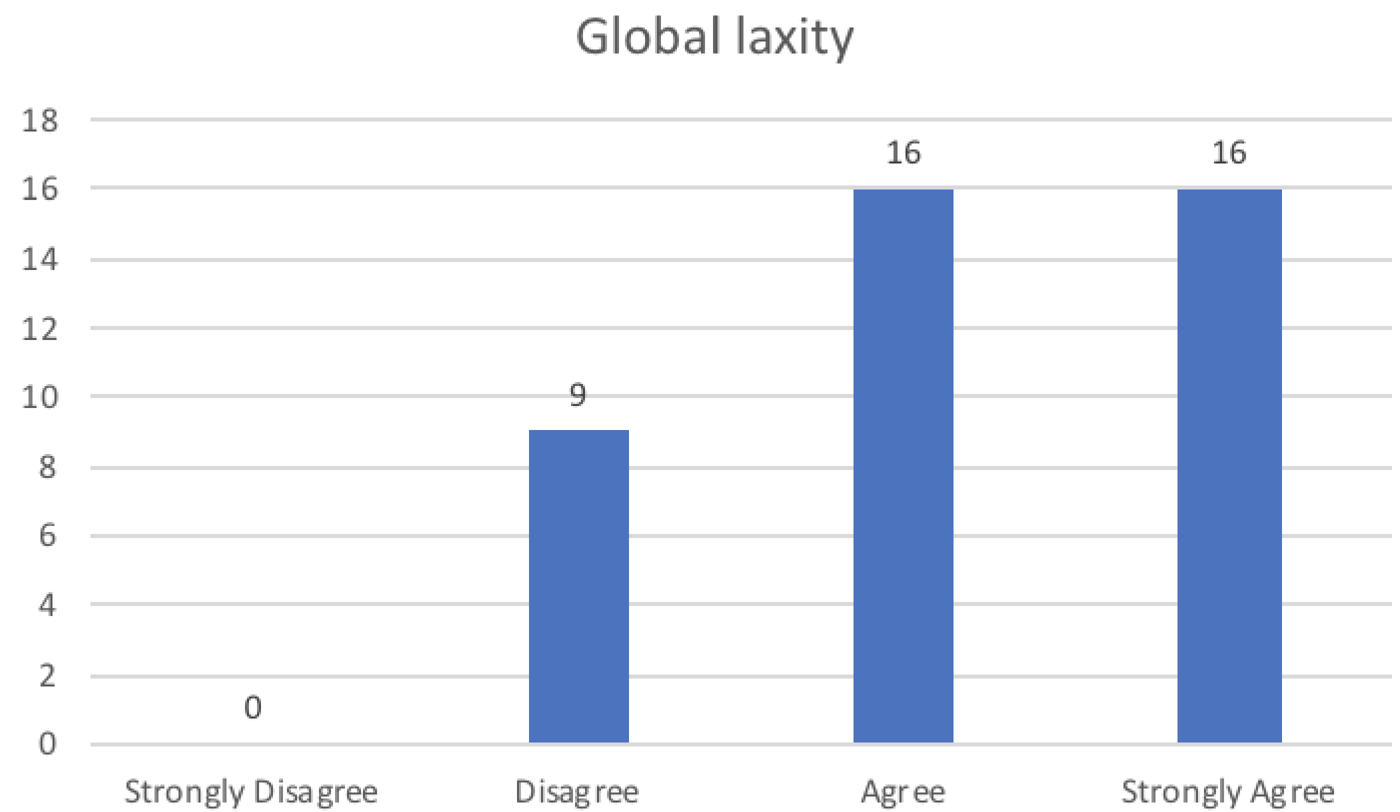
	Strongly disagree	Disagree	Agree	Strongly agree
Labor	○	○	○	○



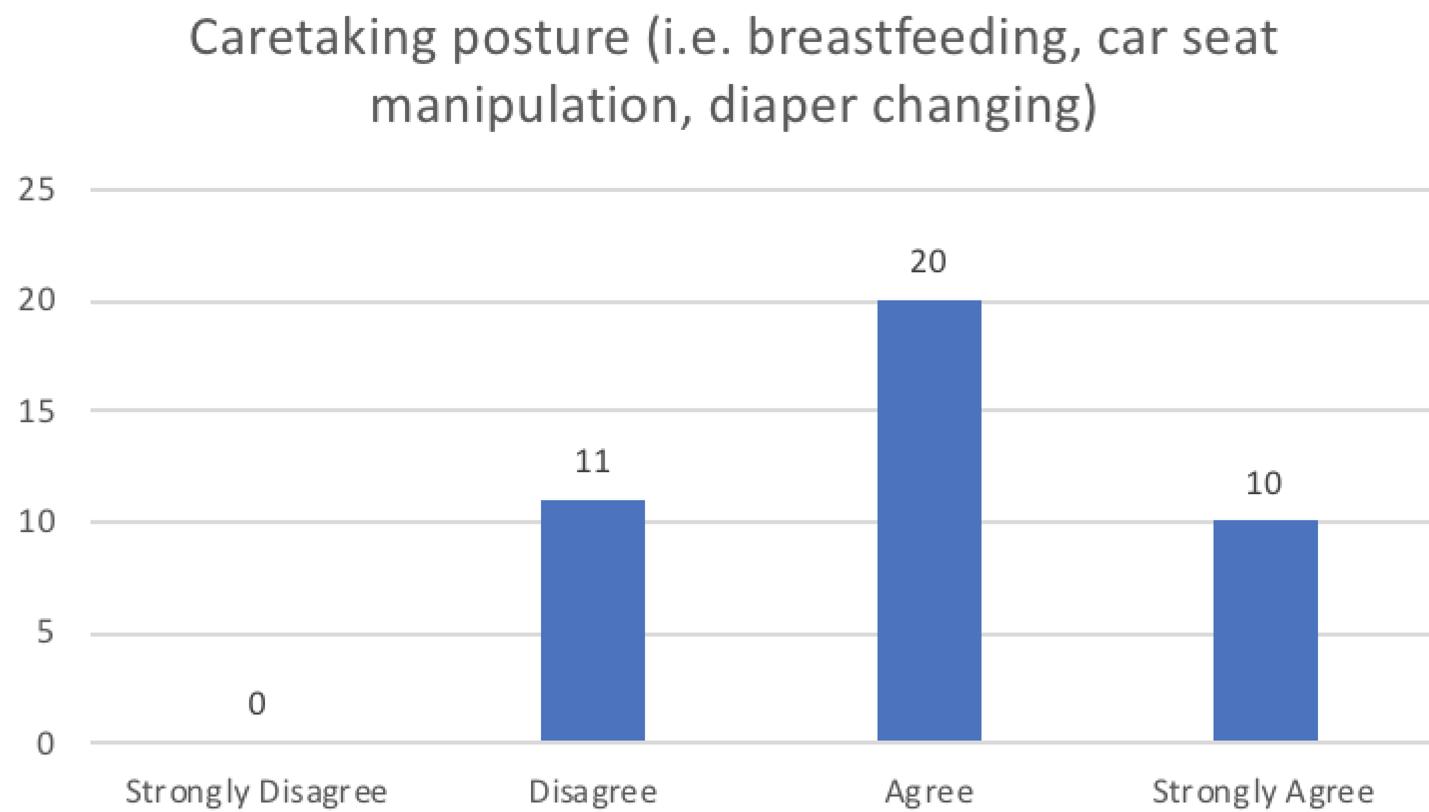
	Strongly disagree	Disagree	Agree	Strongly agree
Trauma to pelvic floor	○	○	○	○



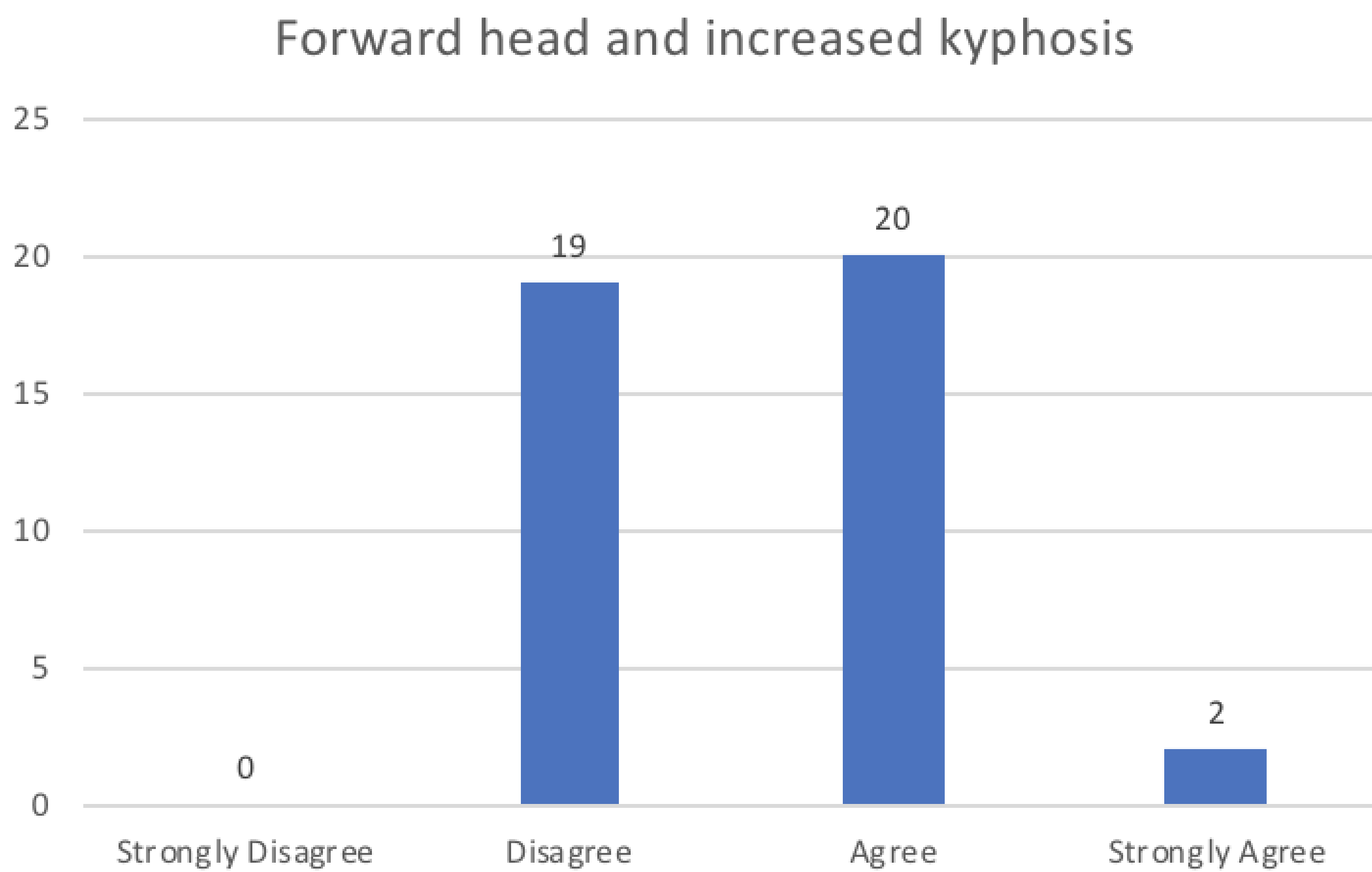
	Strongly disagree	Disagree	Agree	Strongly agree
Altered running mechanics	○	○	○	○



	Strongly disagree	Disagree	Agree	Strongly agree
Global laxity	○	○	○	○



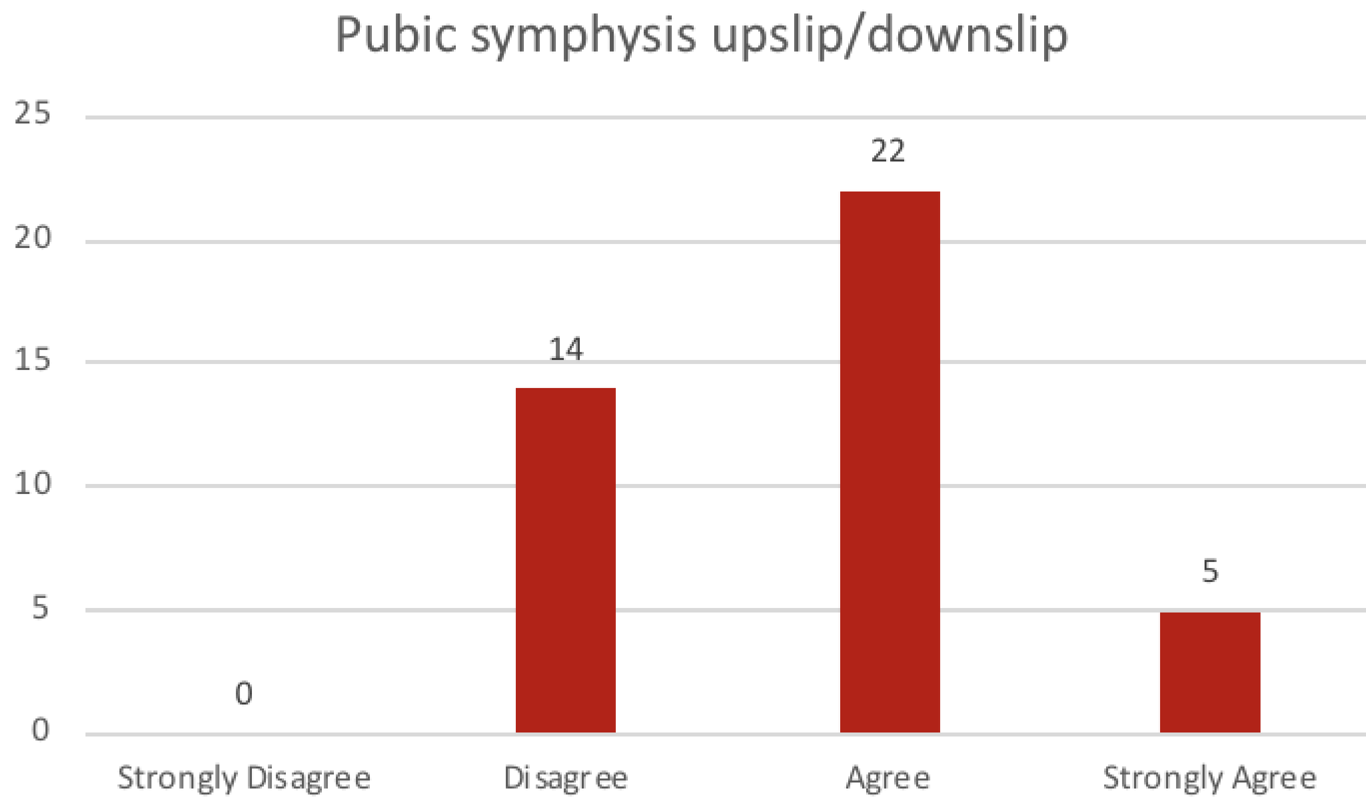
	Strongly disagree	Disagree	Agree	Strongly agree
Caretaking posture	○	○	○	○



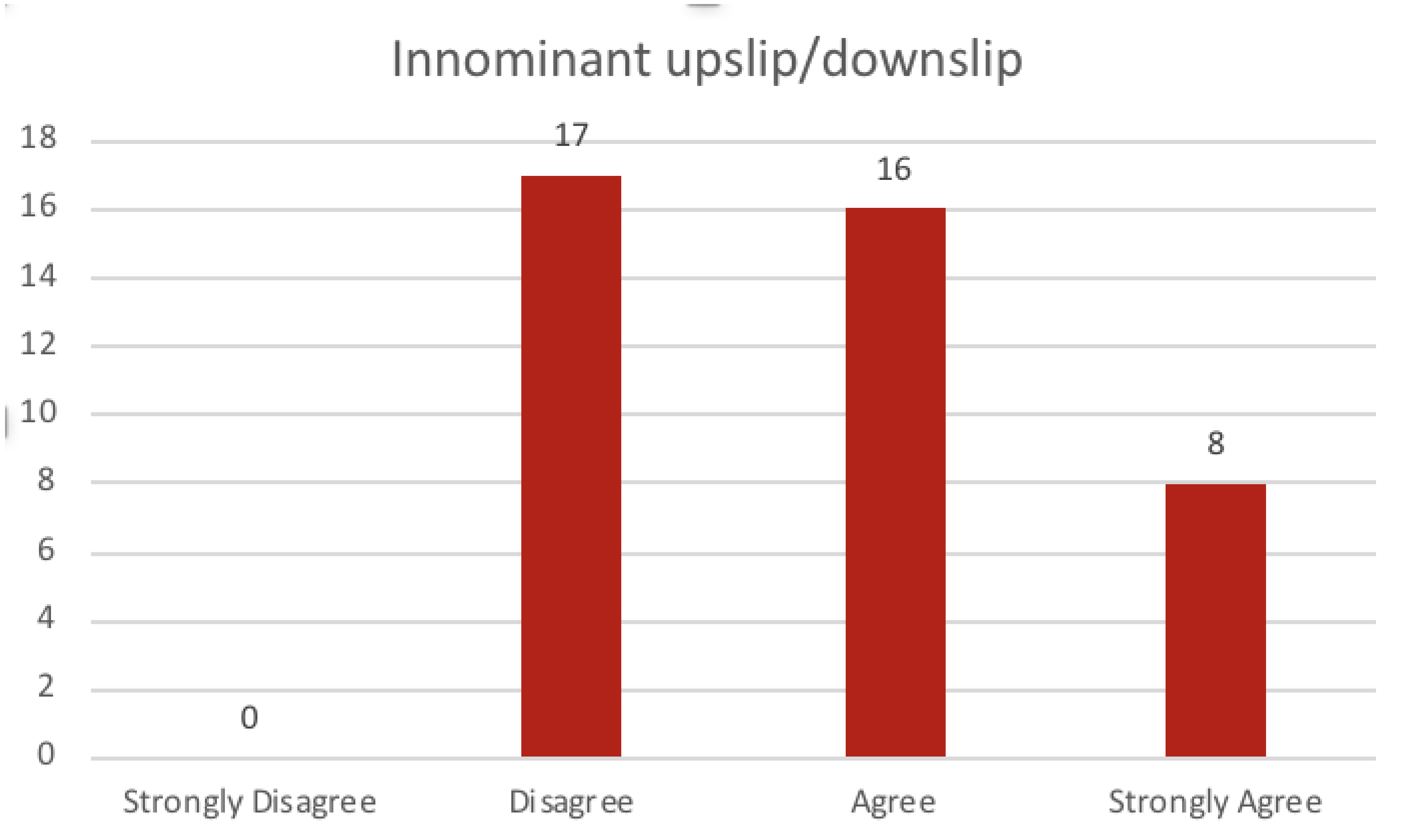
	Strongly disagree	Disagree	Agree	Strongly agree
Forward head and increased kyphosis	O	O	O	O

Comments:

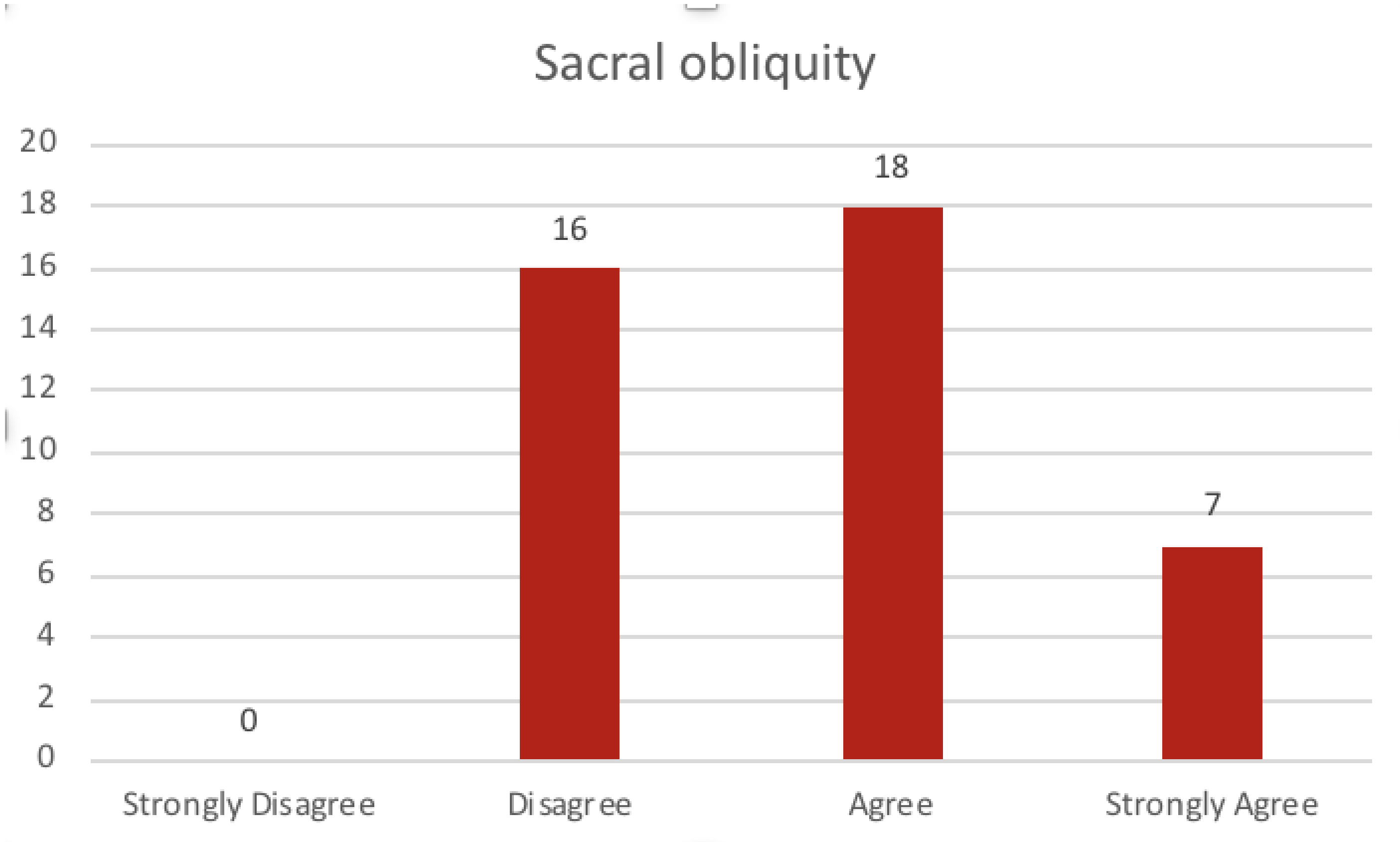
For each of the following alignment impairments please indicate whether or not you agree that it contributes to pain in the postpartum runner.



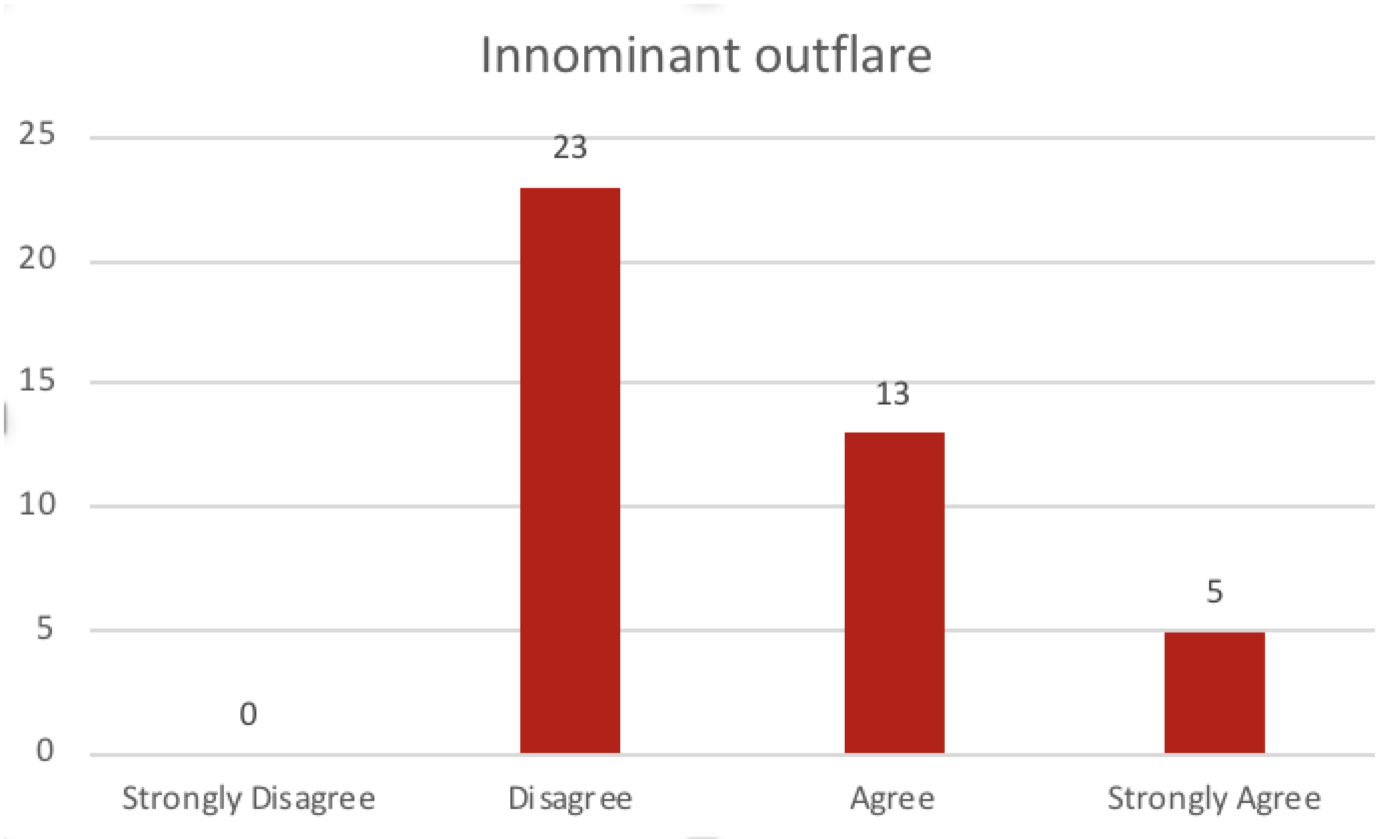
	Strongly disagree	Disagree	Agree	Strongly agree
Pubic symphysis upslip/downslip	O	O	O	O



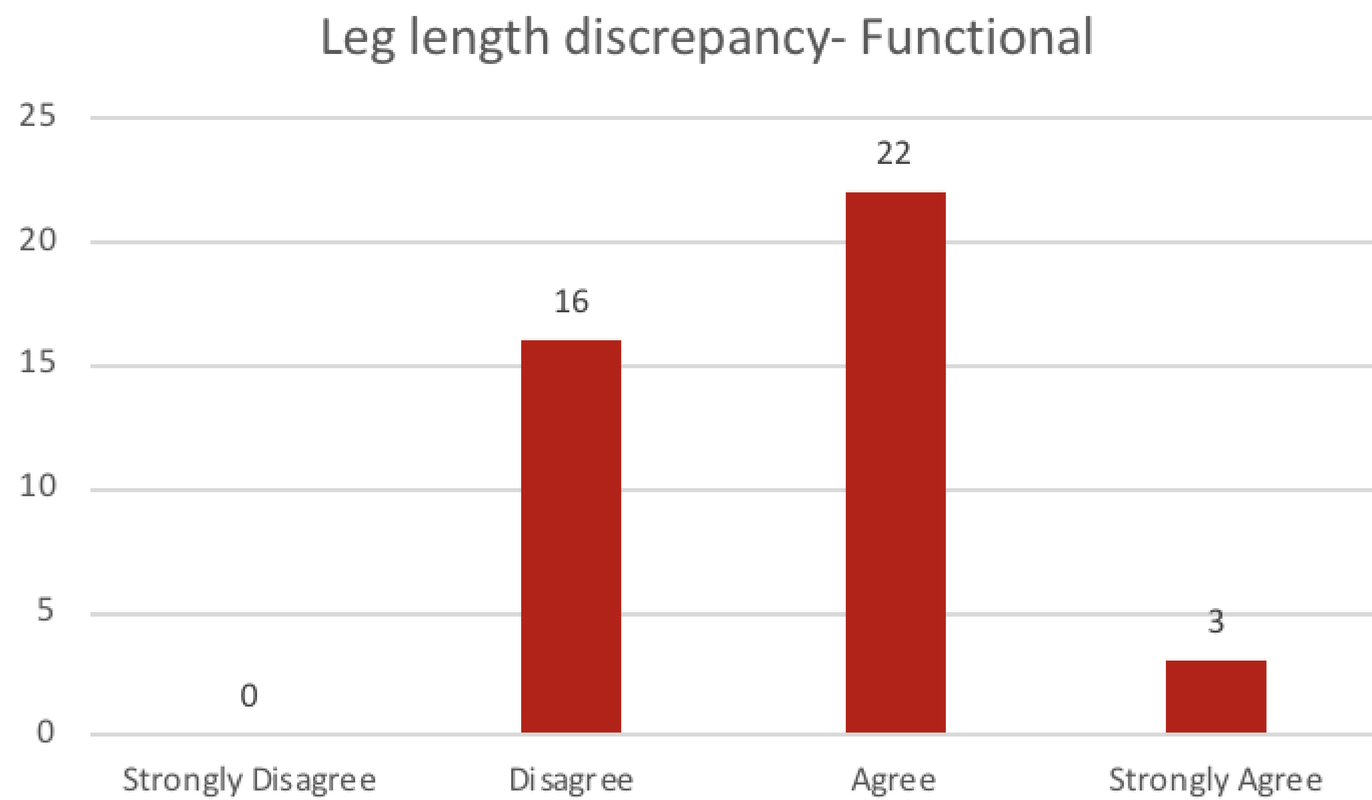
	Strongly disagree	Disagree	Agree	Strongly agree
Innominant upslip/downslip	O	O	O	O



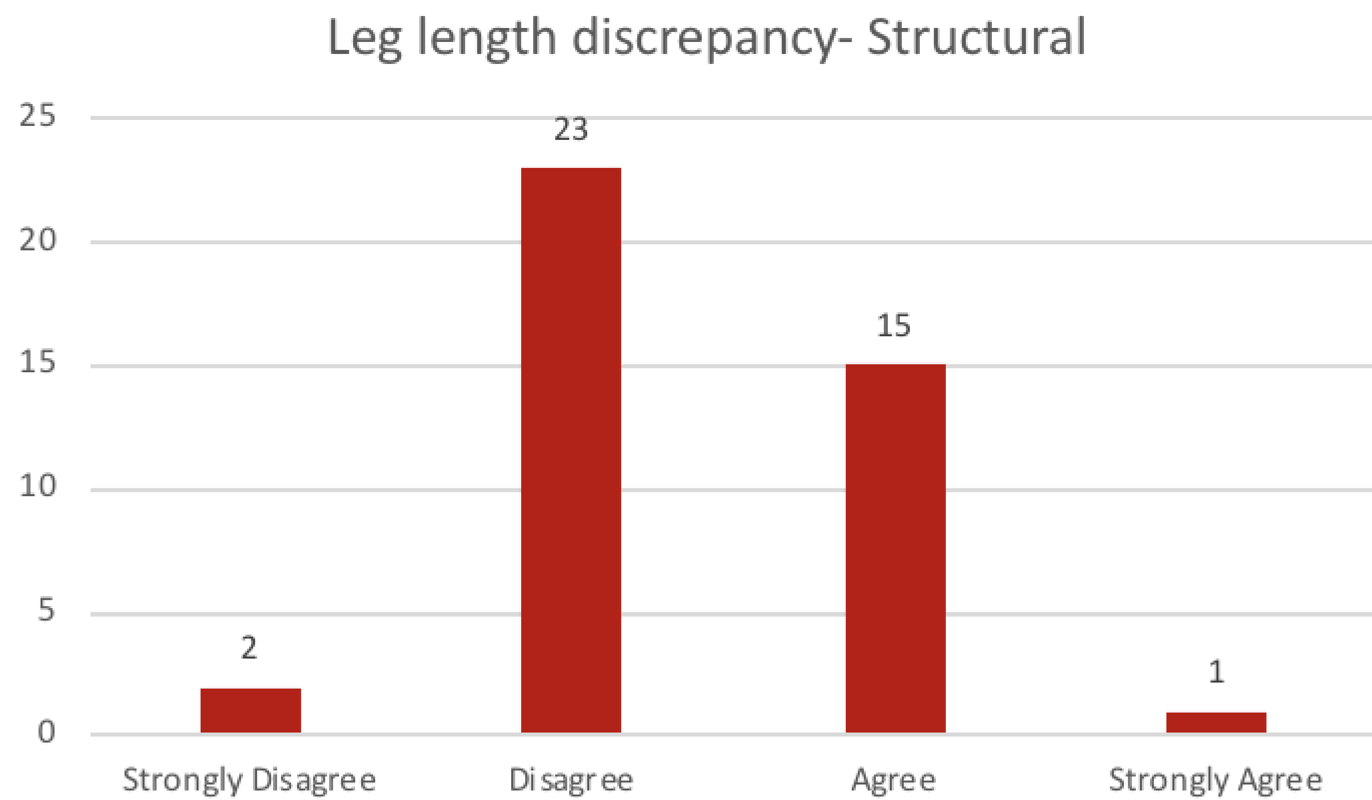
	Strongly disagree	Disagree	Agree	Strongly agree
Sacral obliquity	O	O	O	O



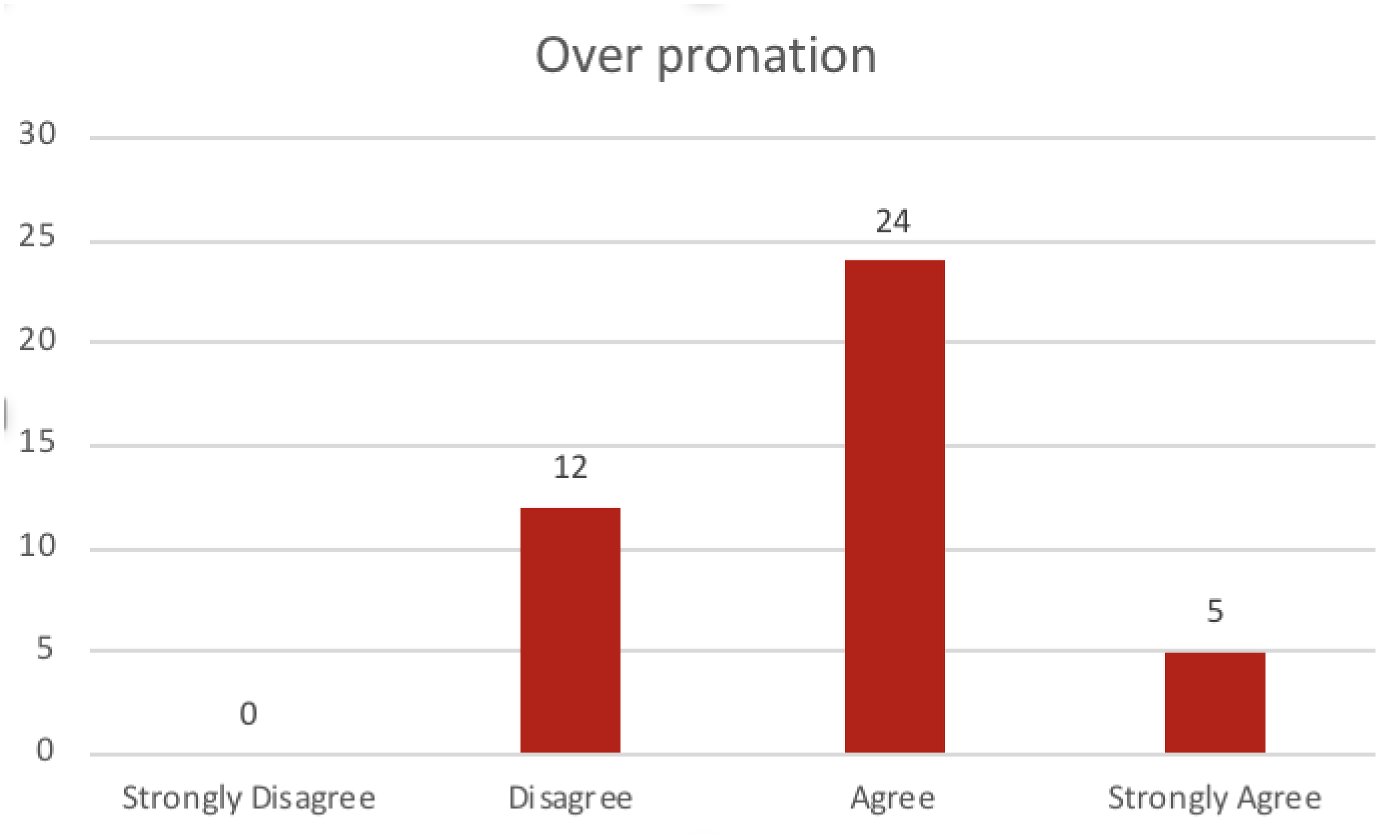
	Strongly disagree	Disagree	Agree	Strongly agree
Innominant Outflare	O	O	O	O



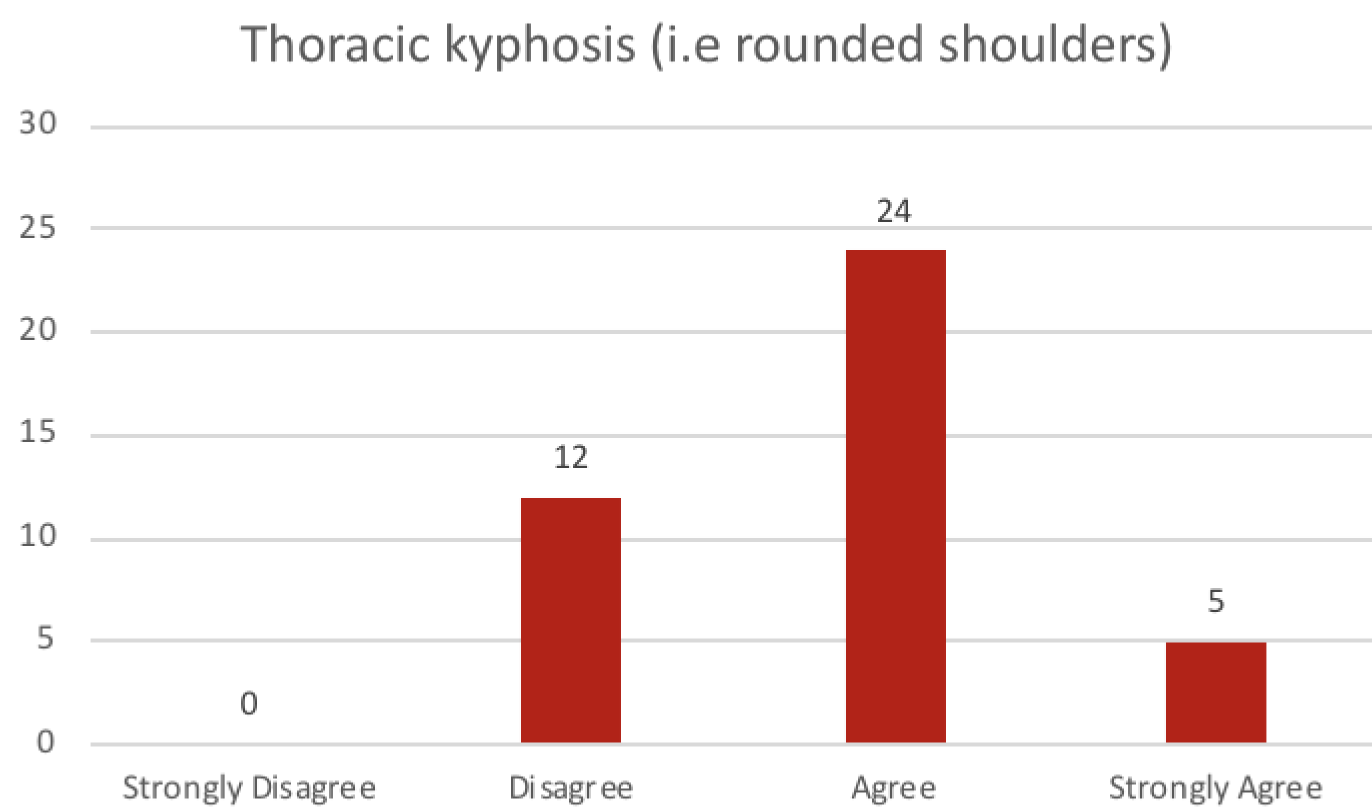
	Strongly disagree	Disagree	Agree	Strongly agree
Leg length discrepancy- functional	O	O	O	O



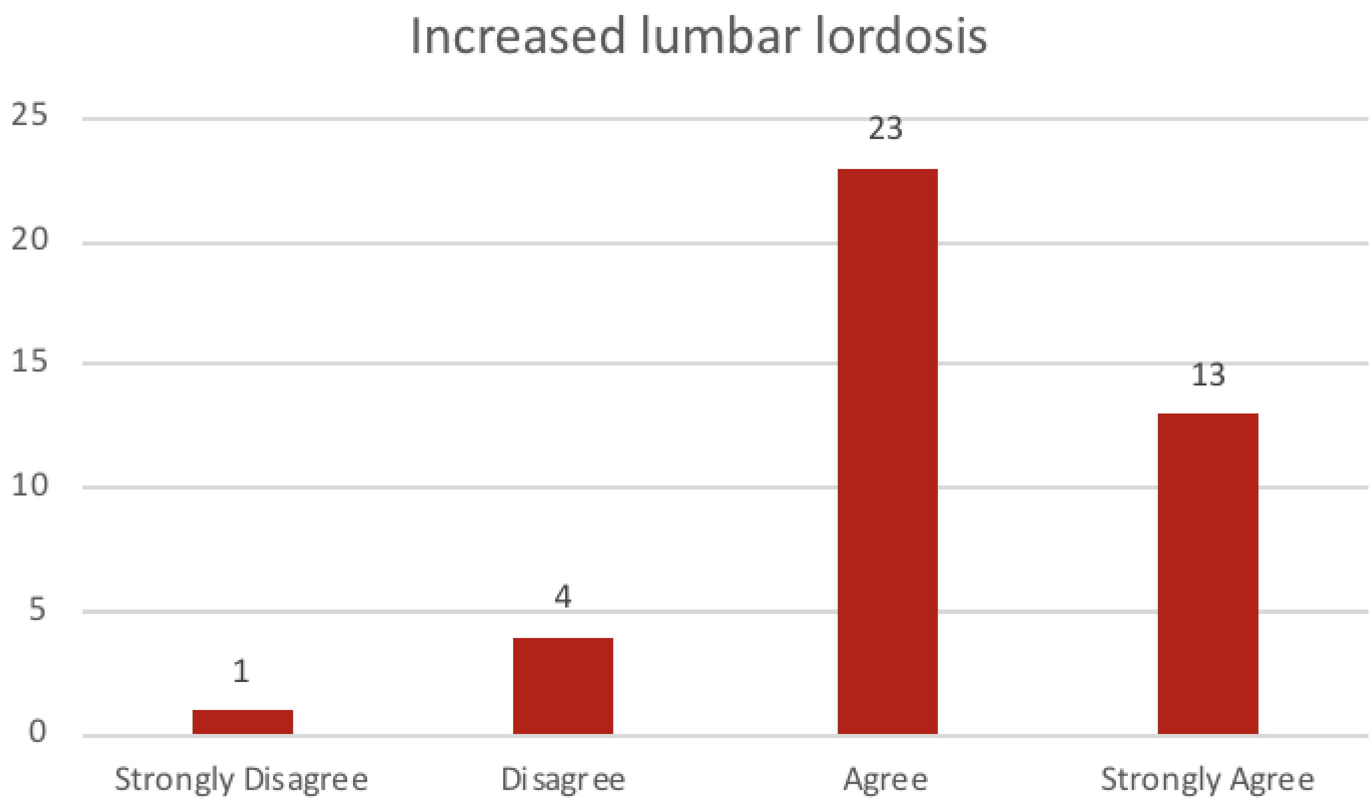
	Strongly disagree	Disagree	Agree	Strongly agree
Leg length discrepancy - structural	O	O	O	O



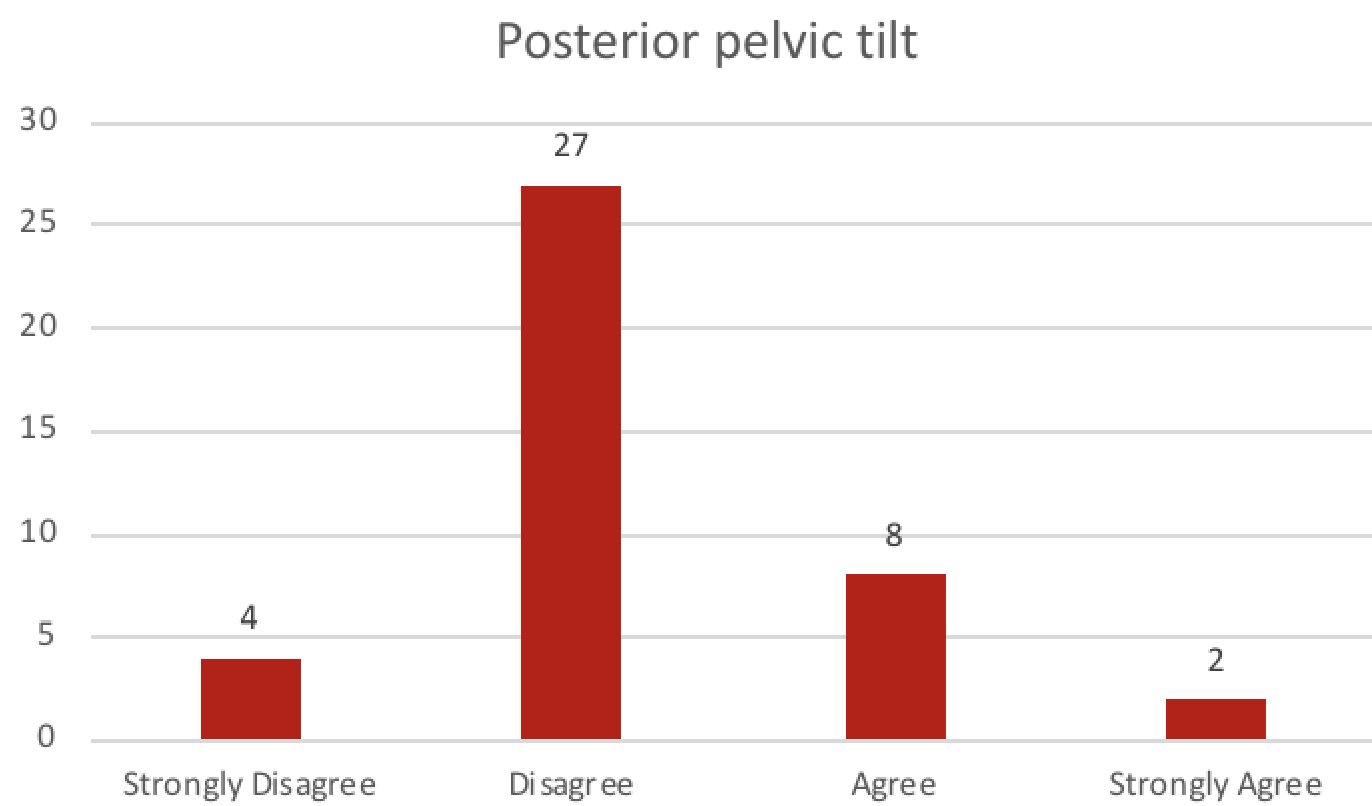
	Strongly disagree	Disagree	Agree	Strongly agree
Over pronation	○	○	○	○



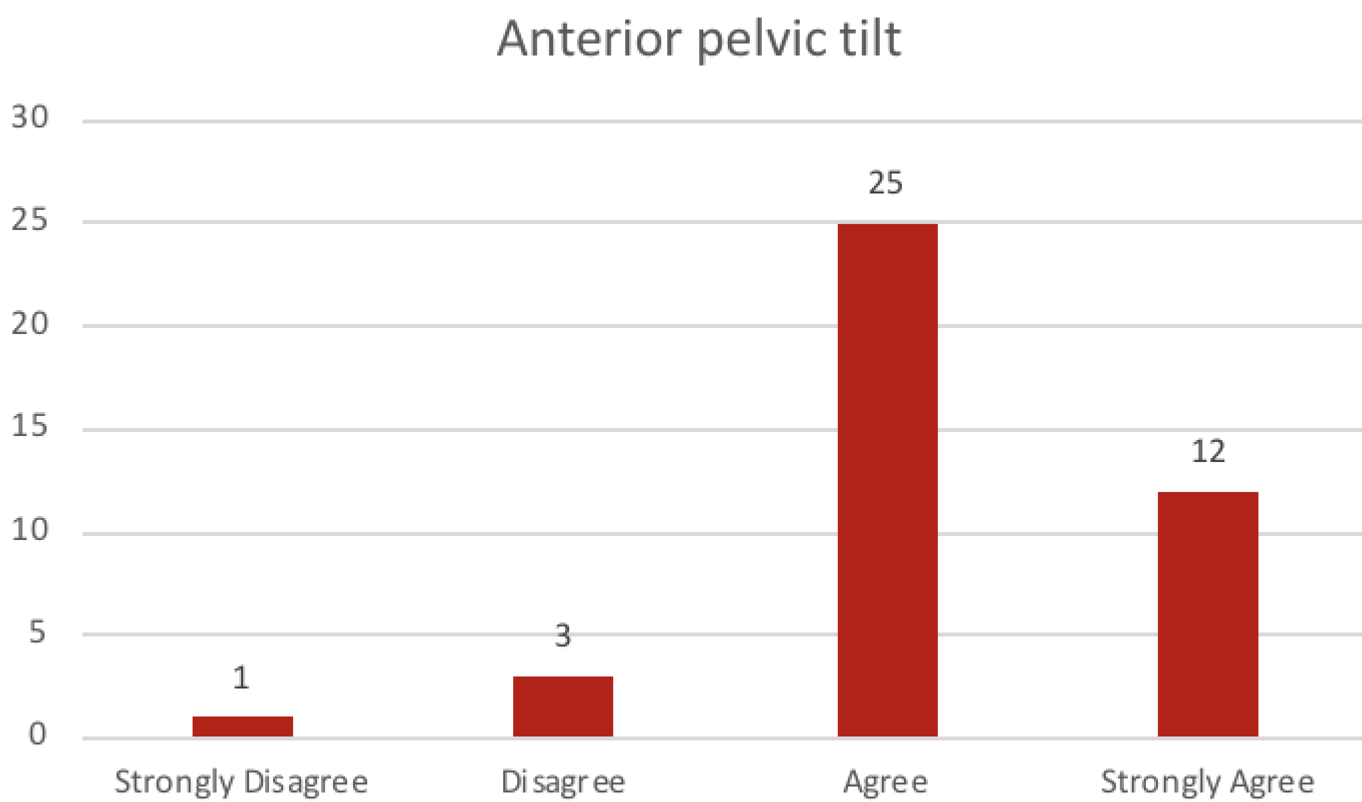
	Strongly disagree	Disagree	Agree	Strongly agree
Thoracic kyphosis	○	○	○	○



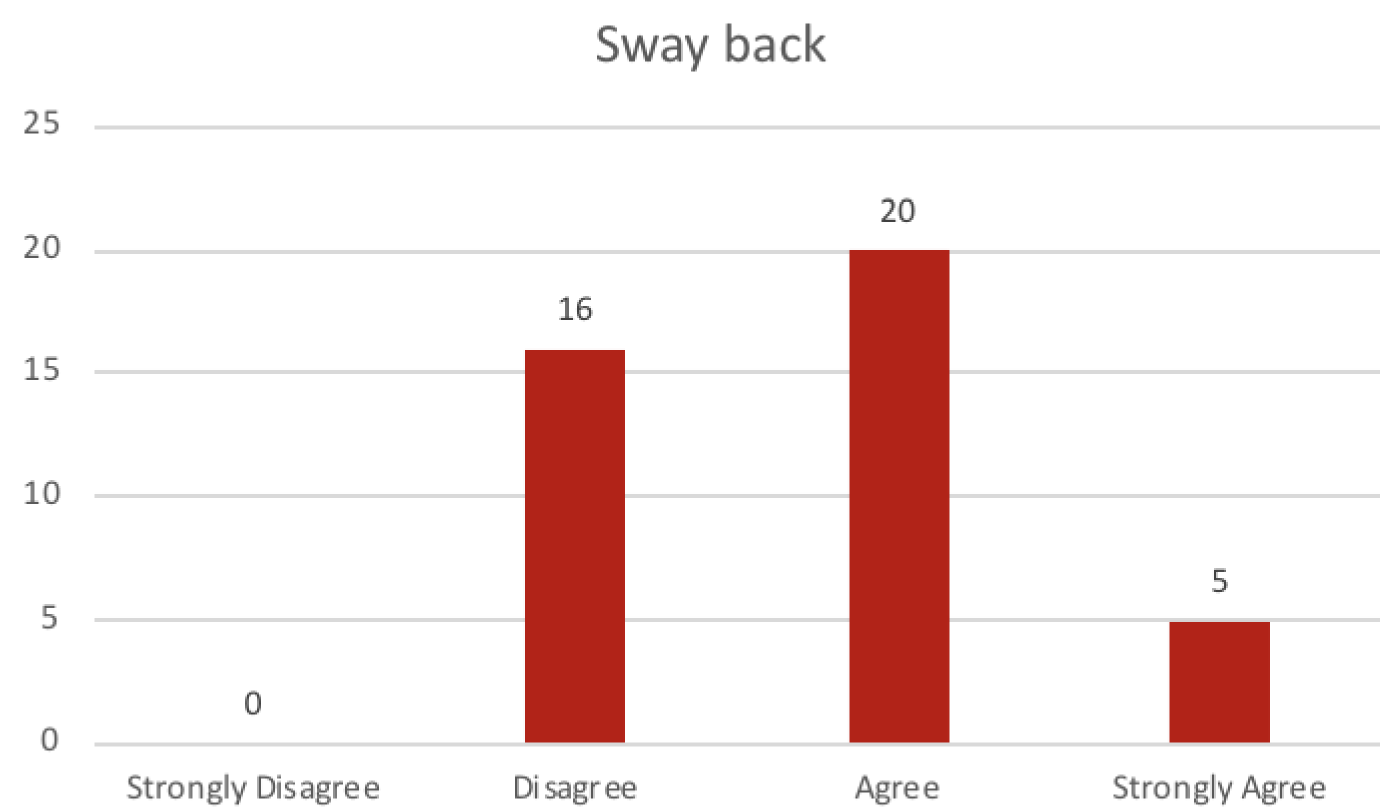
	Strongly disagree	Disagree	Agree	Strongly agree
Increased lumbar lordosis	○	○	○	○



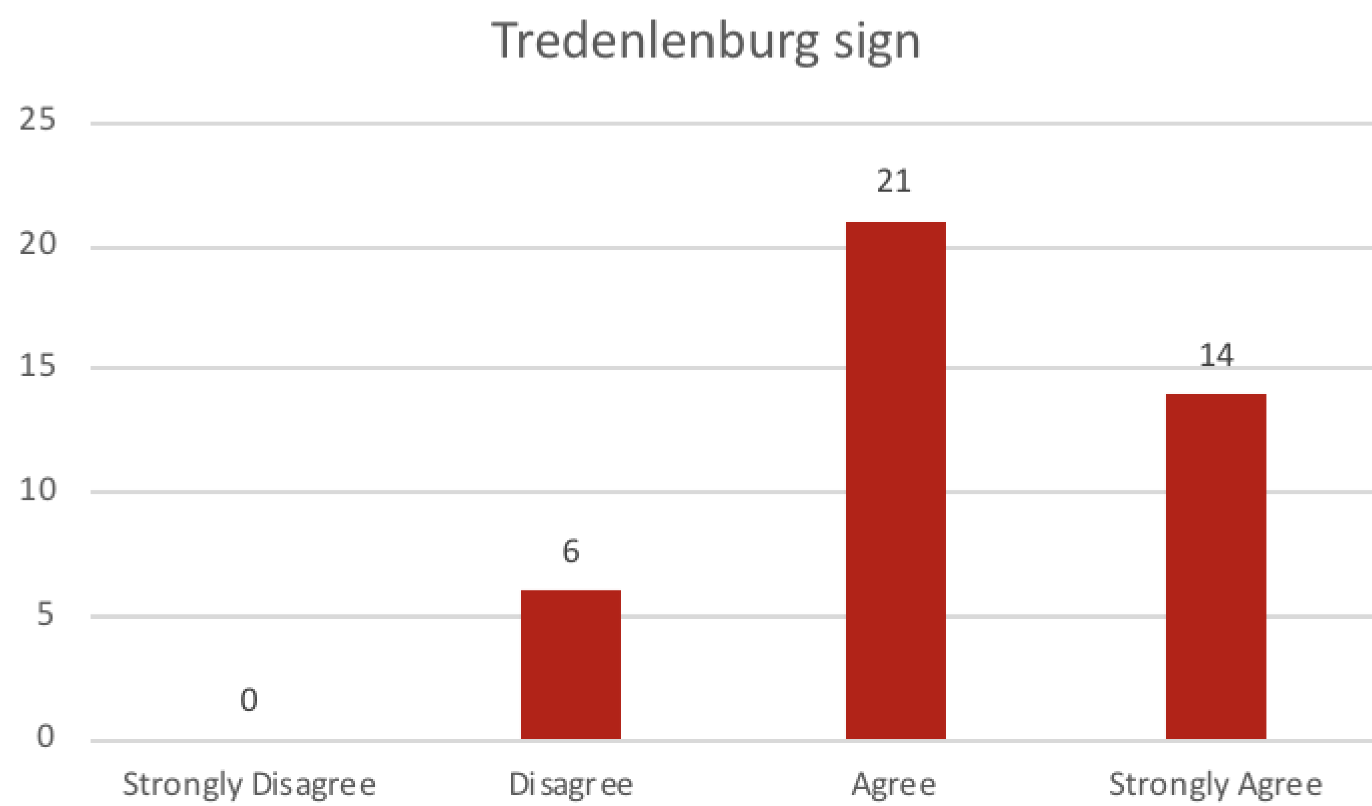
	Strongly disagree	Disagree	Agree	Strongly agree
Posterior pelvic tilt	○	○	○	○



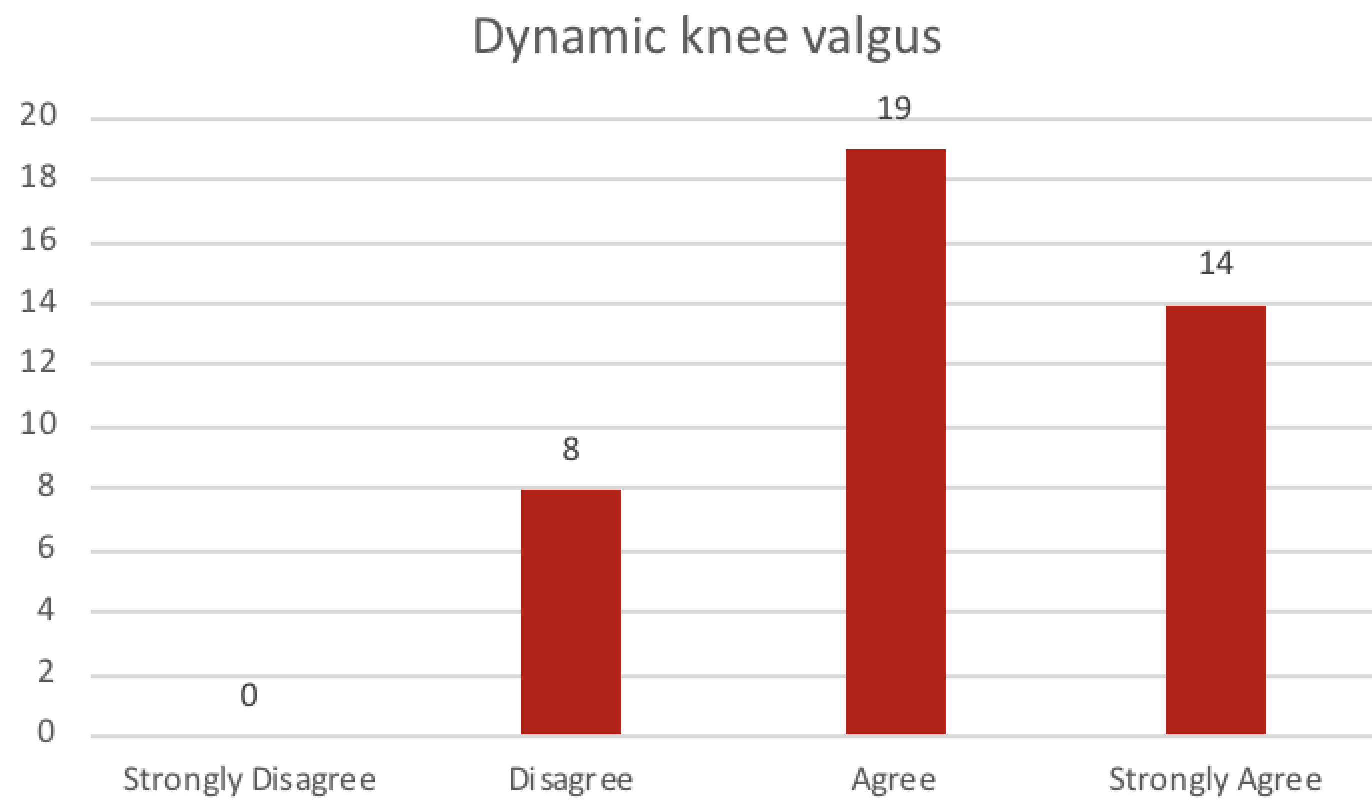
	Strongly agree	Agree	Disagree	Strongly disagree
Anterior pelvic tilt	O	O	O	O



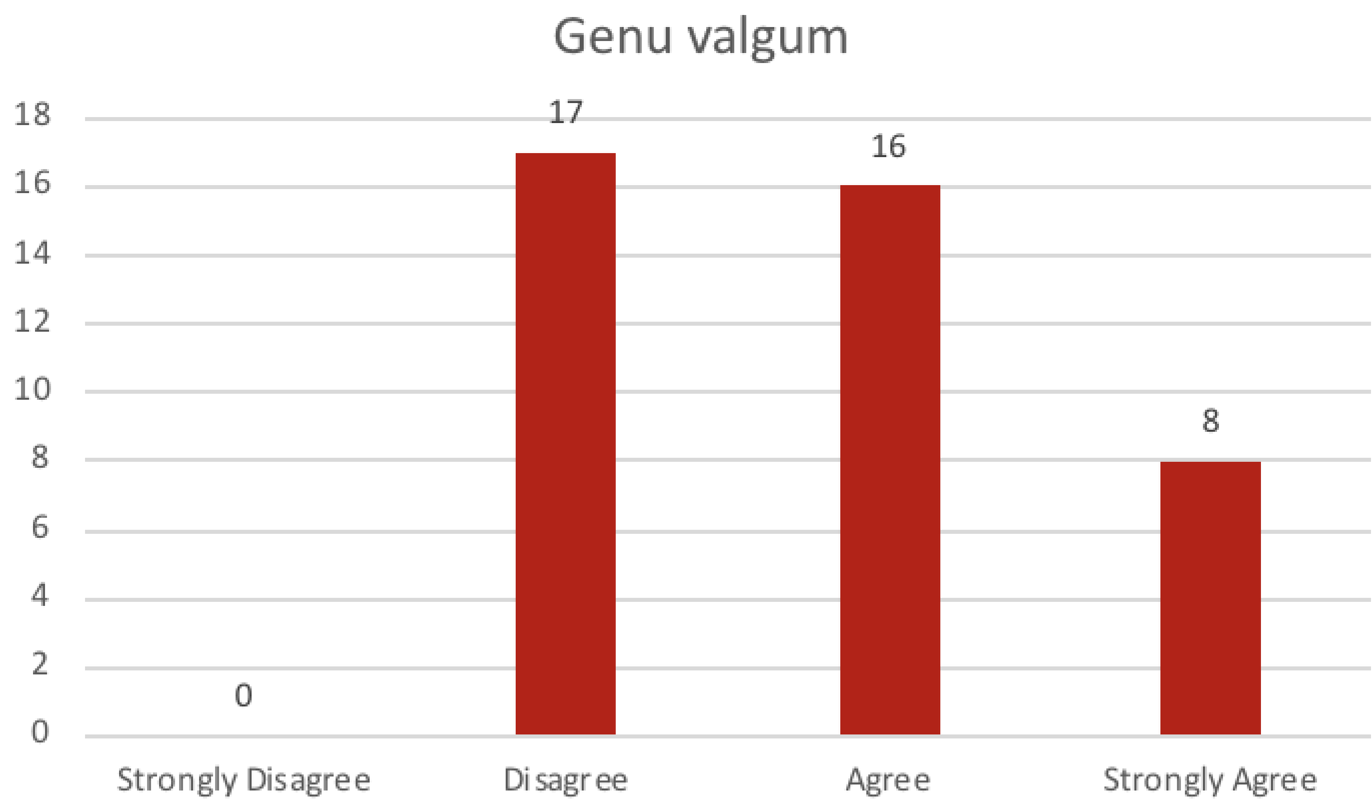
	Strongly disagree	Disagree	Agree	Strongly agree
Sway back	○	○	○	○



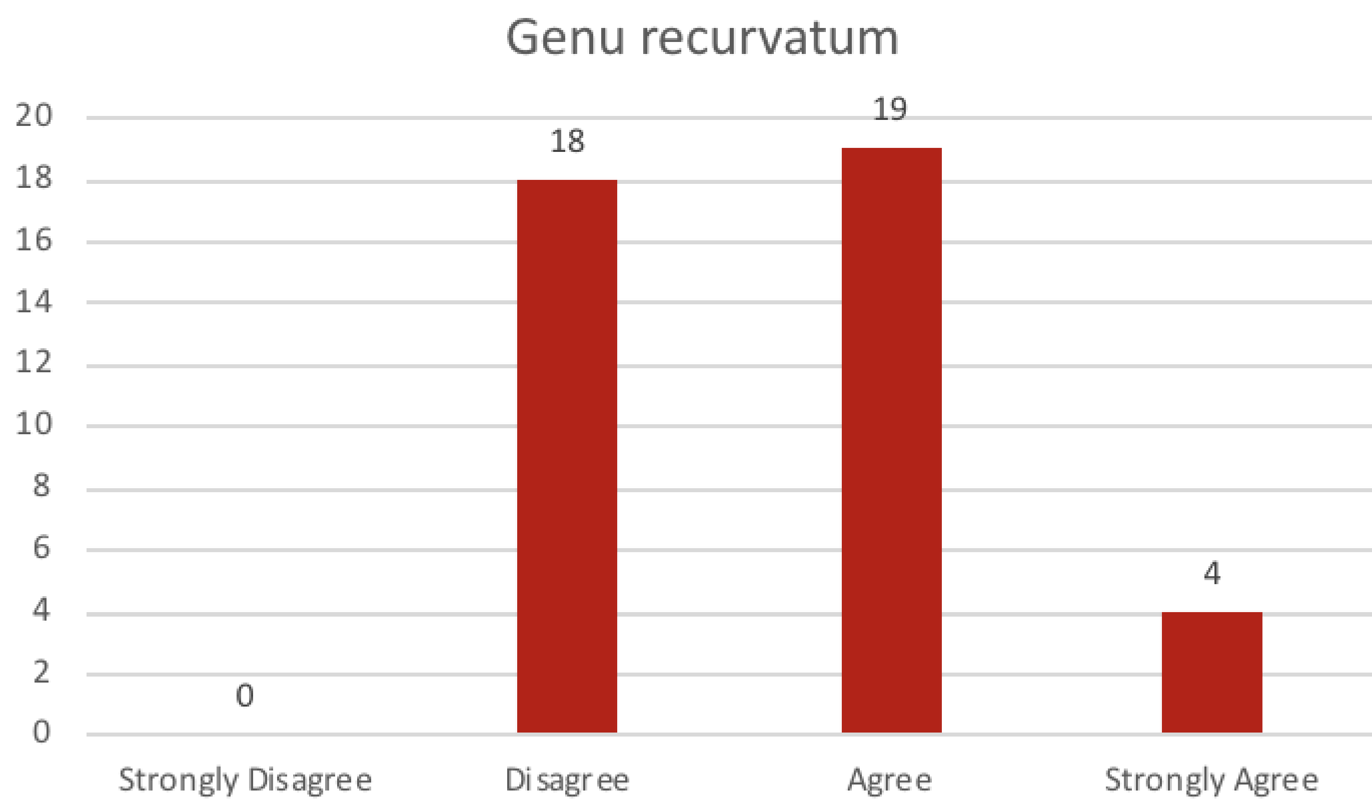
	Strongly disagree	Disagree	Agree	Strongly agree
Tredenlenburg sign	O	O	O	O



	Strongly disagree	Disagree	Agree	Strongly agree
Dynamic Knee Valgus	O	O	O	O



	Strongly disagree	Disagree	Agree	Strongly agree
Genu Valgum	O	O	O	O



	Strongly disagree	Disagree	Agree	Strongly agree
Genu recurvatum	O	O	O	O

Comments:

Thank you for your participation in this Delphi study. By clicking the arrow below your results will be submitted. Please provide any summative comments below.

Appendix G: Survey Flyer (Study 4, Chapter 6)

ELON RUNS

Are you a postpartum runner willing to participate in a research study ?

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

If you are interested in completing this questionnaire, enter the following address in your browser window:
http://bit.ly/elonruns

You are eligible to participate in this survey if you answer yes to the following questions:

- Do you have a child 36 months or younger?
- Are you trying to run at least once a week on average?

The anonymous 15-minute questionnaire will ask postpartum runners questions about running related habits, postpartum depression, and any possible pain related information. Three $25 Amazon gift cards will be given away each month to participants who choose to enter the drawing.
If you have any questions about this research, please contact Shefali Christopher (schristopher3@elon.edu).

Newcastle IRB #H-2019-0118; Elon IRB # 19-222

ELON UNIVERSITY | DEPARTMENT OF Physical Therapy Education

Appendix H: Survey Questionnaire (Study 4, Chapter 6)

Qualtrics survey seen by participants

Postpartum Runner Survey

ELON UNIVERSITY

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

ELON UNIVERSITY | DEPARTMENT OF Physical Therapy Education

Information Statement for the Research Project:
Survey of postpartum runners

You are invited to participate in the research project identified above which is being conducted by Shefali Christopher, PT, DPT, SCS, LAT, ATC, assistant professor at Elon University and PhD candidate from the School of Health Sciences at the University of Newcastle Australia, A/Prof Suzanne Snodgrass and Prof Chad Cook. The research is part of Shefali Christopher's PhD studies at the University of Newcastle, supervised by Suzanne Snodgrass from the School of Health Sciences at University of Newcastle and Prof Chad Cook from Duke University.
Why is the research being done?
Guidelines for returning to running after having a baby are sparse. Many social media outlets have conflicting information and it can be difficult for postpartum women to understand how to get back to running safely. What we do know is that a large number of postpartum women runners have difficulties when running (pain, incontinence, etc). The aim of this study is to understand the habits of postpartum runners as well as measure other variables that affect their running.
Who can participate in the research?
Any woman 18 yrs or older, who is trying to run at least one time per week on average, and has a child 36 months (3 years) or younger is eligible to participate in this survey.
The survey has been developed in collaboration with experts in postpartum running and with postpartum runners.
What would you be asked to do? If you agree to participate, you will be asked to complete an anonymous online questionnaire that asks about your current running

routines and includes questions about you (age, etc.), questions that relate to postpartum depression, questions related to incontinence, and if you have pain, questions related to your pain when running. This survey will be open for 1 year or until we have collected 5,000 responses.

What choice do you have?

Participation in this research is entirely your choice. Only those people who give their consent will be included in the project. Whether or not you decide to participate, your decision will not disadvantage you. If you do decide to participate, you may withdraw from the project at any time prior to submitting your completed questionnaire. Please note that due to the anonymous nature of the questionnaire, you will not be able to withdraw your response after it has been submitted.

How much time will it take?

The questionnaire takes approximately fifteen minutes to complete if you do experience pain, and about five minutes if you are a postpartum runner with no pain.

While there are no anticipated benefits to you personally in participating in this research, the findings will contribute to the available literature on the subject and help clinicians worldwide have a better understanding of postpartum runners with and without pain.

How will your privacy be protected?

Your questionnaire responses are anonymous. The questionnaire responses will be stored on a password-protected server through Qualtrics software. This company is a common vendor used for survey research and has significant data protection policies in place. Please see the Qualtrics security statement here: http://www.qualtrics.com/security-statement/. Following the data collection period, the data will be downloaded from the Qualtrics server and securely stored on Shefali Christopher's encrypted and password-protected laptop computer, with a back-up copy securely stored on the University of Newcastle's secure cloud server. Your data will be retained for a minimum of 5 years as per University of Newcastle policy provisions and destroyed via deletion in accordance with University of Newcastle and Elon University policies. To the extent allowed by law, we limit the viewing of your personal information to people who must review it. The Institutional Review Board (IRB), Elon University and the Human Research Ethics Committee, University of Newcastle (Australia), and other representatives of these organizations may inspect and copy your information.

How will the information collected be used?

The collected data will contribute to Shefali Christopher’s Ph.D. thesis and may be presented in peer-reviewed publications or conferences. You can access a copy of the published report by visiting this webpage: https://www.elon.edu/e/directory/profile.html?user=schristopher3 after July 2020. Individual participants will not be named or identified in any reports arising from the project.

What do you need to do to participate?

Please read this Information Statement and be sure you understand its contents before you consent to participate. If there is anything you do not understand, or you have questions, please contact the research team. If you would like to participate, please complete the questionnaire by clicking on this link: (Survey of postpartum runners).

Completion and submission of this online questionnaire will be taken as your consent to participate. Will you be paid for participating?
Three $25 Amazon gift cards will be given away each month to participants who complete the questionnaire and choose to enter the drawing. A link will be provided at the end of the survey in order to provide your contact details separate to the questionnaire (your questionnaire responses will remain anonymous).

Further information
If you would like further information, please contact one of the members of the research team below:

Shefali Christopher
Assistant Professor, Elon University
Tel: +1-336-278-6416; Email: schristopher3@elon.edu

Associate Professor Suzanne Snodgrass
Associate Professor, University of Newcastle, Australia
Tel: +61 2 4921 2089; Email: Suzanne.Snodgrass@newcastle.edu.au

Professor Chad Cook
Professor, Duke University
Tel: +1-919-684-8905; Email: Chad.Cook@duke.edu

Complaints about this research
This project has been approved by the University’s Newcastle's Human Research Ethics Committee, Approval No H-2019-0118 and Elon University's Institutional Review Board (Protocol #19-222)
Should you have concerns about your rights as a participant in this research, or you have a complaint about the manner in which the research is conducted, it may be given to the researcher, or, if an independent person is preferred, to Stephen Bailey Elon IRB chair, telephone (336) 278-6346 or e-mail baileys@elon.edu.. You may also contact the Human Research Ethics Officer, Research Services, NIER Precinct, The University of Newcastle, University Drive, Callaghan NSW 2308, Australia, telephone +61 (2) 4921 6333, email Human-Ethics@newcastle.edu.au, email Human-Ethics@newcastle.edu.au.
If you would like to complete the questionnaire, please click on the arrow below.

Please fill out the following information:

Do you have a child 36 months (3 years) or younger?

○ Yes

○ No

Display This Question:

If Please fill out the following information: Do you have a child 36 months (3 years) or younger? = No

Thank you for your participation. You have indicated that you do not have a child under the age of three. We are currently only including postpartum runners who have a child under three and are trying to run a least 1x/week on average unless they are limited by pain. If you feel you have received this message in error, please contact schristopher3@elon.edu

Skip To: End of Survey If Thank you for your participation. You have indicated that you do not have a child under the age o... Is Displayed

Are you currently pregnant?

- Yes
- No

Display This Question:

If Are you currently pregnant? = Yes

Thank you for your participation. You have indicated that you are currently pregnant. We are only including postpartum runners at this time. If you feel you have received this message in error, please contact schristopher3@elon.edu

Skip To: End of Survey If Thank you for your participation. You have indicated that you are currently pregnant. We are only... Is Displayed

How many times did you run in the last four weeks?

- ○ 0
- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7
- ○ 8
- ○ 9
- ○ 10
- ○ >10

Display This Question:

If How many times did you run in the last four weeks? = 1

Or How many times did you run in the last four weeks? = 2

Or How many times did you run in the last four weeks? = 3

Or How many times did you run in the last four weeks? = 0

Why are you currently unable to run at least one time per week?

- ◯ My pain limits me
- ◯ I cannot find the time
- ◯ Other- Please Specify: ____

Display This Question:

If Why are you currently unable to run at least one time per week? = I cannot find the time

Thank you for your participation. You have indicated that you are currently not running at least one time a week. We are currently only including postpartum runners who are trying to run a least 1x/week on average unless they are limited by pain. If you feel you have received this message in error, please contact schristopher3@elon.edu.

Skip To: End of Survey If Thank you for your participation. You have indicated that you are currently not running at least... Is Displayed

End of Block: Default Question Block

Start of Block: Running info

The following questions are about your running habits.

How many total miles/ kilometers did you average in the past 7 days?

- ◯ Miles ____
- ◯ Kilometers ____

Has your running mileage changed due to COVID-19?

- ◯ Yes, it has increased
- ◯ Yes, it has decreased
- ◯ No change in amount of running

When did you start running after having a baby? (in weeks)

____

What type of runner are you **currently**?

○ Novice (I am new to running)

○ Recreational (I run for exercise, race for fun)

○ Competitive (I have a training plan and race to achieve personal best time)

○ Elite (I place in the top 10% of my age group at races)

○ Other- Please Specify:

____

End of Block: Running info

Start of Block: Pain

The following questions ask you about your current pain when running.
Do you currently have any pain when running?

○ Yes

○ No

End of Block: Pain

Start of Block: Depression

As you have recently had a baby, we would like to know how you are feeling. Please check the answer that comes closest to how you have felt IN THE PAST 7 DAYS, not just how you feel today.

In the past 7 days:

I have been able to laugh and see the funny side of things

- ◯ As much as I always could
- ◯ Not quite so much now
- ◯ Definitely not so much now
- ◯ Not at all

I have looked forward with enjoyment to things

- ◯ As much as I ever did
- ◯ Rather less than I used to
- ◯ Definitely less than I used to
- ◯ Hardly at all

I have blamed myself unnecessarily when things went wrong

- ◯ Yes, most of the time
- ◯ Yes, some of the time
- ◯ Not very often
- ◯ No, never

I have been anxious or worried for no good reason

- ◯ No, not at all
- ◯ Hardly ever
- ◯ Yes, sometimes
- ◯ Yes, very often

I have felt scared or panicky for no very good reason

- ◯ Yes, quite a lot
- ◯ Yes, sometimes
- ◯ No, not much
- ◯ No, not at all

Things have been getting on top of me

- ◯ Yes, most of the time I haven't been able to cope at all
- ◯ Yes, sometimes I haven't been coping as well as usual
- ◯ No, most of the time I have coped quite well
- ◯ No, I have been coping as well as ever

I have been so unhappy that I have had difficulty sleeping

- ◯ Yes, most of the time
- ◯ Yes, sometimes
- ◯ Not very often
- ◯ No, not at all

I have felt sad or miserable

- ◯ Yes, most of the time
- ◯ Yes, quite often
- ◯ Not very often
- ◯ No, not at all

I have been so unhappy that I have been crying

- ○ Yes, most of the time
- ○ Yes, quite often
- ○ Only occasionally
- ○ No, never

The thought of harming myself has occurred to me

- ○ Yes, quite often
- ○ Sometimes
- ○ Hardly ever
- ○ Never

Display This Question:

If The thought of harming myself has occured to me = Yes, quite often

Or The thought of harming myself has occured to me = Sometimes

Thank you for your response. If you are feeling sad, anxious, and depressed or have plans to harm yourself please reach out to an emergency medical provider immediately. This is a worldwide survey and the following information will be displayed You can also reach out to a hotline for support with depression below: Argentina: +5402234930430 Australia: 131114 Austria: 017133374 Belgium: 106 Bosnia & Herzegovina: 080 05 03 05 Botswana: 3911270 Brazil: 188 for the CVV National Association Canada: 5147234000 (Montreal); 18662773553 (outside Montreal) Croatia: 014833888 Denmark: +4570201201 Egypt: 7621602 Estonia: 3726558088; in Russian 3726555688 Finland: 010 195 202 France: 0145394000 Germany: 08001810771 Holland: 09000767 Hong Kong: +852 2382 0000 Hungary: 116123 India: 8888817666 Ireland: +4408457909090 Italy: 800860022 Japan: +810352869090 Mexico: 5255102550 New Zealand: 0800543354 Norway: +4781533300 Philippines: 028969191 Poland: 5270000 Portugal: 21 854 07 40/8 . 96 898 21 50 Russia: 0078202577577 Spain: 914590050 South Africa: 0514445691 Sweden: 46317112400 Switzerland: 143 United Kingdom: 08457909090 USA: 18002738255 Veterans' Crisis Line: 1 800 273 8255/ text 838255 (https://ibpf.org/resource/list-international-suicide-hotlines)

End of Block: Depression

Start of Block: Delivery, fatigue, sleep, other

The following questions ask about your current level of fatigue.

In the last **two weeks** have you felt fatigued?

◯ Yes

◯ No

Display This Question:

If The following questions ask about your current level of fatigue. In the last two weeks have you... = Yes

Please answer the following questions about your fatigue:

Feel tired in the morning	▼ Rarely ... Often
Feel exhausted (excluding after exercising)	▼ Rarely ... Often
Feel more tired than before	▼ Rarely ... Often
A strong urge to sleep in the daytime	▼ Rarely ... Often
Feel unwell	▼ Rarely ... Often
Feel unrested	▼ Rarely ... Often
Feel depressed	▼ Rarely ... Often
Feel anxious	▼ Rarely ... Often
Feel restless	▼ Rarely ... Often
Feel irritable	▼ Rarely ... Often
Feel apt to make errors	▼ Rarely ... Often
Feel unfocused	▼ Rarely ... Often
Feel unmotivated	▼ Rarely ... Often

The following questions ask about your delivery history.
How many living children do you have (that you have birthed)?

- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5 or more

What is the date of birth of your **youngest** child?

	Month	Day	Year
Please Select:	▼ January ... December	▼ 1 ... 31	▼ 2016 ... 2020

What was the delivery type of your **youngest** child?

- ◯ Vaginal
- ◯ Vaginal assisted (forceps, suction etc.)
- ◯ C-Section
- ◯ Other- Please Specify: ____

Are you currently breast feeding or pumping?

- ◯ Yes
- ◯ No

Display This Question:

If Are you currently breast feeding or pumping? = No

How many months did you breastfeed/pump for?

- ○ I did not breastfeed
- ○ 1-3 months
- ○ 3-6 months
- ○ 6-9 months
- ○ 9-12 months
- ○ 12-15 months
- ○ 15-18 months
- ○ 18-21 months
- ○ 21-24 months
- ○ > 24 months

The following questions ask about your core and pelvic health.

Have you been diagnosed with a "Diastasis Recti" (separated abdominals)?

- ◯ Yes
- ◯ No
- ◯ Unsure
- ◯ Other- Please Specify: ____

Do you leak any amount of **urine** when you cough, sneeze, change positions or run?

- ◯ Yes
- ◯ No

Do you leak **feces/gas** when you cough, sneeze, change positions or run?

- ◯ Yes
- ◯ No

The following questions ask about your sleep.

In the past 7 days, how many total hours of sleep did you average each night?

____

On average in the past 7 days, how many interruptions in sleep do you have per night?

- ◯ 0
- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ More than 5

The following questions ask about your PRIOR running injury history.
Have you **ever** had a running-related injury that you went to see a health professional for? (not current injury if any)

- ◯ No
- ◯ One injury
- ◯ Two injuries
- ◯ Three injuries
- ◯ Four or more injuries

In which country do you currently reside?

▼ Afghanistan ... Zimbabwe

Display This Question:

If List of Countries = United States of America

In which state do you currently reside?

▼ Alabama ... I do not reside in the United States

What is your age (years)?

▼ 18 ... 50

What is your relationship status?

- Single
- Married
- Committed relationship/ partner
- Divorced
- Widowed
- Separated
- Never married/ No partner

End of Block: Country

Start of Block: Demographics Base/Universal

What is the highest level of school you have completed or the highest degree you have received?

- ○ Less than high school degree
- ○ High school graduate (high school diploma or equivalent including GED)
- ○ Some post high school education but no degree
- ○ Associate degree in technical college/ trade school (2-year)
- ○ Bachelor's degree in university (4-year)
- ○ Master's degree
- ○ Doctoral degree
- ○ Professional doctorate degree (JD, MD, DPT, DDS etc.)

Choose one or more races that you consider yourself to be:

- ☐ White
- ☐ Black or African American
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Native Hawaiian or Pacific Islander
- ☐ Prefer not to answer
- ☐ Other- Please Specify:

____

End of Block: Demographics Base/Universal

Please Note:
Questions related to data that has not been included in this manuscript have been removed.