CHARLES UNIVERSITY

Faculty of Physical Education and Sport

DISSERTATION

2024 **Mgr. Ondřej Kališko**

CHARLES UNIVERSITY

Faculty of Physical Education and Sport

Sport Sciences-Biomedical Department

Retroverze pánve při dřepu, její objektivizace a možné řešení pomocí pohybové intervence

Posterior pelvic tilt during squat, its objectification and possible treatment by exercise therapy

Supervisor:

doc. James J. Tufano, MSc., Ph.D.

Author:

Mgr. Ondřej Kališko

Prague, 2024

Declaration

I declare that I have independently written this dissertation thesis under the supervision of doc. James J. Tufano, MSc., Ph.D., and that I have cited all sources of information and literature used. Neither this dissertation nor any substantial part of it has been submitted for any other or the same degree.

Prague, December 17th 2024

Mgr. Ondřej Kališko

....

Mgr. Ondřej Kališko

Acknowledgements

I would like to thank my supervisor, doc. James J. Tufano, MSc., Ph.D., for guiding my thesis in a particular direction and always being available for advice and consultation. I would also like to thank my colleagues from the Faculty of Health Studies at the Jan Evangelista Purkyně University in Ústí nad Labem, namely Mgr. Veronika Kvochová and Mgr. Marek Jelínek, Ph.D., for their help with data collection and RNDr. Karel Hrach, Ph.D., for his help with statistical processing. I would also like to thank my colleagues from the Faculty of Science, Mgr. Lucie Loukotová and Mgr. Alena Černíková, MSc., Ph.D., for their help with statistical processing. Thanks are also due to all participants in the experiment, without whose data this thesis could not have been written. Last but not least, I would like to thank my wife and my parents who have always supported me on life's journey.

ABSTRACT

Introduction: The squat is a compound exercise used in sports, physiotherapy, and activities of daily living. Posterior pelvic tilt during the squat, commonly referred to as „butt wink“ can potentially increase the risk of spinal injury when performing a squat with posterior pelvic tilt.

The objective: The main goal of the thesis is to objectively assess the effect the immediate effect of the exercise intervention on the total pelvis ROM in the sagittal plane (mainly posterior pelvic tilt) during squat. The secondary aim of the thesis is to determine the relationship between the initial pelvic position and the occurrence of PPT.

Methodology: This was a controlled experiment with 42 participants (21 females and 21 males) divided into an experimental group (n = 23) and a control group (n = 19). The division was made according to the incidence of posterior pelvic tiltduring the performance of the bodyweight squat. A baseline measurement that included three-dimensional kinematic motion analysis and a physiotherapy examination and an outocme measurement that included only three-dimensional kinematic motion analysis were performed. Both groups underwent a twenty-minute exercise intervention aimed at strengthening stabilizing muscles, improving squat technique and body awareness in space. Data from the three-dimensional kinematic motion analysis were statistically processed using Restricted Maximum Likelihood analysis of linear mixed models and repeated measures analysis of variance (rANOVA).

Results: There was no statistically significant difference in the range of motion of posterior pelvic tilt before and after the exercise intervention ($p = 0.89$ and $p = 0.42$). Only the individual repetitions of the squat were statistically significantly different from each other ($p < 0.001$) and no statistically significant relationship between posterior pelvic tilt and initial pelvic position was found ($p = 0.13$).

Conclusion: The short exercise intervention did not affect the range of motion of posterior pelvic tilt during squatting, but it is still worth investigating this issue further and looking for possible associations between different variables of squat execution and the incidence of posterior pelvic tilt.

Keywords: exercise intervention, posterior pelvic tilt, squat, three-dimensional kinematic motion analysis

ABSTRAKT

Úvod: Dřep je komplexní cvik, který se využívá nejen v oblasti sportu, ale také fyzioterapie a je i součástí běžných denních aktivit. Retroverze pánve během dřepu, běžně označovaná jako „butt wink" může potenciálně zvýšit riziko zranění páteře při provádění dřepu s retroverzí.

Cíl práce: Hlavním cílem dizertační práce je objektivizace okamžitého účinku pohybové intervence na celkový rozsah pohybu pánve v sagitální rovině (zejm. retroverze pánve) při provádění dřepu. Druhotným cílem práce je určit vztah mezi počátačením postavením pánve a výskytem retroverze pánve při dřepu.

Metodika: Jedná se o kontrolovaný experiment, do kterého bylo zařazeno 42 účastníků (21 žen a 21 mužů), kteří byli rozděleni na experimentální (n = 23) a kontrolní (n = 19) skupinu. Rozdělení bylo provedeno podle výskytu retroverze pánve při provádění dřepu s vlastní vahou. Bylo provedeno vstupní měření zahrnující třírozměrnou kinematickou analýzu pohybu a fyzioterapeutické vyšetření a výstupní měření zahrnující již pouze třírozměrnou kinematickou analýzu pohybu. Obě skupiny podstoupili 20minutovou pohybvou intervenci zaměřenou na posílení stabilizačních svalů, zlepšení techniky dřepu a uvědomění si vlastního těla v prostoru. Data z třírozměrné kinematické analýzy pohybu byla statisticky zpracována pomocí Restricted Maximum Likelihood analýzy lineárních mixovaných modelů a pomocí analýzy rozptylu pro opakovaná měření (rANOVA).

Výsledky: Nebyl shledán statisticky významný rozdíl v rozsahu retroverze pánve před a po pohybové intervenci ($p = 0.89$ and $p = 0.42$). Pouze se od sebe statisticky významně lišila jednotlivá opakování dřepu ($p < 0.001$) a nebyl shledán žádný statisticky významný vztah mezi rozsahem retroverze pánve a výchozím postavením pánve ($p = 0.13$).

Závěr: Krátká pohybová intervence neovlivnila rozsah retroverze pánve během dřepu, přesto je vhodné se touto problematikou dále zabývat a snažit se hledat možné spojitosti mezi různými proměnnými v provedení dřepu a výskytem retroverze pánve.

Klíčová slova: dřep, pohybová intervence, retroverze pánve, třírozměrná analýza pohybu

CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

1RM – One repetition maximum

3D – three-dimensional

ADL – Activities of daily living

ASIP – Anterior superior iliac spine

BSA – Back Squat Assessment

FMS – Functional Movement Screen

FTVS UK – Faculty of Physical Education and Sport at Charles University in Prague

FZS UJEP – Faculty of Health Studies at the Jan Evangelista Purkyně University in Ústí nad Labem

GPP – General physical preparation

PPT – Posterior pelvic tilt

PSIP – Posterior superior iliac spine

rANOVA – Repeated measures analysis of variance

REML – Restricted Maximum Likelihood

ROM – Range of motion

1 INTRODUCTION

The squat is considered a compound exercise used in a variety of sports. It is also a part of physiotherapy/rehabilitation for various musculoskeletal conditions and is also a common movement stereotype of the human species (Chelly et al., 2009; Havel et al., 2009; Kolář et al., 2020).

Squat safety involves a number of factors, including e.g. warm-up, proper footwear, and most importantly, a proper squat technique (Myer et al., 2014). And this is where we have seen a discussion over the last decade or so on the topic of posterior pelvic tilt (PPT) in the squat, colloquially known as the „butt wink“ (Henoch, 2014; Nielsen, 2015; Todoroff, 2017).

The term PPT includes both the term for physiotherapy (posterior position or movement of the pelvis in the sagittal plane, with lumbar lordosis flattening or even becoming kyphotic) and the term for squatting, which is a movement that occurs during the descending phase of a deep squat, with the pelvis moving below the thigh axis during this movement (Snášel, 2017; Vašíčková, 2024).

The reason why this topic is often discussed is mainly because of the risk of injury to the athlete who squats with PPT. Very often the premise is that the lumbar flexion (lumbar lordosis flattening or even becoming kyphotic) that occurs with PPT is dangerous to the intervertebral discs, or that it increases the risk of disc herniation (Jesenická, 2018; McGill, 2021; Sedláková, 2023).

However, there is often no precise explanation of this phenomenon and possible ways to correct it are only vaguely mentioned. The aim of this thesis is certainly not to describe or clarify the exact mechanisms of the phenomenon, but to try to objectify the phenomenon by means of three-dimensional (3D) kinematic motion analysis and, based on the research already carried out (Kushner et al., 2015), to try to influence this phenomenon with a short exercise intervention.

2 THEORETICAL BACKGROUND

2.1 SQUAT

Often referred to as the king of all exercises, the squat is a fundamental, compound and multi-joint exercise that predominantly trains the muscles of the lower limbs (Contreras, 2014; Doll, 2024; Král, 2017; Krčová, 2019; Pavluch & Frolíková, 2004; Petr & Šťastný, 2012; Roubík, 2012; Schwarzenegger & Dobbins, 2018; Smejkal, 2015; Stackeová, 2014; Stoppani, 2016; Tlapák, 2022a).

The key is to master the correct technique of the bodyweight squat before moving on to the externally loaded squat (Myer et al., 2014). There are a multitude of squat variations with external load, the most common being the back squat with a barbell on the back with variations of high bar and low bar squat, followed by the front squat with, Zercher squat, Hack squat, box squat, Sissy squat, skater squat, squats performed with dumbbells, kettlebells, expanders or medicine balls, squats performed in a Smith machine or other apparatus. Squats can also be performed on one leg, with elevated support (Bulgarian squat), with support against a wall, in a lunge, or a jump squat (Carr & Feit, 2024; Contreras, 2014; Diamond-Walker, 2019; Doll, 2024; Král, 2017; Pavluch & Frolíková, 2004; Stoppani, 2016; Tlapák, 2022a). When squatting, it is possible to stand on various balance supports, e.g. balance hemisphere ball, air pads, cylindrical, conical or circular pads, gymnastic ball, balance step, or one can stand on solid ground and use unstable tools filled with water or sand instead of barbell or dumbbells, e.g. aqua training bag or aqua training tube. The goal of such squats is to develop coordination, postural stability and neuromuscular control (Glass & Albert, 2018; Havel et al., 2010a; Jebavý & Zumr, 2014). However, these balancing supports may not always result in increased muscle activity, especially in the core and deep stabilization muscles, and may even limit hypertrophy, strength, and power output (Clark et al., 2012; Hamlyn et al., 2007; Nuzzo et al., 2008).

Some authors point out that squatting with a barbell on the back with a load puts the athlete at increased risk of injury, typically to the knee joint and lumbar spine, and is therefore not recommended for beginners who are inexperienced with the exercise or who do not have a well-trained core and strengthened gluteal muscles (Carr & Feit, 2024; Smejkal, 2015; Stackeová, 2014; Tlapák, 2022a). At first, performing squats with a kettlebell or dumbbell held in front of the body may be a solution, as it is easier to perform, teaches proper technique, and minimizes the risk of injury (Carr & Feit, 2024; Smejkal, 2015). Or, start by squatting in a smaller range of motion (ROM) (Tlapák, 2022a). Despite the potential risks, squats should be incorporated into a beginner's training plan as early as possible (Tlapák, 2022b). Some authors disagree with this view (Comfort et al., 2018; Myer et al., 2014; Petr & Šťastný, 2012; Schoenfeld, 2010) and point out that the risk is mainly due to inadequate load and poor squatting technique, or adding load quickly while not mastering proper squatting technique, and that fatigue also plays a role, especially when trying to determine one repetition maximum (1RM), where the benefit of knowing the 1RM doesn't necessarily outweigh the potential risk of injury.

The squat is commonly used to develop strength and speed and should be included in training for basketball, futsal, gymnastics, long jump, shot put, swimming, and downhill skiing (Havel et al., 2009; Havel et al., 2010a). The squat can also be used to test strength endurance in the Burpee test (Havel et al., 2010b). Thus, the squat is an excellent exercise for developing muscle hypertrophy and strength, particularly in the extensor muscles of the knee and hip joints, which can then be transferred to other areas of sports performance such as sprinting or jumping (Chelly et al., 2009; Choe et al., 2021; Roubík, 2012; Styles et al., 2016).

In addition, squat can also be labeled as a common (physiological) human movement pattern, as it appears around the tenth month of the child's life as an uprighting mechanism for the child to become bipedal (Hellbrügge et al., 2010; Kačírková & Rybová, 2022; Kolář et al., 2020; Palaščáková Špringrová, 2024). Squatting is also an essential part of activities of daily living (ADL), such as sitting down and getting up from a chair, toilet etc., and it is very important to include it in a general physical preparation (GPP) exercise unit/conditioning, as it is an important factor in preventing the development of geriatric frailty (Liebenson, 2019).

Related to this is the fact that the squat is also used as a diagnostic tool in physiotherapy, where core muscle activation can be inferred from the performance of the squat, or different deviation in performance can be observed – e.g. accentuation of thoracic and lumbar lordosis, failure to maintain a neutral position of the head, chest and pelvis, or the occurrence of valgus/varus deformity of the knees or ankles. The squat is also used as a therapeutic exercise in physiotherapy, either as a static position (e.g. squatting or lunging on one lower limb, stopping in the transition from the quadruped position to the bipeal position, etc.) but also as regular dynamic exercise with various modifications (performing the squat in front of the ladders with correction of the pelvic position, sumo squat, front squat, etc.). The goal of such therapy is often to teach the patients correct stabilization of the trunk and lumbar spine in the sagittal plane (training the activation of intra-abdominal pressure or abdominal hydraulics), or training of interconnection of individual body segments (Hagovská et al., 2016; Kolář et al., 2020; Palaščáková Špringrová, 2024; Švejcar & Šťastný, 2013; Tlapák, 2022b).

It is also beneficial to include the squat and its variants, such as the wall-supported squat, in physiotherapy after knee injury given that squatting is known to be safe for the knee joint (Biscarini et al., 2022; Kolář et al., 2020). Single-leg squats performed on a lateral oblique and decline plane may also be beneficial for patients with sacroiliac and knee joint pain (Yoo, 2016). Squatting is even safe for patients after total hip arthroplasty, as there was no abnormal ROM that could lead to subluxation or impingement syndrome (mean hip flexion was 80.7° with mean PPT of 12.8°), and the surgery itself allowed more patients to perform squats than before surgery (only 23.5% of patients were able to squat before surgery and after surgery, 46% of patients) (Harada et al., 2022). The combination of squats with other exercises (bridge and stability ball exercises for anterior and PPT training) can also affect sphincter function in children, with a significant reduction in daytime and nighttime bedwetting (86% of children were completely free of symptoms after four months) (Garcia-Fernandez & Petros, 2020).

The most active muscle during the squat is the quadriceps femoris, but the hamstrings, hip adductors, gluteal muscles, lumbar spine erectors and triceps surae are also involved (Contreras, 2014; Král, 2017). In general, it can be assumed that the greater the depth of the squat and the load applied, the greater the muscle activation. This is supported, for example, by the research of Gorsuch et al. (2013), who found that the activation of the rectus femoris and erector spinae muscles was greater in the parallel squat than in the partial squat. The hamstrings and gastrocnemius muscles then show similar levels of activation in both variants. Gender was found to play no role in muscle activation. However, other authors (Contreras et al., 2016; Gullett et al., 2009) report that the effect of the squat variant used (back – front squat) does not play a major role in muscle activation, despite the fact that different loads (higher in the back squat) or squat depths are used. The difference in muscle activation when using loads of 80, 90 and 100% 1RM is also negligible, and increasing the load causes a increase in forward lean of the trunk, which increases the load on the lumbar spine. A load of 90% 1RM is sufficient for adequate muscle stimulation as it is comparable to a 100% 1RM load and may even reduce the risk of injury (Yavuz & Erdag, 2017). The activation of all muscles can be increased by up to 43% when the squat is performed with a barbell compared to a Smith machine (Schwanbeck et al., 2009).

The contraindications for squatting are not clearly defined, but caution should be exercised in athletes with (low) back pain and in pregnant women (Sikorová, 2009; Stackeová, 2014).

2.1.1 PROPER SQUAT TECHNIQUE

Correct alignment of multiple segments of the human body is essential for proper squat technique/performance (Kushner et al., 2015; Myer et al., 2014). The classification of segments into stable and mobile zones is often used (Contreras, 2014; Diamond-Walker, 2019; Horschig et al., 2022; Vančura, 2024). Squat performance can then be assessed using, for example, the Back Squat Assessment (BSA) or Functional Movement Screen (FMS) protocol (Breen et al. 2016; Myer et al., 2014; Peterson, 2018).

A large number of variables determine the specific execution of the squat and the maximum squat strength, but anthropometric factors, such as fat-free mass normalized to height, and lower limb length, or the Crural index (ratio of tibia to femur length), seem to be the most relevant, and only then do biomechanical and psychological parameters come into play (Vigotsky et al., 2019). Abelleira-Lamela et al. (2021) have a similar view, although not in relation to squatting, but in relation to outdoor fitness equipment, indicating that anthropometric parameters, namely the Cormic index (ratio of sitting height to height) and height, play a crucial role in the position of the spine and pelvis, respectively, that individuals with a higher value of this index tend to have an increase in thoracic kyphosis, a flattening of the lumbar lordosis and a decrease in anterior pelvic tilt when using outdoor fitness equipment.

The squat itself is divided into a descending (eccentric) and an ascending (concentric) phase. The descent phase can resemble a movement like sitting in a chair (Bertram, 2018; Stoppani, 2016). It begins with simultaneous flexion of the knees and hips and then the straight trunk descends down (Contreras, 2014; Diamond-Walker, 2019; Stackeová, 2014). Doll (2024) and Tlapák (2022b) state that it is preferable to begin the squat by pushing the buttocks backward. During the flexion, the knee joints should remain above the ankles (Carr & Feit, 2024; Doll, 2024). The depth of the squat should at least „parallel“, this means that the thighs are parallel to the ground (Bertram, 2018; Carr, 2024; Clémenceau & Delavier, 2021; Diamond-Walker, 2019; Pavluch & Frolíková, 2004; Schwarzenegger & Dobbins, 2018; Stackeová, 2014; Stoppani, 2016; Švejcar & Šťastný, 2013). A more accurate description of the correct squat depth is as deep as the athlete can maintain the lumbar spine without flexion (i.e., in lordosis) (Comfort & Kasim, 2007; Contreras, 2014; Straub & Powers, 2024). At the end of the descent phase, the knees and head should be above the toes (Švejcar & Šťastný, 2013). Then follows an ascending phase, which starts with a strong push of the heels into the ground with an upward movement of the pelvis, which must precede the movement of the knees (Stoppani, 2016). Breathing in is done during the descending phase, breathing out during the ascending phase (Clémenceau & Delavier, 2021; Pavluch & Frolíková, 2004; Stackeová, 2014; Stoppani, 2016; Švejcar & Šťastný, 2013; Tlapák, 2022a, 2022b).

Certain mistakes can be made when performing the squat. Common ones include positioning the knees in front of the toes, misalignment of the lower limb joints, excessive forward lean of the trunk, improper breathing, excessive head / cervical spine flexion or extension, excessive or very low ROM, quick execution of the descent phase with rebound in the lowest phase, and improper placement of the barbell (it should be placed on the top of the shoulder blades) (Stackeová, 2014; Švejcar & Šťastný, 2013). However, opinions on some of the above-mentioned mistakes, especially the positioning of the knee joints and the trunk, are not unanimous and will be discussed in the following text.

Stance width

The width of the stance is most often shoulder width (Bertram, 2018; Diamond-Walker, 2019; Doll, 2024; Král, 2017; Pavluch & Frolíková, 2004; Popowychová, 2023; Schwarzenegger & Dobbins, 2018; Stoppani, 2016) or slightly wider (Bertram, 2018; Carr & Feit, 2024; Stoppani, 2016), one can also find pelvic width (Bertram, 2018; Stackeová, 2014; Tlapák, 2022a, 2022b) or hip width (Clémenceau & Delavier, 2021; Jarkovská & Jarkovská, 2016; Švejcar & Šťastný, 2013) stances.

If the stance is hip width, squat depths up to 80° of knee flexion can be achieved without PPT. Increasing the squat depth requires either a wider stance or PPT, which is not recommended when training with a load (Švejcar & Šťastný, 2013). Increasing the stance width, to at least twice the width of the anterior superior iliac spine (ASIP), creates a more vertical shank position and also changes the angular alignment of the trunk (less forward leaning is required) and the lumbar spine, where a more upright posture is found, reducing its load (Escamilla et al., 2001; McKean et al., 2010; Swinton et al., 2012). Thus, the wide stance squat appears to be more appropriate for those athletes who have sufficient ROM at the hip joint, but lack ROM at the ankle joint and are therefore unable to descend to a sufficient depth with the rest of the body positioned correctly (Swinton et al., 2012). Lorenzetti et al. (2018) present a slightly different view, namely that the overall ROM in the lumbar spine is virtually identical at different stance widths, although the smallest ROM was indeed observed in the widest stance variant (twice the ASIP width) combined with extreme (42°) external rotation of the feet, these findings are valid for both beginners and experienced athletes.

Foot position

It should be such that the toes point forward (Carr & Feit, 2024; Clémenceau & Delavier, 2021; Doll, 2024; Schwarzenegger & Dobbins, 2018; Tlapák, 2022b), or the whole foot can be externally rotated (Bertram, 2018; Contreras, 2014; Král, 2017; Pavluch & Frolíková, 2004; Stackeová 2014). The feet can be supported under the heels with a disk or wedge, and weightlifting shoes can also be used, with the amount of support being individualized and depending on the ROM in dorsiflexion at the ankle (Král, 2017). Heel support can reduce forward leaning of the trunk, which can be dangerous for the lumbar spine (increasing shear forces) (Charlton et al., 2017; Stackeová, 2014). However, maintaining a neutral spine position appears to be a far more important factor in minimizing the risk of lumbar spine injury, and this factor is not affected by heel support (Charlton et al., 2017). In another finding (Mata et al., 2021), heel support of 4.5 cm allows for a deeper squat and greater ROM at the knee and ankle joints, but hip flexion ROM and the occurrence of PPT are not affected by heel support, also the PPT occurs almost always at the same time with and without heel support. Thus, PPT is most likely a compensatory mechanism that occurs when the femur hits the acetabulum at the moment of maximum possible hip flexion. Conversely, Tlapák (2022b) states that heel support may be detrimental because it overloads the articular cartilage between the femur and patella.

The effect of footwear used on squat performance was also examined by Southwell et al. (2016), who found that running and weightlifting shoes showed a statistically significantly greater knee extension moment than performing the squat barefoot, and weightlifting shoes showed a statistically significantly greater knee external rotation moments than the other two footwear conditions. At the hip joint, barefoot squatting showed a statistically significantly greater internal rotation and less external rotation moments than the other two footwear conditions. In terms of lumbosacral compression and shear forces, no differences were found between the footwear types, with only the barefoot squat showing a greater forward leaning of the trunk.

Oshikawa et al. (2018) hypothesized that squatting with the toes pointed outward (i.e., external rotation at the hip joint) brings the iliotibial band and the and attachments of the gluteus maximus muscle closer together, increasing hip flexion ROM. Thus, external rotation at the hip joint may indirectly prevent PPT during squats by increase the hip flexion ROM, thereby decreasing lumbar kyphosis during deep squats. However, this hypothesis was not confirmed because even with external rotation at the hip joint during deep squat, no difference in lumbar lordosis angle was found compared to normal stance. In parallel squat, however, lumbar kyphosis actually decreased with external rotation of the hip joint.

Knee joint

The knee is the largest synovial joint in the human body. It is a compound joint consisting of the patellofemoral and tibiofemoral joints and a large number of passive stabilizers – menisci and ligaments. High demands are placed on the joint in terms of stability, but also in terms of ensuring a sufficient ROM. These conflicting requirements can only be met by a combination of the specific shape of the articular surfaces, the presence of passive stabilizers, and the muscles that cross the joint. The knee joint can move in flexion, extension, and external and internal rotation. The ranges of motion are roughly as follows: standing flexion is 120°, the flexion with the hip joint flexion is up to 140° and passive flexion can reach up to 160°, extension is 0° but can be 5–10°, and both rotations are around 60–70° (Standring, 2020).

During the descending phase of the squat, the knees should point above the toes without lateral deviation (Pavluch & Frolíková, 2004; Tlapák 2022a, 2022b). In other words, the hips, knees, and ankles are in the same line (Bertram, 2018; Stackeová, 2014). However, Contreras (2014) states that the knees should be pushed outward so that they are further from the center of the body than the center of the foot. Jarkovská & Jarkovská (2016) then state that the knees should not be pushed too far forward.

However, it is generally agreed that the movement of the knee joint should not be restricted, i.e. the knee should be able to go over the toes, otherwise there will be more load on the lumbar spine and hip joint (Comfort & Kasim, 2007; Comfort et al., 2018; List et al., 2013). According to List et al. (2013), unrestricted squats result in less stress in lumbar spine because more motion occurs at the knee joint, reducing segmental motion between the pelvis and thoracic spine while also reducing forward leaning of the trunk. Conversely, limited squats increase forward leaning of the trunk, which increases the stress on the lumbar spine. Similar findings apply to parallel high bar squats with unrestricted knee movement, which show greater knee torque, whereas restricted squats result in greater hip torque. The restricted squat also resulted in a more vertical shank position and a greater forward leaning of the trunk, while less flexion was observed at the knee and hip joints. Therefore, it is advisable to allow the knees to slightly exceed the toes during the parallel squat in order to optimize the forces on all joints involved (Fry et al., 2003).

The fact that half squats show less movement of the lumbar spine into flexion at the L3–L5 segments and less forward leaning of the trunk and less lumbosacral flexion compared to unrestricted half squats also contributes to the use of unrestricted squats. However, despite these findings, the entire lumbar spine showed movement into flexion from start to finish in both variants. Although unrestricted squats place less stress on the spine as a whole, it is recommended not to perform squats at all if the athlete is unable to flex the spine (e.g., with disc herniation) (Hebling Campos et al., 2017).

Hip joint

The hip joint is a large, weight-bearing, ball-and-socket, three-axis joint with a relatively limited ROM (so called enarthrosis). The reason for the limited ROM is that the femoral head fits into a relatively deep socket called the acetabulum (Dylevský, 2021; Eliška, 2023). The hip joint is anatomically and functionally related to the lumbar spine and pelvis, or their curvature / position, and therefore it is necessary to examine the pelvis and lumbar spine and vice versa when assessing the correct function of the hip joint (Jesenická, 2018; Kapandji, 2019a; Muscolino, 2023; Pirola, 2024; Stackeová, 2023).

The hip region is essential for proper force distribution and ensuring overall stability when performing the squat, where limited ROM into hip flexion and weakness of the gluteal muscles can be limiting factors for proper squat performance (Contreras, 2014). We know that ROM and muscles around the hip show greater values and involvement when performing a standard back squat, whereas muscles around the knee joint and muscles involved in trunk stabilization are more involved in the front squat and squats performed with the safety bar (Braidot et al., 2007; Johansson et al., 2024). Similar results were found when comparing the squat with the hex bar deadlift, i.e. the hip joint shows greater muscle involvement and greater ROM with less forward leaning of the trunk (Stahl et al., 2024). Regarding the variations of the low bar squat and the high bar squat, the low bar squat seems to be preferable because it also increases the muscle activation around the hip joint and also allows the use of higher loads compared to the high bar squat. High bar squat, on the other hand, results in greater activation of the muscles around the knee joint and requires a more upright posture. Greater activation of the muscles around the hip joint may reduce forward leaning of the trunk and increases stability, potentially reducing the stress on the lumbar spine and ankle compared to the high bar squat (Glassbrook et al., 2019).

If we want to increase the activation of the muscles around the hip joint, we can perform the counterbalanced squat, where the load is held in the extended upper limbs in front of the body (Lynn & Noffal, 2012). However, Sinclair et al. (2017) reported that there were no statistically significant differences in joint kinematics and muscle activation levels (quadriceps femoris and hamstrings) between the back squat and front squat, and the kinematic data were very similar.

Although a connection between the hip joint muscles and their influence on the position of the pelvis and lumbar spine is often reported (Čihák, 2011; Jesenická, 2018; Kapandji, 2019a; Stackeová, 2023), an isometric activation of the abductor group of the hip joint muscles before performing a squat does not lead to an influence on the ROM of the lumbar spine (Kelly et al., 2018).

Chest and back

The chest is braced and held upright during the squat (Carr & Feit, 2024; Contreras, 2014; Stoppani, 2016). The back should be kept as straight as possible (Bertram, 2018; Clémenceau & Delavier, 2021; Diamond-Walker, 2019; Král, 2017; Pavluch & Frolíková, 2004; Schwarzenegger & Dobbins, 2018; Stoppani, 2016) and the abdominal wall should be consciously activated (Stackeová, 2014; Stoppani, 2016). Limited extension ROM in the thoracic spine can be a limiting factor for proper squat performance (Contreras, 2014).

Head and eye gaze

The head follows the axis of the straight trunk and faces forward (Bertram, 2018; Clémenceau & Delavier, 2021; Stoppani, 2016; Tlapák, 2022b) or is aligned with the spine (Jarkovská & Jarkovská, 2016; Stackeová, 2014; Švejcar & Šťastný, 2013) and should not be leaning forward (Schwarzenegger & Dobbins, 2018; Stackeová, 2014; Tlapák, 2022a). When the head follows the axis of the straight trunk, activation of the abdominal muscles is increased; conversely, head extension facilitates superficial spinal extensors (Tlapák, 2022b). Related to this is the eye gaze, which should be directed forward or slightly upward (Comfort & Kasim, 2007; Comfort et al., 2018; Stackeová, 2014; Tlapák, 2022a).

2.2 POSTERIOR PELVIC TILT DURING SQUAT

The term PPT generally refers to the posterior position or movement of the pelvis in the sagittal plane, with lumbar lordosis flattening or even becoming kyphotic and thoracic kyphosis increasing eventually leading to hyperkyphosis, depending on the degree of PPT

(Vašíčková, 2024). From a physiotherapy point of view, specific palpatory findings are present when the ASIP are at the same level or even higher than the posterior superior iliac spine (PSIP) and the pubic symphysis shifts cranially (Gross et al., 2023; Jedličková, 2019; Jesenická, 2018; Kolář et al., 2020; Véle, 2006).

PPT during a squat, colloquially known as the „butt wink“, is a phenomenon that occurs when performing a deep squat. It is sometimes reported to be quite common, but if the degree of PPT is excessive and/or occurs prior to parallel squat depth, it can potentially increase the risk of lumbar spine injury. Conversely, if the athlete focuses too much on eliminating it, compensatory mechanisms such as increased lumbar extension or severely limited squat depth may occur, making the whole situation worse. Standard causes include anatomical predisposition, limited ROM in the hip and ankle joints, impaired function of the core muscles or impaired neuromuscular control in the lumbar spine and pelvis, and a suboptimal starting squat position in terms of excessive anterior pelvic tilit and lumbar hyperlordosis. It may also be due to a lack of instruction on how to hold the trunk and pelvis during squat. At the same time, it is important to remember that not every athlete can achieve full squat depth, mainly due to individual anatomical differences (Boyce, 2018; English, 2023; Henoch, 2014; Lau, 2022; Mahaffey, 2021; Phili, 2023; Rippetoe, 2018; Snášel, 2017; Todoroff, 2017).

2.2.1 CAUSES OF POSTERIOR PELVIC TILT

Femoroacetabular impingement syndrome (FAI)

Femoroacetabular impingement syndrome (FAI) is a relatively new diagnosis and is usually defined as a condition of the hip joint that occurs as a result of physiological movement in the hip joint, most often caused by an incorrect shape or orientation of the articulating joint surfaces. It is therefore a mechanical conflict between the two articulating ends of the hip joint. There are two types – Cam and Pincer. Cam pathology is the result of a lack of sphericity of the femoral head and/or an excess of protruding bone tissue at the edge of the femoral head. Pincer pathology is caused by poor orientation of the acetabulum – the acetabulum does not have the normal depth and anteversion. Both types most often lead to premature contact of the acetabular rim with the femoral head during flexion and internal rotation of the hip joint, resulting in gradual degeneration of the articular cartilage of the acetabulum and subsequently of the femoral head. However, both types can occur simultaneously (Chládek, 2016; Rychlíková, 2019).

The prevalence is reported to be up to 15%, but is significantly higher in athletes (50–95%). Cam type is typical for athletes and is more common in runners and jumpers and less common in climbers and swimmers (Chládek, 2016). Rychlíková (2019) reports that FAI is generally more common in young athletes, where repetitive sudden movements occur and in sports where there is uneven loading of the hip joints.

There is evidence (Bagwell et al., 2016; Catelli et al., 2018, 2021; Kolber et al., 2018; Yoshimoto et al., 2018) that FAI alters the squat technique. In general, authors agree that FAI causes a change in pelvic positioning, limits ROM in flexion and internal rotation at the hip joint, and decreases squat depth and velocity of the descent phase of the squat. However, the change in pelvic posture is more complex, as Catelli et al. (2021) reported that participants with FAI had a greater PPT in their pelvic posture during squatting, but on the other hand, Bagwell et al. (2016) reported that participants with FAI had a decreased PPT during the descent phase of the squat at 90° of hip flexion. Kobayashi et al. (2021) then further report in their 3D simulation of computed tomography scan data that reducing anterior pelvic tilt by 10° in standing has a comparable effect to surgery on ROM into internal rotation, which increased after surgery and after 3D simulation of the data.

Catelli et al. (2018) also noted that the differences in squat performance between patients with FAI and patients with Cam pathology without subjective symptoms are primarily in terms of differences in activation and strength of muscles around the hip joint, differences in pelvic ROM in the sagittal plane, and differences in squat depth. Patients with FAI have greater hamstring activity, less pelvic ROM, and less squat depth than participants with Cam pathology without subjective symptoms. Patients with Cam pathology have greater activity of the gluteal muscles, which are able to tilt the pelvis into PPT during squatting and thus avoid impingement to some extent. A follow-up study by the same author (Catelli et al., 2021) then describes the fact that the Cam pathology alone may not be the cause of the limited ROM in the hip joint, with the limited ROM being attributed more to a combination of muscle contractures and the clinical manifestations of FAI, especially pain and the attempt to avoid pain during movement. Asymptomatic participants with Cam pathology showed greater pelvic mobility toward anterior pelvic tilt (comparable to the control group), greater hip flexion ROM, and greater hip extensor strength, allowing them to perform a deeper squat than patients with clinically manifesting FAI. Yoshimoto et al. (2018) describe the squat performance of a 46-year-old patient with a Pincer pathology, both before and after surgery. Before surgery, the patient reported pain in the right hip joint, and at maximum squat, the hip flexion value was 70.8° with a PPT of 24°. After surgery, the pain disappeared and flexion was 63.3° with 23.3° of PPT. The pre- and post-operative values still do not show the values of the healthy population, which may be due to contracture in the soft tissues around the joint.

Pastucha et al. (2024) report that the only solution for the FAI with symptoms is surgery. This is in contrast to the findings of other authors (Brekke et al., 2021; Grant et al., 2024), where exercise intervention aimed at activating the core muscles, stretching and strengthening the muscles around the hip joint to reduce excessive anterior pelvic tilt showed an increase in squat depth, an increase in knee flexion ROM, and a decrease in anterior pelvic tilt at eight weeks in patients with symptomatic acetabular retroversion, which may cause FAI in the future. And when we look at the exercise intervention versus surgery, the exercise intervention showed similar results to surgical management of FAI, with an effect on pelvic and trunk motion in the sagittal plane, particularly a reduction in excessive anterior pelvic tilt.

Limited range of motion in the hip joint

ROM in the hip joint is influenced by the anatomical configuration, but also by the condition of the surrounding soft tissues – muscles, fascia, and ligaments (Nelson & Kokkonen, 2023). Most ROM can be increased by engaging the pelvis and lumbar spine, and movements such as abduction, adduction, and external and internal rotation can be increased with simultaneous hip flexion. ROM are generally given as: flexion with the knee extended up to 90°, flexion with the knee flexed up to 120–140°, extension 10–15°, abduction 40–60°, adduction 10–30°, internal rotation 20–50°, and external rotation 15–75°. Circumduction, i.e. combining all movements, is also possible (Čihák, 2011; Dylevský, 2021; Pirola, 2024; Rychlíková, 2019).

Kaminoff & Matthews (2024) suggest that if the ROM at the hip joint is restricted, the lumbar spine will move in the opposite direction to the rotation of the thoracic spine and shoulder girdle, and the movement will generally originate from the thoracolumbar junction. Conversely, if the pelvis is able to move freely over the hip joints, the rotation of the spine will be more evenly distributed and the movement will involve the lumbar spine.

The congenital anatomical angles of the femur – the femoral neck-shaft angle and the femoral torsion angle, also play a role. The femoral neck-shaft angle is the angle that the axis of the femoral head-neck makes with the long axis of the femoral shaft, and its average value in adulthood is approximately 125°. Changes in this angle affect the abduction and adduction ROM and can also cause the length of the lower limb to be relatively shorter or longer. The femoral torsion angle is the angle between the axis of the femoral neck and the line joining the femoral condyles in the horizontal plane. In adults, the average value is about 10°. Changes in this angle have a fundamental effect on the rotation ROM of the hip joint. Any deviation of both angles from the average values leads to suboptimal alignment of the articular surfaces in the hip joint, which reduces the ability to absorb shocks and may lead to more rapid degenerative changes (Čihák, 2011; Dylevský, 2021; Muscolino, 2023; Pirola, 2024). Kapandji (2019a) distinguishes two types of hip joints based on the values of these two angles: the rangy type, which has a greater ROM and reflects the body's adaptation to speed performance during running, and the squat type, which, on the contrary, has a more restricted ROM, lower speed of movement, but a significant increase in the ability to absorb the loads to which the joint is exposed, and is therefore a morphology predisposing to strength performance.

Limited hip flexion ROM may be one of the main limiting factors in achieving a technically correct deep squat (Breen et al., 2016; Contreras, 2014; Kim et al., 2015). PPT occurs when the maximum possible hip flexion ROM is exhausted and is associated with flexion of the lumbar spine, which increases compression and shear forces in this region (Straub & Powers, 2024; Todoroff, 2017).

Limited range of motion in the ankle joint

Normal ROM of the talocrural joint is approximately 40–90°, with dorsiflexion typically in the 20–30° range and plantar flexion in the 40–60° range. The function and movements of this joint are always closely related to the movements of the subtalar joint and the distal and proximal tibiofibular joints, as well as to the movements of the knee joint when the lower limbs are loaded during standing position (Barták et al., 2024; Vařeka & Vařeková, 2009).

Limited dorsiflexion at the ankle can be a limiting factor in proper squat performance (Breen et al., 2016; Carr & Feit, 2024; Comfort et al., 2018; Contreras, 2014; Ishida et al., 2022; Kim et al., 2015; Schoenfeld, 2010). Carr & Feit (2024) literally describe that if an athlete has limited ankle dorsiflexion, they will be forced to compensate during the descending phase of the squat through toe adduction, increased foot pronation, tibial internal rotation, and femoral adduction, which can actually cause a valgus position at the knee joint with subsequent overloading of the medial aspect of the knee joint. Breen et al. (2016) further add that when testing the deep squat within the FMS, individuals with limited dorsiflexion showed lower scores in the quality of squat performance (either inability to perform the squat as instructed or performance with some compensation) than participants with full ROM. This suggests that ankle ROM, as well as hip ROM, may be one of the factors leading to lower performance on the deep squat test. Therefore, treatment aimed at increasing ROM in the sagittal plane of the hip and ankle joints seems to be an appropriate therapy. According to Comfort et al. (2018), there is a relationship between limited dorsiflexion at the ankle and increased forward leaning of the trunk. Static stretching of the triceps surae muscle or the use of weightlifting shoes with an elevated heel may be a solution.

Schoenfeld (2010) states that limited ankle dorsiflexion can cause compensatory movements in the knee and hip joints or spine, potentially increasing the risk of injury at higher loads. It further states that the dorsiflexion ROM for full squat performance should be 38.5±5.9°. According to Kim et al. (2015), the dorsiflexion ROM, along with the hip flexion ROM, is one of the main parameters for achieving an appropriate squat depth in males, while in females it is the dorsiflexion ROM and the strength of the dorsal flexors; in other words, if we want to increase the depth of the squat, we should focus on increasing both ROM in males, while in females we should focus on increasing the ROM and strengthening the dorsal flexors. However, Endo et al. (2020) state that there is no correlation between the ankle dorsiflexion ROM, knee extensor strength, hip flexor strength, and maximal squat depth. The mean ankle dorsiflexion of the enrolled participants was 23.4–25.9°, and the right ankle dorsiflexion ROM was a significant predictor of the right hip flexion angle and vice versa.

Ishida et al. (2022) add that the antero-posterior localization of the Center of Pressure (COP) determines the magnitude of the extensor moment forces in the knee joint during squatting, and also that in the rehabilitation of knee joint disorders it is advisable to work with this localization so as not to unnecessarily increase the forward leaning of the trunk. It is also desirable to work on increasing the ankle dorsiflexion ROM, since an increase in this ROM corresponds to an increase in the extensor moment of the knee joint.

Starting position of the pelvis and lumbar spine

Pelvis

The pelvis is often referred to as a stable center of the body (Reichert, 2021), a load transducer that provides a firm and stable base for the spine (Tlapák, 2022a), a differential that transmits force moments to the lower limbs by means of a powerful muscular apparatus (Krucký, 2017), and a place where the center of gravity of the body is located (Marek et al., 2005), or as a place that ensures the correct posture of the whole body (Véle, 2012), or as a junction where almost all deviations of the trunk and lower limbs are projected (Janda, 1984), and we cannot forget the fact that it forms an anatomical and functional unit with the spine (Levitová & Hošková, 2015; Lewit, 2024). Based on this, it can be seen that the position of the pelvis is very important not only in terms of physiotherapy, but also for the correct execution of the squat.

For the correct position of the pelvis and lumbar spine, the cooperation of muscles is very important, namely pelvic floor muscles, diaphragm, abdominal muscles (especially rectus abdominis), lumbar extensors, but also the muscles in the hip joint area – hip flexors (especially iliopsoas), hip extensors (especially gluteus maximus). If there is a muscular imbalance in this area, e.g. lower crossed syndrome, which typically leads to the development of lumbar hyperlordosis, it can cause pain or even accelerate the development of degenerative changes (Kapandji, 2019b; Levitová & Hošková, 2015; Muscolino, 2023; Stackeová, 2011; Striano, 2022; Tichý, 2017). This imbalance can be further exacerbated by performing exercises that load the spine in the axial direction while causing excessive extension of the lumbar spine, a typical example being squats performed with poor technique (Tlapák, 2022a).

In general, authors agree that the physiological standing pelvic position is a slight anterior pelvic tilt that also ensures a physiological depth of lumbar lordosis, and that the palpable bony landmarks (ASIP, PSIP and iliac crests) are symmetrical on both sides in the frontal plane, and that the ASIP and PSIP should be aligned in the sagittal plane with a possible tolerance of deviation of up to 1 cm (Bimbi-Dresp, 2009; Chaitow, 2017; Gross et al., 2023; Jedličková, 2019; Jesenická, 2018; Lewit, 2024; Malanga & Mautner, 2017; Marek et al., 2005; Stackeová, 2018, 2023; Tichý, 2017; Tlapák, 2022a; Véle, 2006, 2012).

In clinical practice, however, the pelvic position is very often pathological or asymmetrical. Most commonly, there is excessive anterior pelvic tilt (see above) or PPT (ASIP and PSIP are at the same level or PSIP are even higher than ASIP), as well as pelvic rotation (when viewed from above, the pelvis is tilted clockwise or counterclockwise), lateral shift of the pelvis (the whole pelvis is shifted to one side or the other), oblique pelvis (all of the bony landmarks are lower on one side than on the other), and pelvic torsion (one pelvic bone is in anterior tilt and the other in posterior tilt). Most problematic is the fact that each author describes the pathology in a slightly different way, and in some cases even by name (e.g., pelvic torsion – fixed nutation of the pelvis). However, there is a consensus on the causes of these findings, with the authors agreeing that the cause is most often a functional musculoskeletal disorder (typically muscle imbalance, with certain muscles being stiff/tense and others weakened, functional joint blockages, inadequate neuromuscular control, poor function of the core muscles, etc.), but in some cases there may also be a structural disorder/deformity (e.g. anatomically uneven lower limb length, asymmetrically flat feet, scoliosis, congenital defects such as lumbarization of first sacral vertebra, sacralization of fifth lumbar vertebra, redundant lumbar vertebra, history of diseases such as developmental dysplasia of the hip, etc.) (Gross et al., 2023; Gúth, 2020; Janda, 1984; Jedličková, 2019; Kolář et al., 2020; Marek et al., 2005; Véle, 2006, 2012).

Suboptimal pelvic positioning may also be a result of poor motor development in the first year of life. For example, if a child adopts a fencer's position with an opisthotonic trunk posture at 6 weeks of age, the child will continue to develop normally in terms of gross motor skills, but may be diagnosed with, for example, lumbar hyperlordosis or other postural disorders in the preschool years – these children account for approximately 25% of the population (Vojta & Peters, 2010).

According to Reichert (2021), the deeper structures (multifidus muscle, transversus abdominis muscle and thoracolumbar fascia) play a more important role in stabilizing the lumbar spine. Pilný (2018) suggests the same, stating that the deep muscles need to be activated/strengthened when practicing proper breathing and sitting, as during lifting and exercise it is required of these deep muscles to activate first and then the superficial muscles should be activated. However, determining the ideal degree of lumbar lordosis is difficult because it creates a conflict between the two main functions of the spine – stability and mobility. A flattened curvature is disadvantageous, especially when we need to move; on the other hand, a greater curvature could theoretically increase flexibility, but on the other hand, it places increased demands on the intervertebral foramen (Rašev, 1992). Although hyperlordosis of the lumbar spine is often considered a sign of poor posture, it provides greater stability to the lumbar spine due to the tucking of the articular processes of the vertebrae into each other, and on the contrary, the flattening of the lumbar lordosis (leading to kyphosis) is more vulnerable to the spine, as the articular processes become more distant apart and the risk of disc herniation increases, especially in the case of the lumbar spine. The risk of disc herniation is higher with torsion and flexion-extension loading mechanisms (Jesenická, 2018).

Exercise intervention that target the lumbar spine, pelvis, and abdominal muscles to improve stability and flexibility can prevent the development of this imbalance (Sedláková, 2023; Striano, 2022). Specific exercises can also increase the lumbar lordosis angle by several degrees (from an average of 21.2° to 25.1°), which can be considered a positive phenomenon, as a reduced lumbar lordosis angle is often associated with the occurrence of low back pain (Kadono et al., 2017).

The position of the pelvis when squatting is important for both safety and maximum performance. It is advisable to maintain proper pelvic position to maintain neutral lumbar lordosis (to reduce the risk of injury). Excessive anterior pelvic tilt can cause low back pain and excessive PPT can reduce the maximum performance during the squat. Ensuring proper pelvic alignment not only increases the effectiveness of strength training, but also minimizes the risk of injury (Rippetoe, 2009). Other authors have a similar view (Braidot et al., 2007; Edington, 2017; Masi, 2020; Stackeová, 2014; Stoppani, 2016; Todoroff, 2017) and recommend maintaining a neutral or slight anterior pelvic tilt position to minimize excessive lumbar motion, therefore it is desirable to avoid excessive flexion and extension. Other authors (Jarkovská & Jarkovská, 2016; Tlapák, 2022a) then state that the pelvis should not be in excessive anterior pelvic tilt. Only the Carr & Feit (2024) state that the starting position of the squat should be in a slight PPT. In the deepest squat position, i.e. maximum flexion at the knee and hip joints, the pelvis is indeed in PPT, the lumbar lordosis is flattened (11.7° in squat vs. 32.9° in standing), and the sacrum is vertical (Moon et al., 2021).

Because there are anatomical differences between men and women, the execution of the squat may differ slightly between men and women. The sacrum is slightly longer in men than in women, but not as wide. Overall, the female pelvis is wider and more oval, and the lumbar vertebrae are shorter, allowing women more flexibility in movement. The flexion ROM in the lumbar spine is two times greater in men than in women, likely due to the limited motion of the sacrum in men, who compensate for this limited motion specifically in the lumbar spine (McKean et al., 2010; Paulsen & Waschke, 2018). Stackeová (2023) adds that women have a physiologically more anteriory tilted pelvis, which, along with other anatomical differences, makes them more susceptible to gluteus maximus weakness. Men, on the other hand, are more prone to weakening of the gluteus medius and minimus muscles.

The differences between men and women are also highlighted in a study by Weeks et al. (2015), where women show a greater ROM in pelvic rotation, internal rotation, and adduction at the hip joint when performing single-leg squats. After subjecting the participants in this study to performing lunges to maximal exhaustion, it was found that fatigue significantly affected the way in which single-leg squats were performed, with increased ROM in trunk flexion, rotation and lateroflexion, as well as anterior pelvic tilt, pelvic rotation and obliquity in both genders. This suggests that pelvic position (or stability) is essential for maintaining stability during squatting.

Other studies conducted have examined the differences between high bar and low bar squats (Edington, 2017), the differences between partial and full depth squats (Marchetti et al., 2017), and the effect of pelvic position on iliopsoas muscle thickness and activation (Miyachi et al., 2021). In summary, it can be concluded that the high bar squat causes a greater forward lean of the trunk, the low bar squat shows a greater flexion ROM in the lumbar spine, partial squats show a motion more into anterior pelvic tilt (mean 32.4±10.9°) and, on the other hand, full squats show a motion more into PPT (mean value 21.7±12.3°). The initial position of the pelvis in anterior tilt causes an increase in the thickness of the iliopsoas muscle and an increase in the hip flexion ROM at a squat depth of 60° of knee flexion and, conversely, PPT limits the hip joint ROM.

Although it is often assumed that increased anterior pelvic tilt is a sign of muscule imbalance (or poor posture), the results of Greyling (2013) show that individuals with anterior pelvic tilt have slightly better activation of the core muscles than those with a neutral pelvic posture, and that the initial pelvic posture does not play a role in terms of muscle activation during squatting. Similarly, PPT may not always be harmful; for example, in patients with stenosis of the intervertebral foramina, it is advisable to include exercises that promote PPT, as PPT itself causes the foramina to enlarge and thus relieves the symptoms of the stenosis, typically pain from a pinched nerve root (Mansfield & Neumann, 2024).

Excessive anterior pelvic tilt associated with increased lumbar lordosis in the squat starting position may be one of the causes of PPT during squatting (Boyce, 2018; Henoch, 2014; Masi, 2020). Typically, the hip flexors are more involved and the maximum ROM is reached more quickly, preventing the athlete from reaching an adequate squat depth. At the same time, there may be compensatory flexion of the lumbar spine associated with PPT (Masi, 2020). Excessive anterior pelvic tilt can also be caused by the athlete trying to avoid any PPT at all costs, or trying to maintain a perfectly neutral or lordotic curve of the lumbar spine during the squat. This subsequently alters the squat technique, resulting in excessive anterior pelvic tilt at the start of the squat and/or an earlier end to the descending phase of the squat, which may prevent adequate strength development and hypertrophy (Boyce, 2018; English, 2023).

Lumbar spine

Physiologically, the lumbar spine is in lordosis (Muscolino, 2023) and is composed of five lumbar vertebrae, which have a massive kidney-shaped body, a quadrilateral spinous process, and their vertebral foramen is triangular in shape (Stuchlá, 2024). The lumbar spine is subjected to heavy loads, the intervertebral discs in this region are the highest (height about 9 mm), but nevertheless movement between the relatively rigid pelvis and the semi-rigid thorax is allowed here in all three planes (Eliška, 2023; Gross et al., 2023; Levitová & Hošková, 2015; Sedláková, 2023; Tichý, 2017).

The orientation of the articular processes on the lumbar vertebrae is practically in the sagittal plane, which allows a relatively large flexion and extension ROM. During the flexion of the lumbar spine, the body of the upper vertebra tilts and slides anteriorly, decreasing the height of the intervertebral disc anteriorly and increasing it posteriorly; the nucleus pulposus is pushed posteriorly, stretching the dorsal fibers of the annulus fibrosus. During extension, the exact opposite mechanism occurs (Kapandji, 2019b). Based on x-ray examinations, the average lumbar lordosis can be determined and is approximately as follows: in the L1–L5 segments 42.6±10.2°, in the L1–S1 segments 55.8±10.2°, in the L5–S1 segments 14.0±5.9°, and the average anterior pelvic tilt is 11.6±7.0° (Le Huec & Hasegawa, 2016). The ROM for the entire lumbar spine are approximately as follows: flexion 50–60°, with 70% of the motion occurring at L5–S1, 20% at L4–L5, and 10% at L1–L4 (during flexion, the articular processes move apart, causing the lumbar lordosis to flatten from proximal to distal segments as flexion increases), extension 15–30° (during extension the articular processes move closer together and the lordosis increases), lateroflexion to one side 20–30° (lateroflexion is always accompanied by rotation) and rotation to one side 5–10° (Dylevský, 2021; Eliška, 2023; Hey et al., 2017; Kapandji, 2019b; Muscolino, 2023; Pirola, 2024; Reichert, 2021). At the lumbosacral junction, the orientation of the articular processes changes from the sagittal to the frontal plane. At the transition between the 5th lumbar vertebra and the ventral part of sacrum, the sacral promontory is prominent, the last intervertebral disc is located here, and at the same time the greatest mobility of the lumbar spine is found here (Eliška, 2023; Hey et al., 2017; Levitová & Hošková, 2015; Stuchlá, 2024). The lumbosacral junction is the most vulnerable point, especially during extension, which creates enormous anterior pressure on the vertically positioned articular facets. This may explain the frequent occurrence of degenerative changes in facet joints in this region (Dylevský, 2021; Eliška, 2023; Gross et al., 2023).

The lumbar spine should be in a neutral position throughout the squat, i.e. in a slight lordotic curve, with the abdominal wall braced and held straight to provide sufficient stability. Maintaining a neutral position of the lumbar spine increases the activation of the lumbar extensors and oblique abdominal muscles, which provides adequate support for the spine during loading and reduces the risk of injury. When this is not done, the lumbar spine loses its ability to tolerate higher loads, which can slow the progression of adding weight with a consequent increase in the risk of injury. Causes of failure to maintain a neutral lumbar spine position may include: weakening of the thoracic and lumbar extensors, limited hip joint ROM (if lumbar flexion occurs before 120° of hip flexion, the cause may be a restriction in the posterior fibers of the iliotibial band and/or impaired motor control in the lumbar spine), head or cervical spine flexion (causing compensatory extension of the lumbar spine, increasing the magnitude of compression forces in the lumbar spine), a dorsal myofascial chain disorder (e.g. inability to perform scapular depression and retraction, resulting in an overall weakening of the dorsal chain) (Myer et al., 2014). Similar recommendations have been made by other authors (Braidot et al., 2007; Edington, 2017; Masi, 2020; Stackeová, 2014; Stoppani, 2016; Todoroff, 2017), i.e., to maintain the neutral position of the lumbar spine and pelvis in the sagittal plane, since any small deviations from the neutral position and possible movements in the frontal or transverse plane may increase the risk of injury.

The initial (habitual) posture of the lumbar spine, or its curvature, often determines the subsequent movement and how it is performed. This has been demonstrated in people who were asked to lift a cargo off the ground without instruction. Participants with flat back bend more at the knee joints for the cargo (squatting technique), while participants with pronounced spinal curvature show more flexion in the lumbar spine (stoop technique) (Pavlova et al., 2014). These same participants then show a greater depth of lumbar lordosis (or still maintain some level of lordosis) at the moment of liftting a cargo off the ground compared to participants with flat back, and also show greater intersegmental movements of the lumbar spine associated with greater flexion of the sacrum. Participants with flat back then tend to have greater lumbar rigidity (less intersegmental motion). Greater mobility has been found in the upper segments of lumbar spine (L1–L3), and movement in this region precedes movement at lower segments of lumbar spine (L3–L5) (Pavlova et al., 2016). These findings are in fact consistent with Čápová (2016) argument that initial posture (so called „atitude“) determines the goal and execution of subsequent movement.

The use of load in the squat leads to a change in the curvature of the lumbar spine, and opinions on this issue are not entirely consistent. Some authors (Hamlyn et al., 2007; Hartmann et al., 2013; Walsh et al., 2007) report that with increasing load, starting from 40% of 1RM, there is a deeper lumbar lordosis and thus more load on the dorsal part of the annulus fibrosus of the intervertebral disc, and also that with increasing load the lumbar spine flexion ROM decreases and the extension ROM of the lumbar spine increases. A similar finding was reported by Biscarini et al. (2022), although they did not study squats but wall-supported squats with 45° flexion at the knee joints, where greater activation of the lumbar extensors was found when the support was moved to the scapular region (similar to holding a barbell on the back), while at the same time the position of the lumbar lordosis and pelvis was changed in terms of increased lordosis and anterior pelvic tilt.

This is in contrast to the findings of McKean et al. (2010), who found that the lumbar spine is already flattened or slightly kyphotic before the start of the descending phase of the squat when performing a squat with a load of more than 50% of the body weight. Thus, lumbar spine kyphosis is likely to be a natural part of the deep squat and should not be strictly prohibited. This same conclusion was reached by List et al. (2013), who found that lumbar lordosis was reduced as early as 25% of 1RM, with flattening (or even becoming kyphotic) of the lumbar lordosis occurring at higher loads.

Pelvifemoral rhythm

The pelvifemoral rhythm is a natural phenomenon, similar to the humeroscapular rhythm in the shoulder girdle, which describes that during hip flexion there is not only movement in the hip joint itself (movement of the femur relative to the acetabulum), but also in the pelvis in the sense of PPT. In other words, hip flexion is accompanied by PPT and lumbar flexion (Pirola, 2024). This phenomenon was first reported in 1982 while performing the Straight leg raise test (Bohannon, 1982). Since then, several studies have been conducted to further investigate this phenomenon when performing hip flexion in various ways: passive, active, unilateral, bilateral, flexion performed supine, in a hanging position, standing on one lower extremity (Bohannon et al., 1985; Dewberry et al., 2003; Murray et al., 2002). Bohannon et al. (1985) state that PPT is evident before the hip flexion range reaches 8°. This finding contradicts the general view that this movement occurs after the maximum hip flexion ROM has been reached. The ratio of PPT is approximately such that during the movement into hip flexion, 2.3–2.8° of the movement is due to the femur's own movement relative to the acetabulum and 1° is due to the PPT, i.e., of the total ROM of 3.3–3.8° of hip flexion, 2.3–2.8° is due to the femur's own movement and 1° is due to the PPT. Similar conclusions have been reached by authors of other studies (Dewberry et al., 2003; Murray et al., 2002).

A systematic review was conducted in 2017, which included a total of 9 studies on this topic. PPT was found to account for between 13.1% and 37.5% of the total hip flexion ROM, with higher values recorded when the knee joint was in extension and when the participants' hamstrings were more shortened and PPT began almost immediately after the start of hip flexion (Bohannon & Bass, 2017).

Lumbopelvic rhythm

Lumbopelvic rhythm refers to the pattern of movement during flexion and extension of the lumbar spine and the accompanying movement of the pelvis in the sagittal plane (anterior/posterior pelvic tilt). It is a coordinated movement between the lumbar spine and the pelvis that contributes to the movement of the trunk as a whole (Vazirian et al., 2016b). Pirola (2024) states that flexion of the lumbar spine is accompanied by movement of the pelvis around the bicondylar axis, which increases the ROM; if this movement did not occur, the ROM would be approximately half. Sometimes this rhythm is further divided into sequential, where the movement of the lumbar spine and pelvis occurs based on sequential muscle activation, and simultaneous, where the lumbar spine and pelvis move simultaneously and the muscles in the lumbar spine, pelvis, and hip joint are activated together (Kongkamol et al., 2020).

Some of the studies conducted (Vazirian et al., 2016a, 2016b) show that the assessment of lumbopelvic rhythm is highly heterogeneous, e.g. sometimes pelvic motion is related to thigh motion, sometimes to a global coordinate system, markers for motion analysis are often placed differently, etc. We also know that women, the elderly, and patients with back pain have a different lumbopelvic rhythm in terms of a smaller lumbar spine ROM. Conversely, this motion increases with the addition of external load and with increasing fatigue. One test to assess lumbopelvic rhythm may be the ability to perform an isolated standing PPT or a squat with 50–70° of hip flexion while maintaining anterior pelvic tilt. Patients with back pain will be unable to perform these tests and will have compensatory movements in the lower limbs or thoracic region (Luomajoki et al., 2008).

With respect to lumbar flexion, we also know that patients with low back pain have a different squatting pattern than subjects without pain. Patients with low back pain have a lower lumbar flexion ROM but a greater hip flexion ROM, which is likely a compensatory mechanism to avoid a painful or stiff lumbar spine region (Sung, 2013). It has also been found that individuals with chronic non-specific low back pain of mild severity show significant differences in neuromuscular adaptations in the lumbopelvic region in response to static deep squatting position compared to asymptomatic individuals. For example, recruitment of the hip extensors and lumbar extensors is altered in subjects with pain. Targeted training of these muscles may be a solution (Lui et al., 2018). Patients with back pain also show a different movement stereotype when lifting a cargo off the ground than participants without pain. Patients with pain show a slower motion more into squatting technique (knee-dominant motion), but with increasing fatigue both groups show more of a stoop technique (knee extension, trunk tilted significantly forward) (Saraceni et al., 2021).

2.2.2 CONSEQUENCES OF POSTERIOR PELVIC TILT DURING SQUAT

The main negative consequence is the potential risk of injury to the lumbar spine, specifically the risk of disc herniation. In general, disc loading is a frequently discussed phenomenon, either when performing the squat itself, or squat with PPT, but also when lifting a cargo off the ground using the squat technique. The risk of injury (herniation) of the intervertebral discs is reported to increase, especially during flexion of the entire trunk or the combination of flexion and rotation, when the disc is deformed and the pressure in the lower part of the disc increases, which can lead to herniation. Muscle and ligament strains also occur in these flexion positions (Jesenická, 2018; McGill, 2021; Rašev, 1992; Sedláková, 2023). However, according to the recommendations of Contreras & Schoenfeld (2011), it is not necessary to strictly prohibit any flexion movements/exercise of the spine; in contrast, if performed in a controlled manner and with an adequate loading, they can be beneficial, provided that the athlete does not already have a certain level of degenerative changes (e.g. disc herniation). However, the process of developing these degenerative changes is very complex, and in addition to the standard mechanical factors, genetic, age, and nutritional factors also play a role. On the other hand, Adams et al. (2000) reported that in cadaveric lumbar vertebrae, during extension of the lumbar spine, there is a higher pressure in the dorsal part of anulus fibrosus and, conversely, this load decreases during flexion, resulting in a more even distribution of pressure across the disc.

The problem is the determination of the maximum load or overloading, because the work done on this topic is not completely consistent – the load values are often in different units (in Newton or Pascal), and some measured values even exceed the maximum textbook values of load, after which damage to the disc or vertebrae should occur. However, we know that regular strength training leads to gradual tissue adaptation and that experienced strength athletes (1–2 years of regular training) have a greater amount of mineralized bone tissue than a comparable population without strength training. Also, there was no higher incidence of degenerative changes or spinal injuries in these strength athletes compared to the non-exercising population. Half and quarter squats are expected to place less stress on the lumbar spine and knee joint than a full deep squat, assuming the technique of the squat performed is correct (Hartmann et al., 2013).

With regard to lifting a cargo off the ground using the squat technique, it is advisable to purposefully increase anterior pelvic tilt in the starting position, or consciously maintain anterior pelvic tilt in the range of 10–20° during the lift, as there is a reduction in the amount of compression and shear forces in the lumbar spine compared to without increased anterior pelvic tilt, which may subsequently reduce the incidence of back pain (Hayashi et al., 2016; Kongkamol et al., 2020). If we want to reduce the range of lumbar spine flexion when lifting a load with the stoop technique, and thus potentially reduce the risk of spinal injury/pain, then actively inducing head and cervical spine retraction may be the solution, resulting in increased activation of the lumbar spine extensors, obliquus externus abdominis, and sternocleidomastoid muscle (Hlavenka et al., 2017).

It is also interesting to note that disc loading between the lumbar segments L4–L5 and L5–S1 was greater in parallel squats than in half squats, despite the fact that parallel squats had a smaller anterior pelvic tilt angle and lumbar lordosis angle. The explanation for this phenomenon is likely to be the specific lumbosacral movements that accompany the squat and occur with increasing squat depth (Yanagisawa et al., 2021). When performing the static half-squat position, the L4–L5 and L5–S1 segments still remain in lordosis at all times, and the angle of this lordosis does not differ significantly from regular standing posture (Hey et al., 2017). The position of the barbell also plays a role in the load on the lumbar spine, as the front squat has lower compressive forces on the lumbar spine, while the back squat has higher compressive forces (Braidot et al., 2007).

2.2.3 SOLUTION FOR POSTERIOR PELVIC TILT DURING SQUAT

Maintaining a neutral spine and correct pelvic position throughout the squat is a priority. By practicing the squat in this way, we build muscle memory and strength in the correct movement pattern. A comprehensive approach may then be to combine regular strength training with progressive loading and mobility training (Lau, 2022; Phili, 2023). Progressive loading is relatively straightforward, starting with lighter weights and higher repetitions and gradually increasing the load as strength increases. As a result, it is possible to gradually build strength in the muscles that are activated during the squat, such as the gluteal muscles, hamstrings, quadriceps femoris, and lumbar spine extensors (Petr & Št'astný, 2012; Phili, 2023).

For this very reason, a significant number of athletes need to reduce the weight with which they squat in the first place and concentrate on practicing the correct squat technique. In other words, it is advisable to give priority first to achieving technically correct squat depth before increasing the load, leading to long-term progression with minimized risk of injury (Henoch, 2014; Lau, 2022; Rippetoe, 2018). These recommendations are thus in agreement with other authors (Petr & Šťastný, 2012; Tlapák, 2022a).

It is also a good idea to include mobility training during the warm-up or after strength training that targets the hip and ankle joints. To increase the range of motion of these joints, certain squat variations can be used, such as the goblet squat and the overhead squat. This training allows for proper squat technique and the ability to gradually and safely increase the depth of the squat. Another option may be traditional stretching, whether it is stretching the hip flexors in the lunge, stretching the hip flexors in the 90/90 position, or other variations of static and dynamic stretching (Boyce, 2018; Lau, 2022). Isolated pelvic movements, such as anterior and PPT, quadruped rocking, and so on, are also appropriate for improving body awareness in space and pelvic and lumbar postural control (Lau, 2022). As a result, the athlete can become aware of the neutral position of the spine and avoid excessive posterior and anterior pelvic tilt when performing squats.

If we target the trunk and pelvic area specifically, then according to the Kushner et al. (2015) the excessive forward lean of the trunk and kyphotic lumbar spine can be corrected. It is advisable to start with verbal correction and, if that does not help, to move on to exercises where we teach the athlete to maintain a neutral lumbar spine position (lordosis), first in a standing position and then dynamically (exercises can be aimed at increasing strength, improving neuromuscular control and/or improving mobility). Proper execution of the squat (with moderate lumbar lordosis) requires optimal spinal mobility; when mobility is not present, compensatory, excessive forward leaning of the trunk increases the load on the intervertebral discs.

Unnecessary concerns and efforts to eliminate PPT at all costs are never the solution as they lead to limited squat depth or a change in lower limb alignment. However, these concerns can also act as a source of motivation, as they force the athlete to focus on mobility training or training other weaknesses (Boyce, 2018; Henoch, 2014).

Finally, it is important to note that due to individual anatomical differences (e.g. acetabulum position, femur length, tibia length and rotation) it is not possible for every athlete to achieve maximum squat depth while maintaining proper technique (Henoch, 2014; Lau, 2022). Hence, it is necessary to find a squatting setup that does not force the athlete into unnatural positions that could lead to compensatory movements or subjectively unpleasant sensations such as excessive flexion of the lumbar spine or a pinching sensation in the hip joint. Ultimately, specific anatomical differences mean that there is no universal squat depth. Instead, athletes should focus on maintaining proper form and adjusting their stance to match their unique physique, while ensuring they meet their training goals (Boyce, 2018; Phili, 2023).

2.3 SUMMARY OF THE THEORETICAL BACKGROUND

As can be seen from the previous text, the correct execution of the squat and its depth is determined by a number of variables, which are often anatomical. Also, opinions on the potential risk of injury are not uniform, but in summary, if the squat is performed technically correctly, given the capabilities of the athlete and with progressive loading, it is a safe and very effective exercise for developing strength and hypertrophy, especially in the lower limbs. Since it is absolutely essential to master technically correct execution of the bodyweight squat (with no external load), the main part of this thesis will deal with the bodyweight squat and the occurrence of the phenomenon of PPT during this type of squat.

3 GOAL, QUESTIONS, HYPOTHESES OF THE THESIS

3.1 GOAL OF THE THESIS

The main goal of the thesis is to objectively assess the effect the immediate effect of the exercise intervention on the total pelvis ROM in the sagittal plane (mainly posterior pelvic tilt) during squat. The secondary aim of the thesis is to determine the relationship between the initial pelvic position and the occurrence of PPT.

3.2 SCIENTIFIC QUESTIONS

- Does exercise intervention alone affect the PPT ROM in the sagittal plane?
- Is there a relationship between initial pelvic position and PPT ROM?

3.3 HYPOTHESES OF THE THESIS

Main hypothesis

The exercise intervention will have a statistically significant effect on reducing the PPT ROM during the descending phase of the squat.

Secondary hypothesis

Participants with increased anterior pelvic tilt in the standing position will exhibit a statistically significant greater PPT ROM.

4 METHODOLOGY

4.1 STUDY DESIGN

The main part of the thesis is a controlled experiment with the participants divided into experimental and control groups. As the immediate effect of the exercise intervention was investigated, the participants were only monitored during the data collection period. The data collection included the initial physiotherapy examination, 3D kinematic motion analysis of the squat, exercise intervention and 3D kinematic motion analysis of the squat. The total time required was approximately 1.5–2 hours per participant. Data collection took place at the Faculty of Health Studies at the Jan Evangelista Purkyně University in Ústí nad Labem (FZS UJEP) from January 2023 to May 2023.

The thesis was approved by the Ethics Committee of the Faculty of Physical Education and Sport at Charles University in Prague (FTVS UK) (Appendix A) and FZS UJEP (Appendix B) and all participants signed an informed consent (Appendix C).

4.2 RESEARCH SAMPLE

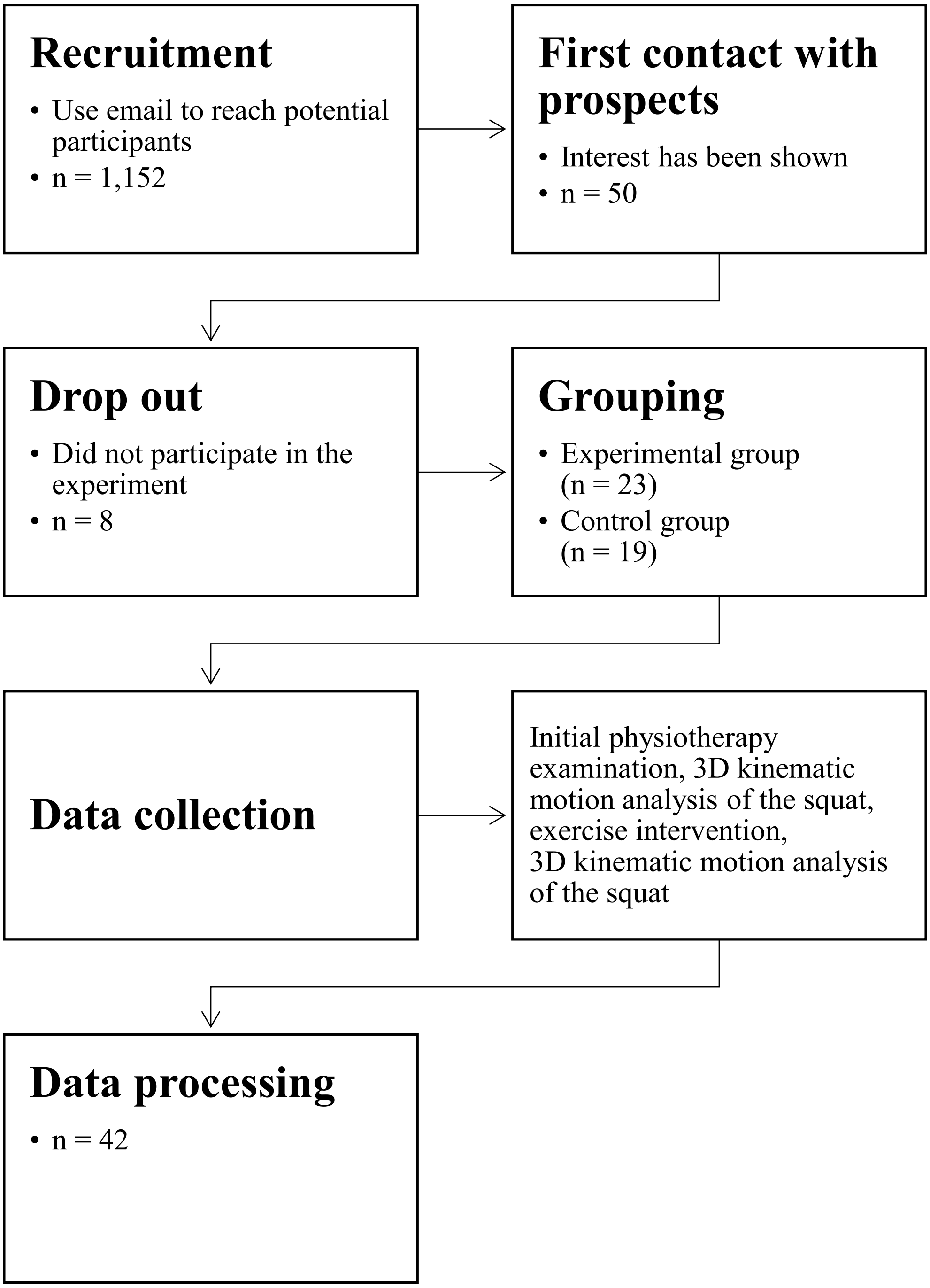
Volunteers from the students of FZS UJEP were included in the experiment. The students were approached via a group email sent from the study system (Figure 1).

A total of 42 participants (n = 42), 21 male (n = 21) and 21 female (n = 21), were included in the experiment. Inclusion criteria for the experiment were as follows: regular squat training at least once a week and good health (i.e., not contraindicated by a physician to perform squats). Exclusion criteria were as follows: back pain in the last three months, acute illness, infectious disease, injury or recovery from injury.

The division into experimental (n = 23) and control (n = 19) groups was determined by the incidence of PPT at the initial physiotherapy examination. If the participants showed PPT during bodyweight squats before or exactly in parallel squat depth, they were assigned to the experimental group; if PPT appeared later, they were assigned to the control group.

Figure 1

Recruitment of participants and experiment execution



4.3 CHARACTERISTICS OF THE EXERCISE INTERVENTION

The exercise intervention was identical for both groups and was adapted from Kushner et al. (2015). A total of six exercises were performed (Table 1), three sets of 6 repetitions of each, with 20 seconds of duration in the plank and with a pause of 45 seconds between sets. The intervention time was approximately 15–20 minutes.

Table 1

Exercise intervention

Exercise	Description	Goal
Cat/Cow	Assume quadruped position on knees and hands. Practice alternating from rounded back posture to arched back posture.	Identify difference between lordotic and kyphotic positions.
Ball Wall Squat	Pin a ball (similar to small Swiss ball) between the lower back and wall. Squat down while keeping ball pinned against the wall. The ball will roll up to the shoulder blades. Ascend and repeat.	Exercise facilitates a more vertical trunk position because horizontal force from wall serves as assistance. Ball rolling encourages the correct spinal curve.
Pole Squat and Fix	Perform squat near a sturdy pole or column. At apex of squat, use column as assistance to pull torso into correct position and hold. Heels must remain on the ground.	Assistance to help athlete self-generate and learn correct deep hold position.
Plank	Hold plank position with emphasis on maintaining lordosis throughout exercise.	Improve isometric strength of the back musculature and promote correct lumbar spine position.
Superman	Lay flat on stomach with your arms straight out in front and legs straight out behind. Keep arms and legs shoulder-width apart for the duration of the exercise. Lift your legs and arms simultaneously at least 6 inches off the ground. Keep each movement slow and controlled to prevent pulling muscles.	Strengthen the lower back musculature.
Overhead Squat	Perform squat with dowel in overhand grip overhead with elbows extended.	Strengthen back musculature and promote erect trunk during squat.

Source: Kushner et al. (2015)

Short information about the exercises included

Cat/cow – is a very popular exercise in Czech physiotherapy, which is part of the exercise unit of Ludmila Mojžíšová's method (Strusková & Novotná, 2020), but it is also used in manual medicine as a self-mobilization of the thoracic spine intervertebral joints into flexion and extension (Lewit, 2024; Rychlíková, 2016). Vančura (2024) reports that it is not necessary to work the whole spine, but it is sufficient to work only the lumbar spine, where the goal is to round up the lumbar spine as much as possible, vertebra by vertebra, and then arch back in the opposite direction.

Ball Wall Squat – in static form, it is an excellent exercise for strengthening the quadriceps femoris muscle, but it is also suitable for training correct squatting technique, where it is possible to focus on correct ankle positioning (Biscarini et al., 2022; Graham, 2009; Vančura, 2024). In dynamic execution, it then promotes correct/vertical trunk posture when performing squats and can also improve proprioception and muscle strength in the knee joint area (Ameer et al., 2024; Kushner et al., 2015).

Pole Squat and Fix – regular squat is performed near a sturdy pole or column. In the bottom phase of the squat the column is used as assistance to pull torso into correct position and hold. Heels must remain on the ground (Kushner et al., 2015).

Plank – is often used to strengthen the core muscles, especially the transversus abdominis, but it also works the muscles of the upper limbs, the shoulder girdle and the chest and is good for stability training (Murchison, 2024; Schlegel, 2024). Although the benefits of this exercise for athletes are often controversial, it is known to be used as an exercise to prevent back pain and injury, to prevent falls in the elderly and, from a physiotherapy perspective, as an exercise to strengthen the abdominal wall (Byrne et al., 2014; Snarr & Esco, 2014).

Superman – is an exercise designed to strengthen the lumbar extensors, gluteal muscles, and hamstrings (Murchison, 2024). With regard to the lumbar spine, it is known that a variation of this exercise with simultaneous upper and lower limb raises shows the greatest activity of the multifidus muscle, which is part of the core muscle group (Hwang & Park, 2018).

Overhead Squat – is an excellent exercise for training the entire dorsal chain, as well as for stability training, with the possible effect of increasing the stimulus for the trunk muscles (since the load is held overhead), and is often used as a supplementary exercise in Olympic weightlifting. Because it is a relatively challenging exercise, it can also be used as a diagnostic tool in FMS (Aspe & Swinton, 2014; Peterson, 2018; Ribeiro Neto et al., 2023).

Although the effects of a exercise intervention targeting the trunk region are commonly reported over a longer time period, typically between 4–8 weeks (Ebrahimi et al., 2015; Elborady et al., 2023; Gandolfi et al., 2019; Shin et al., 2022; Zarei & Norasteh, 2021), it is known that even a short intervention of 10–15 minutes can result in statistically significant changes regardless of the level of training of the participants (Kadono et al., 2017; Lee & McGill, 2016).

4.4 DATA COLLECTION

The initial physiotherapy examination

Palpation examination of the pelvis

For the purpose of pelvic examination, the following palpable landmarks are important: ASIP, PSIP and iliac crest (Rychlíková, 2021; Stuchlá 2024). Despite the fact that palpatory examination has low specificity and repeatability, this method of examination is still a complete necessity and is necessary to evaluate and find the etiology of the patient's symptoms (Malanga & Mautner, 2017).

Palpation of the landmarks was performed according to standard recommendations, i.e., the participant stands in the underwear, the examiner kneels so that his hands and eyes are at the level of the palpated landmarks. The position of the ASIP is examined from the front with the thumbs placed anteriorly on the iliac crest, and then running the thumbs downwards, anteriorly and diagonally towards the pubic symphysis. Here we find a prominent ASIP, and to refine the palpation, we pass slightly above this prominence and then slide into the fossa below, where we place the thumbs firmly. The position of the PSIP is examined from the rear with the thumbs placed caudally and slightly lateral to the expected position of the PSIP, and by moving the thumbs in a cranio-medial direction, the thumbs are moved under the downwardly curled ends of the PSIP, and are placed firmly there. The position of the iliac crest is examined from the rear with the hands extended and placed on top of the pelvic bone, so that the index fingers are at the level of the waist (always palpate from the top, below the last ribs). Lastly, the height of the ASIP is compared to the PSIP from the side (Chaitow, 2017; Gross et al., 2023; Lewit, 2024; Rychlíková, 2021). This is then used to determine the position of the pelvis (see Chapter 2.2.1).

Range of motion measurement in joints

Hip and ankle joint – measurements were performed with a metal goniometer according to the recommendations of Haladová & Nechvátalová (2010). Seven movements were measured in the hip joint: flexion with the knee extended, flexion with the knee flexed, extension, abduction, adduction, external and internal rotation, and in the ankle dorsal and plantar flexion. Although the validity and reliability of this method of testing joint ROM is controversial, it can be said that if the assessment is performed by an experienced and the same therapist, under the same conditions and with the same instrument, it is a relatively reliable tool for measuring ROM (Berryman Reese & Bandy, 2024; Boone et al., 1978; Gandbhir & Cunha, 2020).

Knee to wall test – is a reliable tool for assessing dorsiflexion ROM in the ankle. Performed against a wall, the athlete is instructed to attempt to touch the wall with the knee while keeping the heel on the ground, and the distance between the toe and the wall is measured with tape measure (Powden et al., 2015). According to Horschig (2015), the result of this test must be at least 5 inches (12.7 cm) for the athlete to reach full squat depth.

Other supporting examinations

Examination of the pelvic ligaments – the sacroiliac, iliolumbar, and sacrotuberous ligaments are examined. During the examination, the ligaments are stretched over the lever of the lower limb, and in the case of the sacrotuberous ligament, direct palpation is performed. The purpose of the examination is to rule out pain in the ligaments, which is often associated with other disorders of the lumbar spine, pelvis, sacroiliac joint and hip joints (Kališko & Ježková, 2019; Rychlíková, 2016).

The Sacroiliac Joint Special Test Cluster (Cluster of Laslett) – the purpose of this testing is to rule out structural pathology in the pelvis/sacroiliac joint. The battery includes five specific tests, and if three or more are positive, this indicates dysfunction in the pelvis/sacroiliac joint. Sensitivity of this cluster is 88% and specificity is 78% (Laslett, 2008; van der Wurff et al., 2006).

Assessing Muscle Length – the following muscles were assessed according to Janda et al. (2004): hip flexors, hamstrings, hip adductors, piriformis muscle, and triceps surae muscle. Scoring is on a three-point scale of 0–2, 0 = no shortening, 1 = mild shortening, 2 = severe shortening.

Muscle Strength Testing – flexion and extension movements of the hip joint have been tested in accordance with Janda et al. (2004) and Trendelenburg sign, and its difficult variant (standing with feet together, holding participant's shoulders) was used to identify the weakness of the hip abductors. Scoring of Janda test is on a six-point scale of 0–5, 0 = no movement or flicker, 1 = flicker of movement, 2 = full ROM actively with gravity counterbalanced, 3 = full ROM actively against gravity, 4 = full ROM actively against some resistance, 5 = full ROM actively against strong resistance. The purpose of this testing was to rule out neurological deficits in the enrolled participants (Hardcastle & Nade, 1985; Naqvi & Sherman, 2023). Both muscle length and muscle strength must be performer by skilled clinician in order to improve the reliability of the testing (Berryman Reese & Bandy, 2024).

Diagnostic Tests of the Deep Stabilization System (core) – are part of the Dynamic Neuromuscular Stabilization concept and their goal is to detect dysfunction or imbalance in the human body's stabilization system, or to find pathology in the area of so-called trunk stabilization (Kolář et al., 2020; Schlegel, 2024). The following tests were used: the diaphragm test, the hip flexion test, the hip extension test, and the squat test to detect inadequate trunk stabilization function. In the squat test, the following parameters were also monitored: squat depth, occurrence of PPT (used to divide the participants into experimental and control groups), occurrence of varus/valgus knee position, and heel off the ground.

3D kinematic motion analysis using Qualisys system and Functional Assessment module

Objective assessment of complex movements such as the squat is essential, as unbiased results cannot be achieved by mere visual or verbal assessment (Falk, 2021; Nielsen, 2015; O'Reilly, 2017). For example, according to Falk (2021), PPT during squatting must be at least 34° to be visually detectable, and it is not possible to determine how much PPT is already above or below the physiological norm based on visual inspection alone. Maclachlan et al. (2015) add that when squats are performed slowly and in a controlled manner and only dichotomous verbal scores are used, a sensitivity of 88% and a specificity of 85% can be achieved. It is also important to define the body segments correctly, as if they are defined in different ways, this can lead to an overestimation of the data obtained by up to 30–50%, as has been found for hip extensor force moments with two differently defined hip joints (Blache et al., 2013). The Qualisys system has also been used in other squat research (Choe et al., 2021; Nielsen, 2015; Sinclair et al., 2017; Southwell et al., 2016).

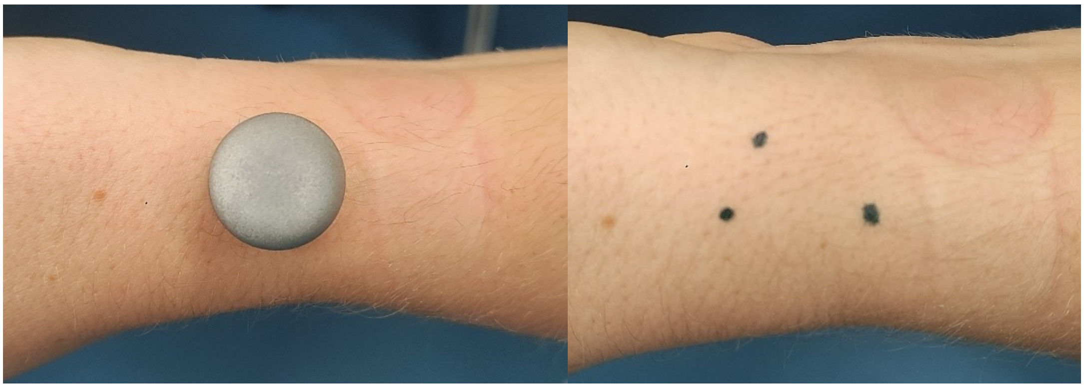
A total of 38 markers were applied to the participant's body and an additional 3 markers were placed on the hat (Figure 2) The markers were applied according to the recommendations of the Functional Assessment Module (Appendix D) and the palpation and marking of the bony landmarks was performed according to Sint Jan (2007). To ensure that the markers could be applied in the same location, the position of each marker was labeled with three dots using a pen prior to removal (Figure 3).

Figure 2

Location of markers front and back

Figure 3

Markers labeling



11 Oqus cameras were used for data capture (specifically: 5x Oqus 300, 4x Oqus 300+, 2x Oqus 310+) with 100 Hz capture rate. Data collection was performed exactly as recommended in the Functional Assessment module. First was the static and functional session, which consisted of two assessments: standing and standing with repeated mild knee flexion. This was followed by a squat session in which each participant performed two sets of bodyweight squats of seven repetitions each. The first set was used for familiarization with the data capture and was not included in the data analysis. The second set was already included in the data analysis, but the first repetition of the squat was not included. Thus, a total of six preintervention and six postintervention squat repetitions were processed. There was a 45 second rest period between each trial.

The instructions for the participants to perform the squat were as follows: stand at pelvic width, squat smoothly to the maximum depth the participant can comfortably manage, do not bounce or pause at the bottom, and then return to the starting position. The arms were held at shoulder level at all times.

4.5 DATA ANALYSIS

4.5.1 DATA PROCESSING FROM 3D KINEMATIC MOTION ANALYSIS

The first stage was to tag all the markers in the software Qualisys Tracking Manager (version 2023.3). This was followed by starting the automatic processing in the Visual3D Professional software (version 2024.09.1). A pipeline (Figure 4) was then manually created to mark the following points on the pelvic curve (Figure 5) in the sagittal plane:

- Blue point – initial position of the pelvis before squat
- Red point – maximum anterior pelvic tilt during the descending phase of the squat
- Khaki point – pelvic position at maximum squat depth
- Green point – pelvic position at 90° right hip flexion
- Pink point – pelvic position at 90° of left hip flexion

Figure 4

Pipeline model

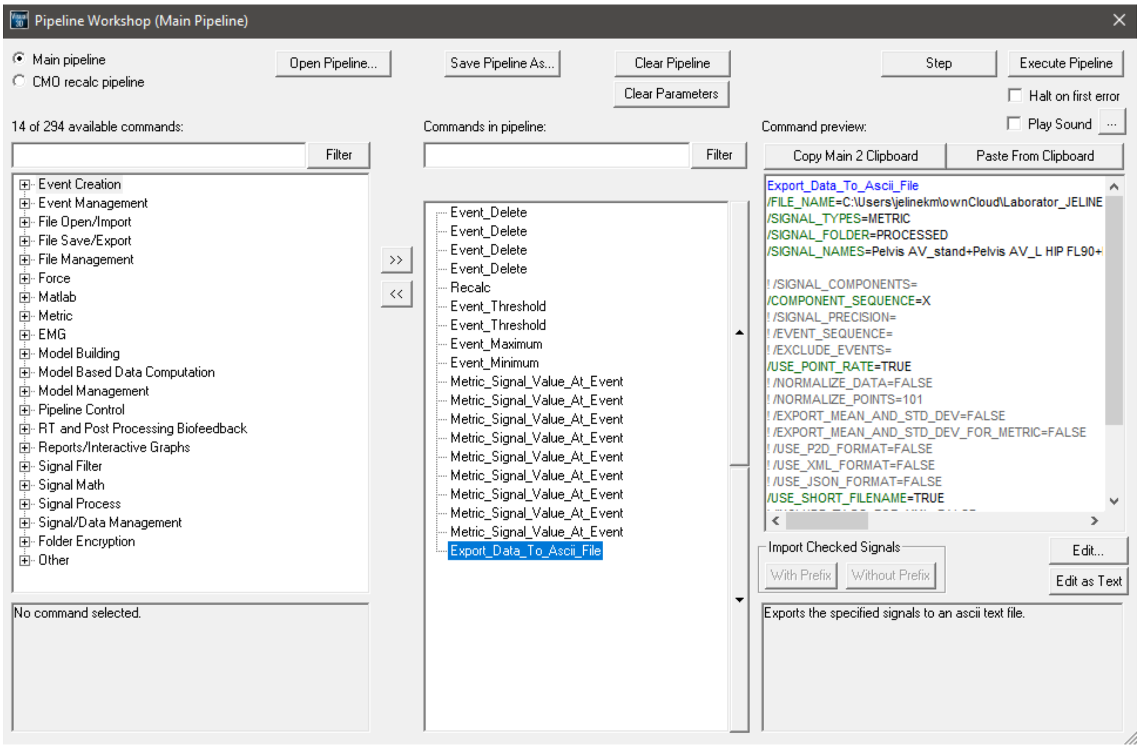
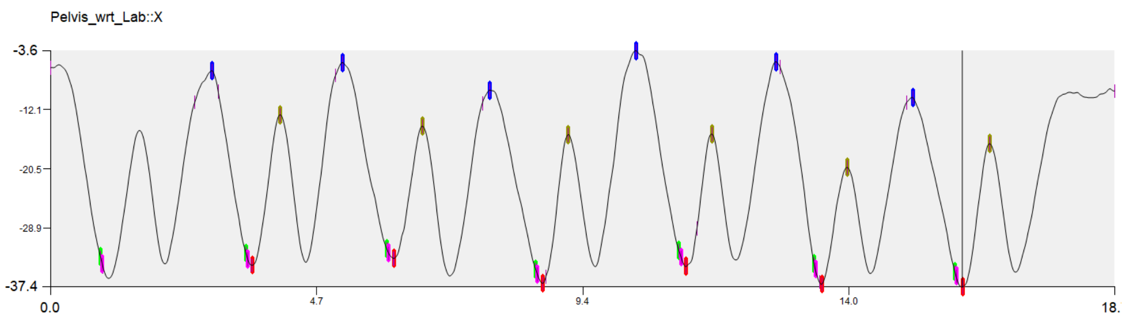


Figure 5

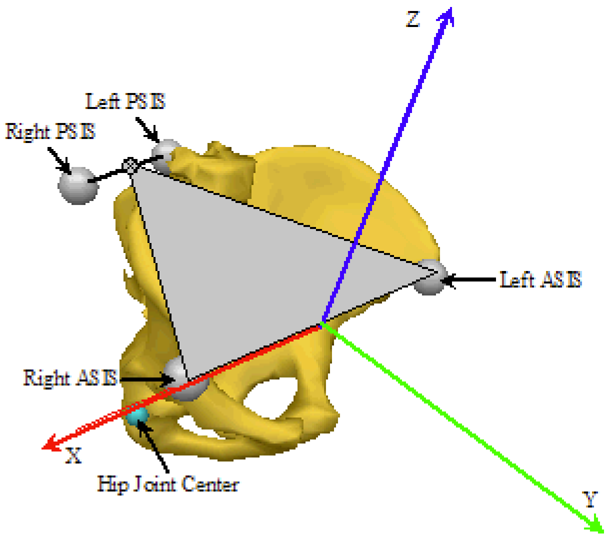
Pelvic curve in the sagittal plane



The pelvic curve is defined as the motion of a pelvis segment (Figure 6) relative to the global coordinate system of the laboratory (in Figure 5, this is the y-axis called „Pelvis_wrt_Lab::X“). The CODA pelvis segment model is used and is defined by using the anatomical locations of both ASIS and the midpoint of the PSIS location.

Figure 6

CODA pelvis segment



Source: (Coda Pelvis, 2024)

Thus, a total of six values (six squat repetitions) were obtained for each participant before exercise intervention and another six after exercise intervention. The following data were used for statistical analysis:

1. Initial position of the pelvis before squat (blue point)
2. PPT ROM during descending phase of the squat (difference between pelvic position at maximum squat depth – khaki point, and maximum anterior pelvic tilt during the descending phase of the squat – red point)

4.5.2 STATISTICAL ANALYSIS

Descriptive statistics (mean, standard error, median, mode, standard deviation, minimum, maximum, count) and frequency distribudtion (frequency, percent, cumululative percent) was used to analyse the data from the initial physiotherapy examination. These basic analyses were performed in Microsoft Excel (version: Professional Plus 2019).

The R software (version: 4.4.0) was used to analyse the 3D kinematic motion analysis data and to test the hypotheses. Restricted Maximum Likelihood (REML) analysis of linear mixed models was performed both for fixed (time = pre- and post-intervention condition, group = experimental and control) and random effects (participant), residuals normality analysis was performed after each REML analysis, and these results are displayed with in Q-Q plot and histogram. Repeated measures analysis of variance (rANOVA) was also use in specific cases. Statistical significance was set at the conventional 0.05 level.

The first analysis carried out was a mixed model for the dependent variable (PPT ROM) with no difference in squat repetition order with the random effect (participant), first with interaction and then without interaction.

Subsequently, rANOVA with differentiation of squat repetition order was performed (works with all independent variables as factors, so it is not possible to examine a linear dependence on squat repetition order; used factors: time, group, repetition, group:time, group:repetition, time:repetition, group:time:repetition) and then a mixed model was implemented. This model considers repetition as a numerical variable and follows a linear dependence on it.

Lastly, mixed model with random effect (participant) was used to assess the dependence of the PPT ROM on the initial pelvic position (first without the time factor). And then the same model was used for the values obtained before the exercise intervention only, for both groups.

5 RESULTS

5.1 BASELINE DATA FROM ENROLLED PARTICIPANTS

The basic characteristics of the included participants follow in Table 2, 3, 4, 5.

Table 2

Experimental group basic characteristics

Number	Sex	Age (years)	Height (cm)	Weight (kg)	Laterality
1	M	25	182	80	Right
2	F	21	176	73	Right
3	F	26	168	59	Left
4	M	21	192	80	Right
5	M	22	188	80	Right
6	F	23	172	81	Right
7	M	28	192	90	Right
8	F	52	163	74	Right
9	F	20	157	63	Right
10	M	46	188	110	Left
11	M	36	190	85	Right
12	F	26	167	78	Right
13	M	22	182	79	Right
14	M	23	186	105	Right
15	M	22	176	80	Right
16	F	22	170	59	Right
17	M	27	171	66	Right
18	M	25	178	70	Right
19	F	21	160	58	Right
20	F	20	165	55	Right
21	M	22	178	85	Right
22	M	19	182	82	Right
23	M	21	184	76	Right

Notes:
M = Male
F = Female

Table 3

Experimental group pelvis and squat characteristics

Number	Initial pelvis position	Squat depth	Posterior pelvic tilt
1	PAPT	Slightly below parallel	Right at parallel
2	PPT	Slightly below parallel	Above parallel
3	Torsion	Slightly below parallel	Above parallel
4	PAPT	Slightly below parallel	Right at parallel
5	PAPT	Slightly below parallel	Right at parallel
6	IAPT	Slightly below parallel	Right at parallel
7	PAPT	Parallel	Above parallel
8	PAPT + OLD	Parallel	Above parallel
9	IAPT	Slightly below parallel	Right at parallel
10	IAPT	Parallel	Right at parallel
11	PAPT + ORD	To the ground	Right at parallel
12	PAPT + OLD	Slightly below parallel	Right at parallel
13	PPT + OLD	Slightly below parallel	Right at parallel
14	PAPT	Slightly below parallel	Right at parallel
15	PPT	Slightly below parallel	Right at parallel
16	PAPT + OLD	Slightly below parallel	Right at parallel
17	IAPT + OLD	Parallel	Right at parallel
18	PAPT	Slightly below parallel	Right at parallel
19	IAPT + OLD	Slightly below parallel	Right at parallel
20	PAPT	Slightly below parallel	Right at parallel
21	PAPT	Parallel	Right at parallel
22	PAPT	Slightly below parallel	Right at parallel
23	PAPT + OLD	Slightly below parallel	Right at parallel

Notes:
PAPT = Physiological anterior pelvic tilt
IAPT = Increased anterior pelvic tilt
PPT = Posterior pelvic tilt
OLD = Oblique to the left downwards
ORD = Oblique to the right downwards

Table 4

Control group basic characteristics

Number	Sex	Age	Height (cm)	Weight (kg)	Laterality
24	F	24	160	56	Right
25	F	21	164	56	Right
26	M	22	179	88	Right
27	F	22	161	50	Right
28	F	20	167	55,5	Right
29	F	23	163	60	Right
30	M	25	173	78	Right
31	F	25	175	56,5	Right
32	F	55	175	75	Right
33	M	46	183	79	Right
34	M	21	178	67	Right
35	M	22	173	86	Right
36	F	42	170	72	Right
37	F	25	173	65	Right
38	F	22	165	60	Right
39	M	21	168	75	Right
40	F	22	165	52	Right
41	M	29	176	76	Right
42	F	27	180	72	Left

Notes:
M = Male
F = Female

Table 5

Control group pelvis and squat characteristics

Number	Initial pelvis position	Squat depth	Posterior pelvic tilt
24	PAPT	Below parallel	Below parallel
25	PAPT	Below parallel	Below parallel
26	PAPT + OLD	Below parallel	Below parallel
27	PAPT	To the ground	Below parallel
28	PAPT	To the ground	Above ground
29	PAPT	Below parallel	Below parallel
30	PAPT	Below parallel	Below parallel
31	PAPT	To the ground	Below parallel
32	PAPT + OLD	Below parallel	Below parallel
33	PAPT	To the ground	Above ground
34	PAPT + OLD	To the ground	Above ground
35	PAPT	To the ground	Above ground
36	PAPT + OLD	To the ground	Above ground
37	PPT	To the ground	Below parallel
38	IAPT + OLD	Almost to the ground	Below parallel
39	PAPT + OLD	Almost to the ground	Below parallel
40	PAPT	To the ground	Above ground
41	PAPT + OLD	To the ground	Above ground
42	IAPT + ORD	Almost to the ground	Below parallel

Notes:
PAPT = Physiological anterior pelvic tilt
IAPT = Increased anterior pelvic tilt
PPT = Posterior pelvic tilt
OLD = Oblique to the left downwards
ORD = Oblique to the right downwards

5.2 RESULTS OF THE INITIAL PHYSIOTHERAPY EXAMINATION

Hip joint range of motion

All participants (regardless of group) showed physiological ROM. Only flexion and abduction movements showed values at the lower limits of physiological ROM. See Appendix E for complete descriptive statistics.

Ankle joint range of motion

All participants (regardless of group) showed physiological ROM. Only plantar flexion movement showed values at the lower limits of physiological ROM. See Appendix F for complete descriptive statistics.

Examination of the pelvic ligaments

The results of this examination are virtually free of adverse findings, with 85–100% of participants, regardless of group, being free of any pathology. See Appendix G for complete frequency distribution.

The Sacroiliac Joint Special Test Cluster (Cluster of Laslett)

Pelvic/sacroiliac joint dysfunction was ruled out in all participants, because no participant had three or more positive tests. Only one participant in experimental group had two positive tests.

Assessing Muscle Length

In both groups, the hamstrings and rectus femoris muscle showed the greatest shortening (80–85% of participants), followed by the tensor fasciae latae (40–50% of participants). The remaining muscles, the hip adductors, piriformis muscle, triceps surae muscle, and iliopsoas muscle, showed almost no shortening. See Appendix H for complete frequency distribution.

Muscle Strength Testing

Nearly all participants demonstrated hip flexion and extension strength at levels 4+ and 5. There was no pathology in the Trendelenburg sign, but in its more difficult version, 50–75% of participants showed poor execution regardless of group. See Appendix I for complete frequency distribution.

Diagnostic Tests of the Deep Stabilization System (core)

Virtually every participant, regardless of group, had some amount of pathology in these tests. The biggest problem was the hip flexion test (up to 85% of participants had poor execution), followed by the diaphragm test (40–60% of participants with poor execution) and the hip extension test (25–50% of participants with poor execution). See Appendix J for complete frequency distribution.

5.3 RESULTS OF THE 3D KINEMATIC MOTION ANALYSIS

5.3.1 MAIN HYPOTESIS

No statistically significant difference was found in the mixed model with interaction (p = 0.89) nor in the mixed model without interaction (p = 0.42). In other words, the exercise intervention did not affect the total PPT ROM during the descending phase of the squat for individual participants. This fact is well illustrated in Figure 7, where the individual participants, the means for the groups (experimental and control), and the differences between before and after the exercise intervention are shown. The normality of the residuals was met for both models (Figure 8 and 9). A borderline of statistical significance was found between the groups (p = 0.06).

Figure 7

Overall results for both groups

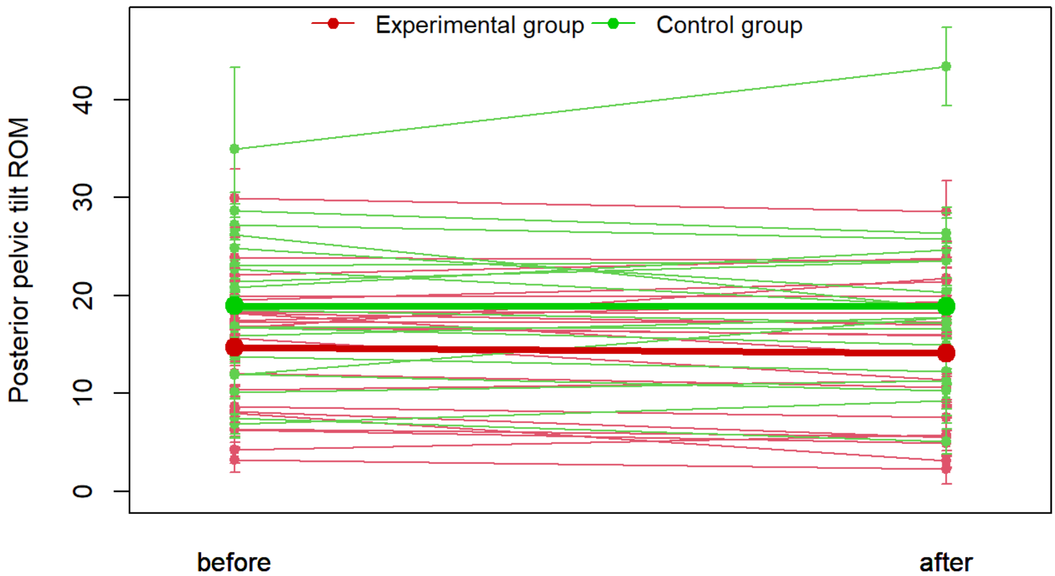


Figure 8

Residuals normality for model with ineraction – Q-Q plot

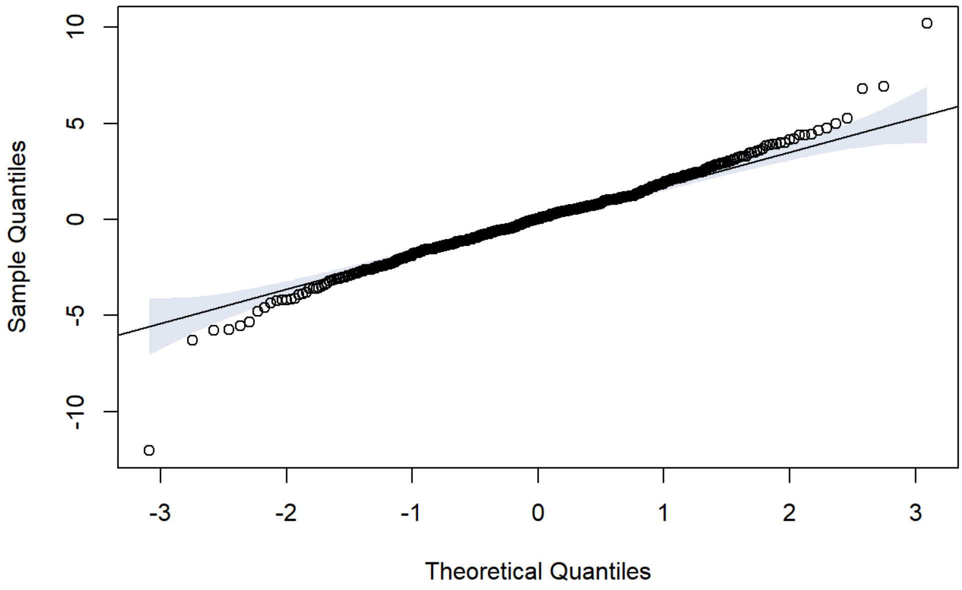
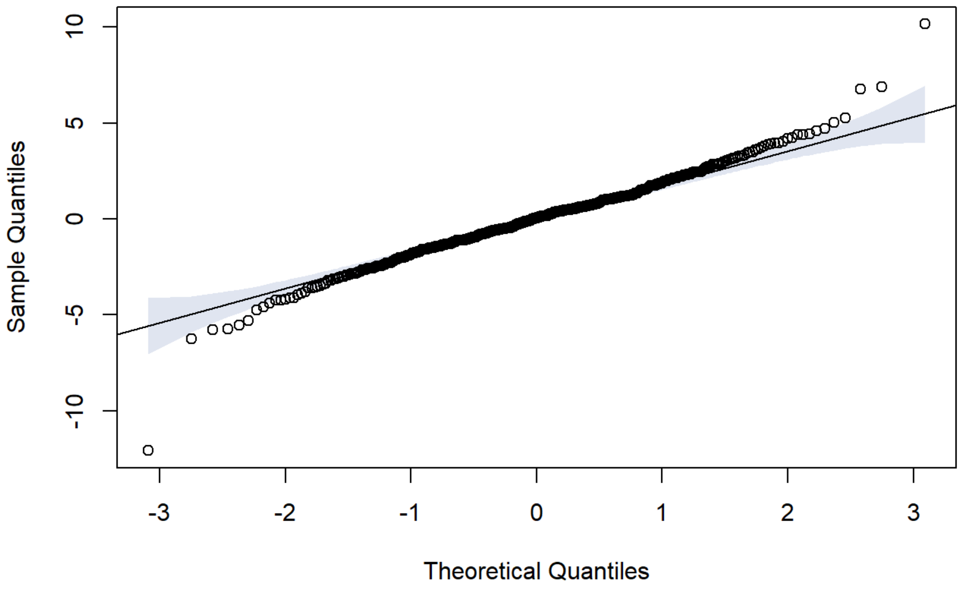


Figure 9

Residuals normality for model without ineraction – Q-Q plot



The results of rANOVA with squat repetition order distinction show a significant difference in the repetitions ($p < 0.001$) and a borderline of statistical significance was found between the groups ($p = 0.06$). No other factors were found to be statistically significant. Using a mixed model that takes into account the order of repetition, the effect of repetition is again found to be statistically significant ($p < 0.001$), and the significance of the group is again borderline ($p = 0.07$). The normality of the residuals was met (Figure 10).

Figure 10

Residuals normality for analysis with squat repetition order distinction – Q-Q plot

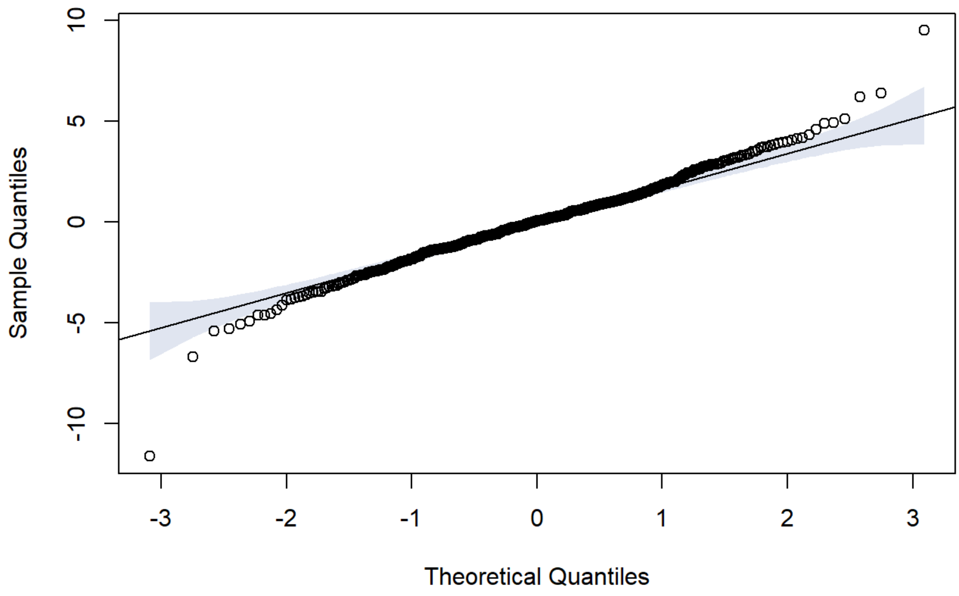


Figure 11 and 12 show very well the differences in individual squat repetitions, distinguishing between experimental and control groups and between pre- and post-intervention conditions.

Figure 11

Differences in individual repetitions of squats – Control and experimental group

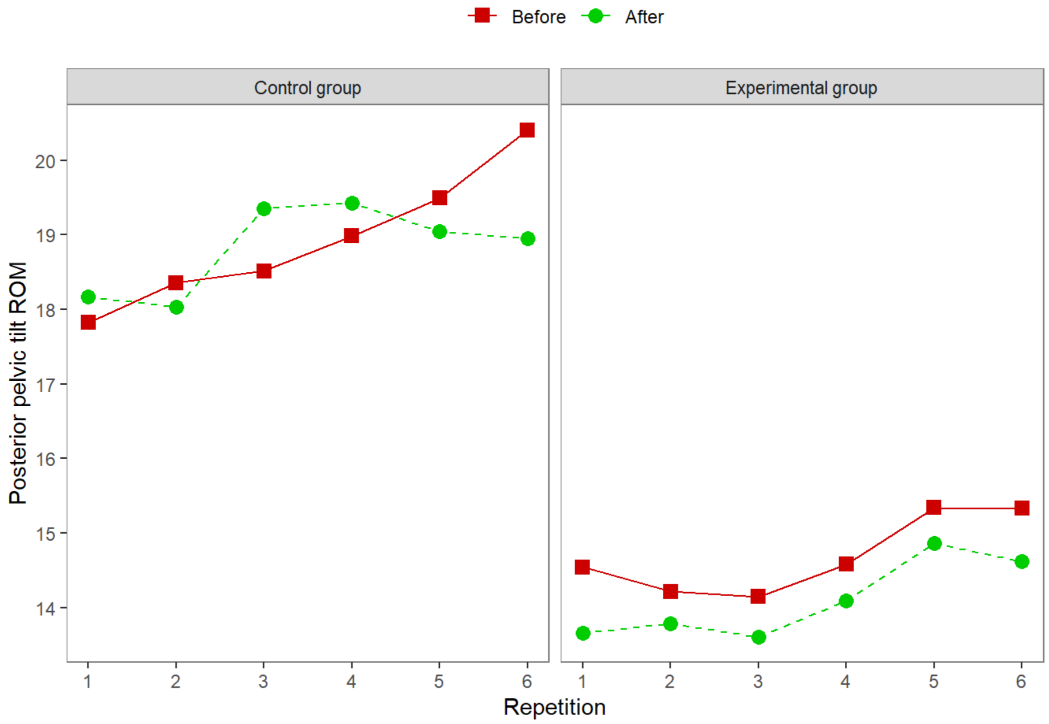
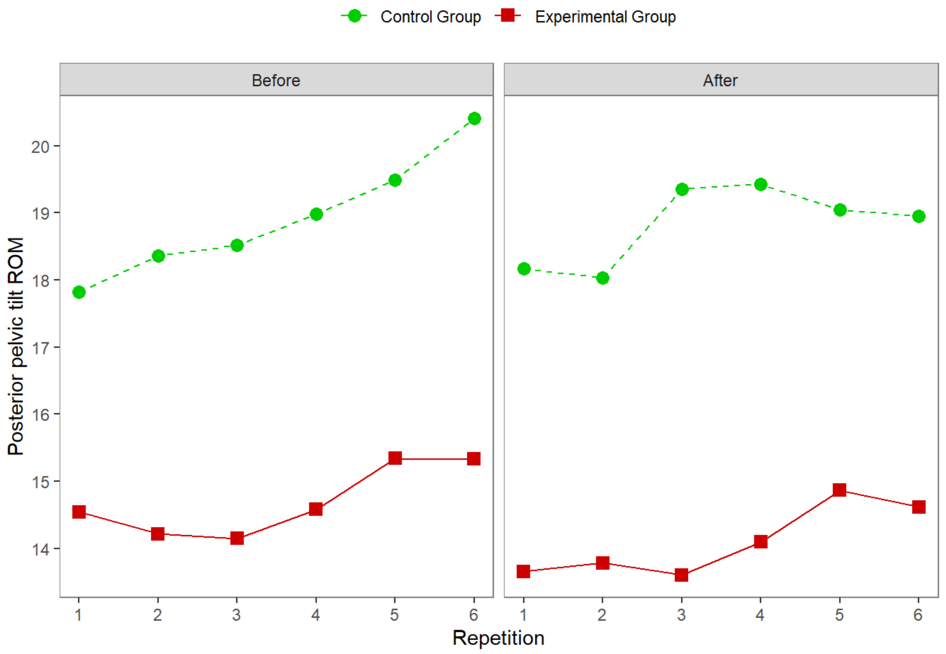


Figure 12

Differences in individual repetitions of squats – Before and after the exercise intervention

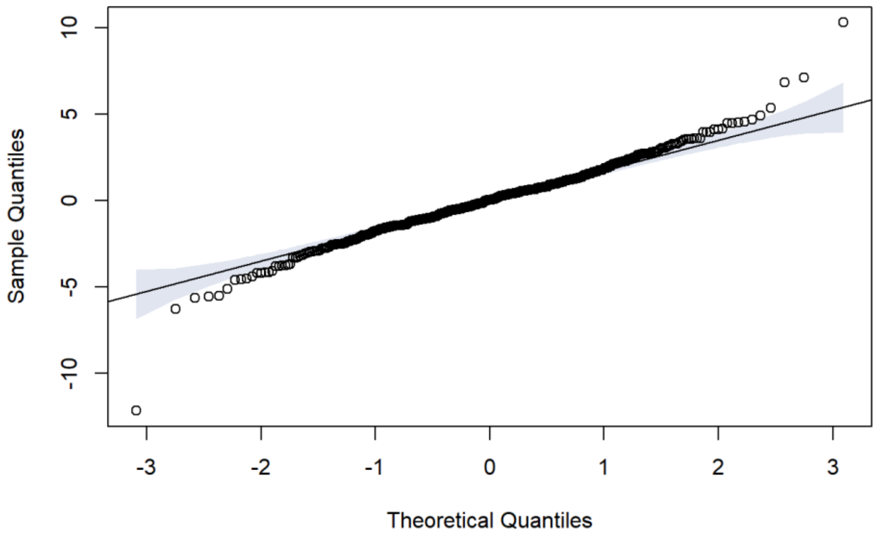


5.3.2 SECONDARY HYPOTESIS

Using a mixed model with random effect (participant) and looking at the relationship between PPT ROM and initial pelvic position, no statistically significant relationship was found ($p = 0.13$). The normality of the residuals was met (Figure 13).

Figure 13

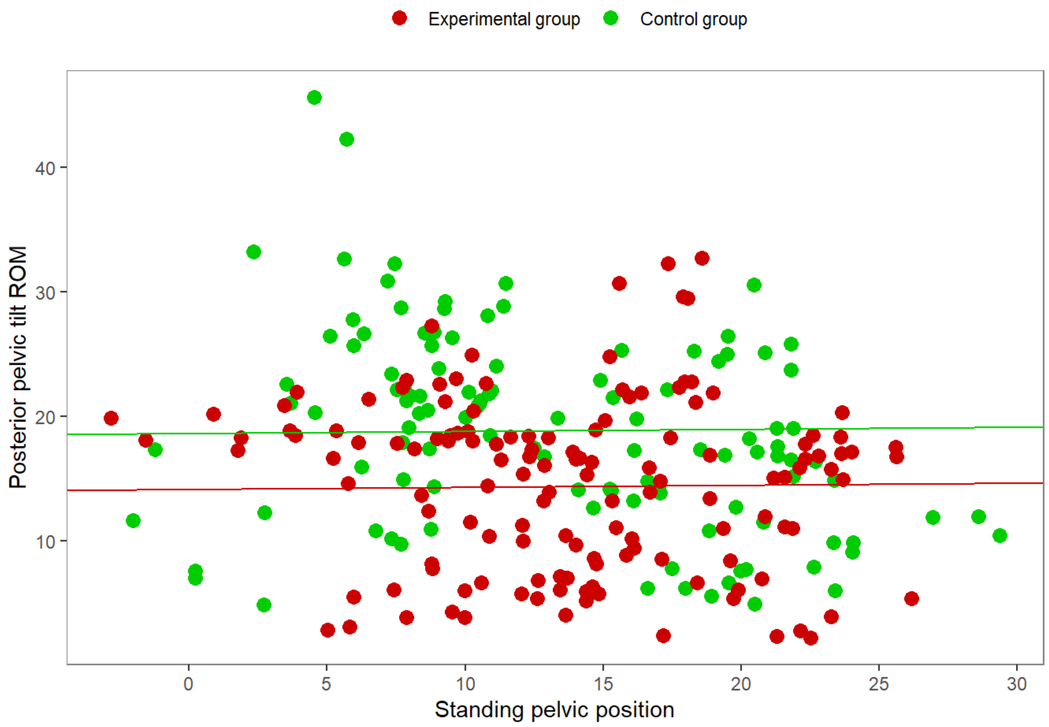
Residuals normality for analysis with squat repetition order distinction – Q-Q plot



Using the same model, but only with data from before the exercise intervention, the relationship between the PPT ROM and the initial pelvic position is even smaller, i.e. again not statistically significant ($p = 0.77$), and the significance of the group is again borderline ($p = 0.06$). To give an idea of the data distribution, the following scatter plot is used (Figure 14).

Figure 14

Relationship between initial pelvic position and total PPT ROM before exercise intervention



6 DISCUSSION

6.1 DISCUSSION OF RESULTS, HYPOTHESES AND LIMITATIONS OF THE THESIS

The main goal of this thesis was to objectively assess the immediate effect of the exercise intervention on the total pelvis ROM in the sagittal plane with the assumption that the exercise intervention will reduce PPT ROM during the descending phase of the squat. Unfortunately, the results of this thesis do not support this main hypothesis, nor do they support the secondary hypothesis.

If we look at the results of the main hypothesis of this thesis, specifically Figure 11 and 12, we can see a trend where PPT ROM decreases in the experimental group after the intervention and also in the control group, but to a lesser extent. However, these changes of about 0.5° are obviously not statistically significant and I dare say that they are at the limit of measurement uncertainty. This brings me to **the first limitation** of this thesis, which is the use of 3D kinematic motion analysis. Although this is a relatively widely used (Choe et al., 2021; Nielsen, 2015; Oshikawa et al., 2021; Sinclair et al., 2017; Southwell et al., 2016) valid and reliable tool for motion objectification (Maclachlan et al., 2015), some errors cannot be completely avoided. The reliability of the measurements was ensured by labeling the marker placement with a pen (Figure 3). So I don't see a problem in that area, but the main concern could be poor palpation of the bony landmarks (ASIP, PSIP, and iliac crest) necessary to define the CODA pelvis segment. Although the palpation was performed according to the generally accepted recommendations (Chaitow, 2017; Gross et al., 2023; Lewit, 2024; Rychlíková, 2021; Sint Jan, 2007) and the author of this thesis is quite experienced in this palpation, one can never completely exclude the possibility of an incorrect palpation of the given landmarks. Because, as stated in Malanga & Mautner (2017), this examination has low specificity and repeatability (this negative was eliminated by the fact that the palpation was done only once), but it is still an absolute basis in the examination of the patient. Even if the palpation was off by a few millimeters, this could change the defining the pelvic segment and therefore affect the PPT ROM data obtained (but probably in the lower units of angular degrees). A theoretical *recommendation for further research* could be the use of other objectification methods that do not rely on subjective perceptions but are truly objective - e.g. x-ray or dynamic magnetic resonance imaging, but the disadvantage of these methods is the high cost and radiation exposure to the patient.

The second limitation I find is in the squat initial settings and its execution. Several authors suggest that a wider stance during squatting can alter PPT ROM (Escamilla et al., 2001; Lorenzetti et al., 2018; McKean et al., 2010; Nielsen, 2015; Swinton et al., 2012; Švejcar & Šťastný, 2013). However, since it is commonly stated that the typical execution of the squat is a pelvic/hip/shoulder level stance width (Bertram, 2018; Diamond-Walker, 2019; Doll, 2024; Král, 2017; Pavluch & Frolíková, 2004; Popowychová, 2023; Schwarzenegger & Dobbins, 2018; Stoppani, 2016), the pelvic width stance execution of the squat was investigated for this reason. Since participants were not measured for pelvic width and were only verbally instructed to stand at pelvic width, it could theoretically be that stance width was narrower than pelvic width, resulting in greater PPT ROM (this conclusion has been reached by some of the research mentioned above). However, based on visual inspection of stance width, I would venture to say that all participants were indeed standing at pelvic width. Therefore, *in future research*, it would be desirable to measure participants' pelvic width to avoid potential errors in the initial squat stance. There is also the question of whether simply changing the stance width during squatting is the right solution/approach to PPT without further investigation/clarification of the causes of this phenomenon.

Related to the execution of the squat is the fact that individual repetitions were not consistent, as can be seen in Figures 11 and 12, respectively, that there was even an increase in PPT ROM with each subsequent repetition. The reason for this may be that the instructions to perform the squat were only verbal: stand at pelvic width, squat smoothly to the maximum depth that you can comfortably manage, do not bounce or pause at the bottom, then return to the starting position and the arms must be held at shoulder level at all times. This may have caused each squat depth to be different, each starting position to be different, and the duration of each descending/ascending phase to be different. A possible solution *for future research* on this topic is the use of metronome-like aids (which was used e.g. in the study by Erman et al. (2023) to standardize execution or introduce a specific pause between each repetitions, and possibly the use of a box or other aid to accurately define the squat depth. This should make the repetitions and the data obtained more consistent. On the other hand, this is an artificial interference with the participant's own squat execution, and it is a matter of consideration whether to study a precisely defined squat execution or a natural way of performing the squat. Also, when we look at the PPT ROM in the experimental and control groups (see Figures 11 and 12), we see that paradoxically, the control group has a greater PPT ROM than the experimental group. The likely reason for this could be that a significant number of participants in the control group had a greater squat depth than the experimental group (see Tables 3 and 5). Thus, this finding may support my point above that squat execution should be clearly standardized in terms of squat depth.

Motor learning and the effect of fatigue might be **the third limitation** of this thesis. Motor learning, or sensorimotor learning, is generally defined as a four-step process associated with practice or experience that results in relatively permanent changes in a skill. Another definition describes motor learning as an activity designed to learn or modify a previously learned movement (Schmidt & Lee, 2011; Shumway-Cook & Woollacott, 2000). Thus, the exercise intervention used may have failed for two reasons. The first is the fact that it was not checked whether the participants had completely mastered the included exercises. This fact is very important because the first step in motor learning is the generalization phase, which is characterized by high expenditure of energy and concentration (Vilímová, 2009). Therefore, in theory, fatigue could increase during/after the exercise intervention and consequently affect the execution of the squat. On the other hand, if we look at the research by Weeks et al. (2015), fatigue only occurred to alter the execution of the squat after several hundred repetitions of bodyweight lunges. A similar study was conducted by Erman et al. (2023), where fatigue that significantly altered joint kinematics occurred after performing 72±27 bodyweight squats. So it is probably very unlikely that a total of 28 squat repetitions (14 before the intervention and 14 after the intervention) and 15–20 minutes exercise intervention would cause such a significant increase in fatigue to alter the execution of the squat. Thus, a *future solution* might be to first have a few days of familiarization with the exercise intervention in order to teach the exercises to the participants, but the question is whether these few days of familiarization are not a targeted intervention itself and will not affect the results of the immediate effect of the exercise intervention.

The second fact may be that only two exercises directly applicable to squat execution (ball wall squat and overhead squat) were included in the exercise intervention, the rest was aimed more at influencing posture or awareness of one's body in space. We know that performance in the squat is to some extent transferable to other sports such as sprinting or jumping (Chelly et al., 2009; Choe et al., 2021; Styles et al., 2016). However, the question is whether the exercise intervention included is transferable to squat performance/technique. According to Mang et al. (2022), both bilateral exercises (hip thrusts) and unilateral exercises (rear foot elevated split squat) are transferable to squat performance. In this context, it is possible to mention the intensity of the included exercise intervention. As can be seen from Table 1 and the following description of the exercises, these are bodyweight exercises. Therefore, it can be concluded that this is a relatively low intensity exercise intervention and it is questionable whether this low intensity can produce any immediate changes.

And this brings me to **the fourth limitation** of this thesis, and that is the intensity of used exercise intervention and the time for which the effect of the exercise intervention has been studied, which is about 20 minutes. When we look at studies that address pelvic and trunk issues and the immediate effects of exercise interventions, we find mostly positive results outcomes regardless of the level of training of the participants. These studies have used a wide range of exercise interventions, from stretching (Kadono et al., 2017) to isometric exercises (Akçay et al., 2024; Huang & Kim, 2022; Lee & McGill, 2016; Rio et al., 2015) to traditional dynamic exercises (Gluppe et al., 2020; Imai et al., 2016). However, the vast majority of research has used at least four and usually up to eight weeks of exercise intervention at a frequency of three times per week (Ebrahimi et al., 2015; Elborady et al., 2023; Gandolfi et al., 2019; Shin et al., 2022; Zarei & Norasteh, 2021). In terms of intensity, there is research that looks at low-intensity, high-repetition exercise interventions. However, the intensities used are often in the range of 30–50% of 1RM and few use pure bodyweight equivalent loads. The results of such research suggest that even low intensity can affect the outcome in 1RM, increasing isometric strength and increasing the amount of muscle mass (Ikezoe et al., 2020; Usui et al., 2016), and it also affects blood flow (Briceño-Torres et al., 2023). However, all of these studies followed participants again for several weeks. Other studies have examined an exercise intervention using bodyweight squats in the elderly population. The results of these studies suggest that performing several bodyweight squats per day for 3–4 months could improve lower limb function, as well as performance in physical functional tests related to ADL and could slightly change neural activation (Hirono et al., 2023; Yoshiko & Watanabe, 2021). Thus, it can be concluded that low-intensity exercise intervention has an effect, but usually with a longer time interval, and although immediate changes can occur even after a short exercise intervention, it is probably necessary to make the exercise intervention more specific to squatting, and this is what I would *recommend for further research*.

And it is the group of participants that brings me to the next, **fifth limitation** of this thesis. The research sample consisted of a relatively small number of participants who were also completely free of health problems, but more importantly, had at least one year of squatting experience, which could have significantly influenced the results of this thesis. If these were beginners just starting out with strength training, the results may have been different. The same can be said if participants have health problems, typically low back pain, as there is a huge amount of research on this topic and we know that changes in movement behaviour/stereotypes do occur after interventions. Where we know, for example, that stabilization exercises targeting the trunk and pelvic area can reduce pain, increase muscle strength and improve stability (Mun et al., 2022), we also know that low-intensity aerobic activity along with strength training and mobility training is an appropriate treatment for chronic non-specific low back pain (Gordon & Bloxham, 2016) and may even affect the central nervous system in terms creating plasticity changes in the motor system, which in turn affects pain perception and disability levels in patients with chronic non-specific low back pain (Li et al., 2022), and stabilization exercise intervention can also reduce kinesiophobia (Filipczyk et al., 2021). However, it is questionable whether it would be appropriate to examine the effect of the exercise intervention on PPT ROM in participants with low back pain, since, as noted in the theoretical background (Lui et al., 2018; Luomajoki et al., 2008; Saraceni et al., 2021; Sung, 2013; Vazirian et al., 2016a, 2016b), these participants often exhibit different movement strategies and subsequent comparison of results with a control group would likely be quite challenging, or perhaps a change in overall pelvic segment behavior could be identified in the experimental group. This leads to a very cautious *recommendation for further* research, namely to compare the pelvic segment behavior of healthy participants (control group) with the pelvic segment behavior of participants with back pain (experimental group).

There is also a **sixth limitation** related to the participants and that is the way the participants were divided into experimental and control groups. When participants were divided based on the occurrence of PPT during squatting, there were still significant differences in pelvic position during standing. Therefore, it may have been more appropriate to divide the participants not only on the basis of the occurrence of PPT, but also on the basis of their pelvic position during standing and possibly by gender (man/woman). This is because the general recommendation is that participant groups should be as homogeneous as possible (Martínez-Mesa et al., 2016), and in the case of this thesis, homogeneity was only partially established based on the distribution according to the occurrence of PPT. A second factor in why the results of the thesis came out this way may be that sample size calculation and power analysis were not performed, which some authors have stated (Suresh et al., 2011; Serdar et al., 2021) is necessary in biological research. However, due to the very limited amount of research available on the topic of this thesis, it was not possible to calculate the parameters from. Thus, a possible flaw in this thesis is the fact that pilot study was not conducted to determine sample size and power analysis, so for *future research I would recommend* that pilot study be conducted on a smaller number of participants and then use these results to determine sample size and power analysis, or the results of this thesis (and can therefore theoretically be regarded as a pilot study in this area) could also be used to determine sample size and power analysis.

A secondary hypothesis was that participants with greater anterior pelvic tilt in standing would also have greater PPT ROM. This hypothesis is based on the opinion of several authors (Boyce, 2018; Henoch, 2014; Masi, 2020). Why this hypothesis was not confirmed is difficult to determine. A possible explanation may be found in one of the concepts of manual medicine (Tichý, 2014), which states that if we have a starting joint position that is moved in one direction (in this case, greater anterior pelvic tilt in standing position), the overall ROM in the joint does not change, but the sub-movements do, by increasing the ROM in the direction of the misalignment (in this case, increasing the anterior pelvic tilt ROM in the descending phase of the squat) and decreasing the ROM in the other direction (in this case, decreasing the PPT ROM in the descending phase of the squat). In the results of this thesis, I only reported the mixed model result for this secondary hypothesis ($p = 0.13$ and $p = 0.77$ using only the „before" data), but a simple correlation was also performed with a result of -0.26, and using the Spearman rank correlation coefficient (due to the non-normality of the data) the result was similar at -0.29. These negative values actually say that there is a relationship between initial pelvic position and PPT ROM, but it is exactly the opposite of what was hypothesized in this thesis, i.e., as the value of pelvic curvature increases (greater anterior pelvic tilt), PPT ROM decreases. Again, I have no explanation for this phenomenon, but one study (Harada et al., 2022) found similar results, but in patients after total hip arthroplasty, where PPT at maximum hip flexion was significantly correlated with pelvic tilt at minimum hip flexion (standing position).

The second to last thing I want to mention is the anatomical predispositions of the individual participants. Several authors (Boyce, 2018; Henoch, 2014; Lau, 2022; Phili, 2023) state that not everyone is capable of performing the deep squat correctly. As a physiotherapist I can only agree. Due to the fact that the participants did not undergo radiographic examination, changes in the femoral angles, which can significantly affect the range of motion and the stereotype of the movements performer (Čihák, 2011; Dylevský, 2021; Muscolino, 2023; Pirola, 2024), cannot be ruled out with certainty. Therefore, I would consider including imaging examinations (typically x-rays) to rule out congenital changes in the femoral angle and possibly to rule out FAI, which is known to alter the movement pattern of the squat (Bagwell et al., 2016; Catelli et al., 2018, 2021; Kolber et al., 2018; Yoshimoto et al., 2018). There are clinical tests to rule out FAI (Chládek, 2016; Rychlíková, 2019) that were not used in this thesis, which may be **another limitation** of this thesis. However, the included participants showed almost physiological ROM in all hip movements, so it is questionable whether the inclusion of these tests is entirely necessary. Nevertheless, I believe that the initial physiotherapy examination carried out in this thesis is more than sufficient and could theoretically serve as a model examination *for further research or clinical practice*.

The last thing I want to address is whether PPT exists at all. In the theoretical background it is said that PPT is a phenomenon that accompanies the hip flexion practically from the beginning (Bohannon, 1982; Bohannon & Bass, 2017; Dewberry et al., 2003; Murray et al., 2002) and some might argue that it is a normal thing that belongs to the execution of the squat or hip flexion itself. In my opinion, this is quite possible, because the pelvis shows a movement into anterior pelvic tilt and then into PPT during the descending phase of the squat (and during the ascending phase, the pelvic movements are in reverse order, as can be seen in Figure 5). A similar finding, i.e. that the pelvis exhibits both movement into anterior pelvic tilt and PPT, has been reported in other research (Brekke et al., 2021; Edington, 2017; Grant et al., 2024; Hara et al., 2014; Hoogenboom et al., 2023; Komiyama et al., 2018; Sinclair et al., 2017; Weeks et al., 2015), but because each time a different data collection system (3D kinematic motion analysis from various manufacturers or x-ray) and a different squat variant is used (e.g. squatting on one leg, standing up from a squat, etc.), the results are very heterogeneous and practically incomparable to the results of this thesis. The pelvic kinematic curves of this thesis most closely match those of the following research: Brekke et al. (2021), Edington (2017), Sinclair et al. (2017), Weeks et al. (2015). However, because the effect of the exercise intervention on PPT ROM was not primarily investigated in these studies, no definitive conclusion can be drawn. And since nowhere is it defined what PPT ROM is physiological and what is not, the research question of how PPT ROM is affected and its consequences is still valid in my opinion.

6.2 IMPORTANCE AND RELEVANCE OF THE RESEARCH

Despite the results and some limitations of this thesis, I am still convinced that addressing the issue of PPT during squat is still a current topic because the amount of research done on this topic is scarce and information must be derived indirectly from other research subjects. Thus, this thesis could motivate someone to delve more into the issue of PPT during squat and clearly determine how to approach and address this issue based on different examinations, variables or parameters. In the same way, I think that in today's world of evidence-based medicine, it's very important to have an objective examination in physiotherapy and also an objective evaluation of physiotherapy results, not necessarily with 3D kinematic motion analysis, but with other tools/instruments as well. This is the only way to have a targeted and precisely dosed intervention.

7 CONCLUSION

Working on this dissertation was a very interesting experience, but also quite frustrating due to the small number of sources dealing with this particular topic, so information often had to be derived indirectly from other areas of research.

In my opinion, the goal of this thesis was achieved, although the hypotheses of the thesis were not confirmed. Nevertheless, I still believe that proper exercise intervention for PPT during squatting is a possible solution, provided the athlete is not limited by innate anatomical predispositions and a comprehensive examination has been performed to uncover the possible cause of PPT.

This thesis is, in my opinion, one of the few publications that have addressed the issue of PPT during squatting, and I would be very pleased if someone else would build on this work and clearly identify the causes and solutions to PPT during squatting.

8 RESOURCES LIST

1. Abelleira-Lamela, T., Vaquero-Cristóbal, R., González-Gálvez, N., Esparza-Ros, F., Espeso-García, A., & Marcos-Pardo, P. J. (2021). Sagittal spine disposition and pelvic tilt during outdoor fitness equipment use and their associations with kinanthropometry proportions in middle-aged and older adults. *PeerJ, 9*, 1–20. https://doi.org/10.7717/peerj.12657

2. Adams, M. A., Freeman, B. J. C., Morrison, H. P., Nelson, I. W., & Dolan, P. (2000). Mechanical Initiation of Intervertebral Disc Degeneration. *Spine, 25*(13), 1625–1636. https://doi.org/10.1097/00007632-200007010-00005

3. Akçay, B., Çolak, T. K., Apti, A., & Çolak, İ. (2024). The Immediate Effect of Hanging Exercise and Muscle Cylinder Exercise on the Angle of Trunk Rotation in Adolescent Idiopathic Scoliosis. *Healthcare, 12*(3), 1–10. https://doi.org/10.3390/healthcare12030305

4. Ameer, M., Al Abbad, A., Subbarayalu, A., Bahey El-Deen, H., Al Sirhani, S., Al Arjan, E., Al Ihawy, W., Al Ruwaili, N., & Kamel, M. (2024). Acute effect of single-session physio-ball wall squat training on knee active reposition sense and isokinetic parameters in sedentary female collegiate students: an experimental study. *Human Movement, 25*(3), 109–120. https://doi.org/10.5114/hm/193208

5. Aspe, R. R., & Swinton, P. A. (2014). Electromyographic and Kinetic Comparison of the Back Squat and Overhead Squat. *Journal of Strength and Conditioning Research, 28*(10), 2827–2836. https://doi.org/10.1519/JSC.0000000000000462

6. Bagwell, J. J., Snibbe, J., Gerhardt, M., & Powers, C. M. (2016). Hip kinematics and kinetics in persons with and without cam femoroacetabular impingement during a deep squat task. *Clinical Biomechanics, 31*, 87–92. https://doi.org/10.1016/j.clinbiomech.2015.09.016

7. Barták, V., Bek, J., Bubová, K., Fulín, P., Hánová, P., Judl, T., Mann, H., Olejárová, M., Pokorný, D., Procházková, L., Soukup, T., Suchý, D., Šabata, L., Šenolt, L., Tomčík, M., Vaněk, P., Veigl, D., & Vodička, Z., Šenolt, L., & Veigl, D. (Eds.). (2024). *Diferenciální diagnostika bolestivého kloubu v klinické praxi* (2., přepracované a doplněné vydání). Grada.

8. Berryman Reese, N., & Bandy, W. D. (2024). *Joint Range of Motion and Muscle Length Testing* (4th Edition). Elsevier.

9. Bertram, O. (2018). *Posilování bez nářadí pro muže*. Euromedia.

10. Bimbi-Dresp, M. (2009). *Velká kniha cvičení pilates: Původní cviky pro všechny úrovně zdatnosti*. Svojtka.

11. Biscarini, A., Dieni, C. V., Losavio, R., Panichi, R., & Contemori, S. (2022). Effect of Forefoot–Rearfoot and Pelvic–Scapular Weight Shifts on Lower-Limb and Lumbar Muscle Activity during Static Wall-Squat Exercises. *Applied Sciences, 12*(8), 1–12. https://doi.org/10.3390/app12084037

12. Blache, Y., Bobbert, M., Argaud, S., de Fontenay, B. P., & Monteil, K. M. (2013). Measurement of Pelvic Motion Is a Prerequisite for Accurate Estimation of Hip Joint Work in Maximum Height Squat Jumping. *Journal of Applied Biomechanics, 29*(4), 428–434. https://doi.org/10.1123/jab.29.4.428

13. Bohannon, R. W. (1982). Cinematographic Analysis of the Passive Straight-Leg-Raising Test for Hamstring Muscle Length. *Physical Therapy, 62*(9), 1269–1274. https://doi.org/10.1093/ptj/62.9.1269

14. Bohannon, R. W., Gajdosik, R. L., & LeVeau, B. F. (1985). Relationship of Pelvic and Thigh Motions During Unilateral and Bilateral Hip Flexion. *Physical Therapy, 65*(10), 1501–1504. https://doi.org/10.1093/ptj/65.10.1501

15. Bohannon, R. W., & Bass, A. (2017). Research describing pelvifemoral rhythm: a systematic review. *Journal of Physical Therapy Science, 29*(11), 2039–2043. https://doi.org/10.1589/jpts.29.2039

16. Boone, D. C., Azen, S. P., Lin, C. -M., Spence, C., Baron, C., & Lee, L. (1978). Reliability of Goniometric Measurements. *Physical Therapy, 58*(11), 1355–1360. https://doi.org/10.1093/ptj/58.11.1355

17. Boyce, L. (2018, March 19). *Beat Butt Wink: Squat Big Without Hurting Your Back*. Bodybuilding.com. Retrieved November 13, 2024, https://www.bodybuilding.com/content/beat-butt-wink-squat-big-without-hurting-your-back.html

18. Braidot, A. A., Brusa, M. H., Lestussi, F. E., & Parera, G. P. (2007). Biomechanics of front and back squat exercises. *Journal of Physics: Conference Series, 90*(1), 1–8. https://doi.org/10.1088/1742-6596/90/1/012009

19. Breen, E. O., Howell, D. R., Borg, D. R., Sugimoto, D., & Meehan, W. P. (2016). Functional Deep Squat Performance is Associated with Hip and Ankle Range of Motion. *Journal of Athletic Enhancement, 5*(3). https://doi.org/10.4172/2324-9080.1000227

20. Brekke, A. F., Naili, J. E., Simonsen, M. B., Hirata, R. P., & Holsgaard-Larsen, A. (2021). Improved functional biomechanics during squat following an exercise program targeting excessive anterior pelvic tilt in patients with symptomatic hip dysplasia. *Gait & Posture, 90*(1), 19–20. https://doi.org/10.1016/j.gaitpost.2021.09.008

21. Briceño-Torres, J. M., Carpio-Rivera, E., Solera-Herrera, A., Forsse, J., Grandjean, P. W., & Moncada-Jiménez, J. (2023). Low-Intensity Resistance Training Improves Flow-Mediated Dilation in Young Hispanic Adults. *Journal of Strength and Conditioning Research, 37*(2), 298–304. https://doi.org/10.1519/JSC.0000000000004273

22. Byrne, J. M., Bishop, N. S., Caines, A. M., Crane, K. A., Feaver, A. M., & Pearcey, G. E. P. (2014). Effect of Using a Suspension Training System on Muscle Activation During the Performance of a Front Plank Exercise. *Journal of Strength and Conditioning Research, 28*(11), 3049–3055. https://doi.org/10.1519/JSC.0000000000000510

23. Carr, K., & Feit, M. K. (2024). *Funkční trénink na anatomických základech* (třetí vydání). Grada Publishing.

24. Catelli, D. S., Kowalski, E., Beaulé, P. E., Smit, K., & Lamontagne, M. (2018). Asymptomatic Participants With a Femoroacetabular Deformity Demonstrate Stronger Hip Extensors and Greater Pelvis Mobility During the Deep Squat Task. *Orthopaedic Journal of Sports Medicine, 6*(7). https://doi.org/10.1177/2325967118782484

25. Catelli, D. S., Kowalski, E., Beaulé, P. E., & Lamontagne, M. (2021). Muscle and Hip Contact Forces in Asymptomatic Men With Cam Morphology During Deep

Squat. *Frontiers in Sports and Active Living, 3*, 1–10. https://doi.org/10.3389/fspor.2021.716626

26. Chaitow, L. (2017). *Palpation and Assessment in Manual Therapy: Learning the Art and Refining Your Skills* (4. ed.). Handspring Publishing.

27. Charlton, J. M., Hammond, C. A., Cochrane, C. K., Hatfield, G. L., & Hunt, M. A. (2017). The Effects of a Heel Wedge on Hip, Pelvis and Trunk Biomechanics During Squatting in Resistance Trained Individuals. *Journal of Strength and Conditioning Research, 31*(6), 1678–1687. https://doi.org/10.1519/JSC.0000000000001655

28. Chelly, M. S., Fathloun, M., Cherif, N., Amar, M. B., Tabka, Z., & Van Praagh, E. (2009). Effects of a Back Squat Training Program on Leg Power, Jump, and Sprint Performances in Junior Soccer Players. *Journal of Strength and Conditioning Research, 23*(8), 2241–2249. https://doi.org/10.1519/JSC.0b013e3181b86c40

29. Chládek, P. (2016). *Femoroacetabulární impingement syndrom*. Galén.

30. Choe, K. H., Coburn, J. W., Costa, P. B., & Pamukoff, D. N. (2021). Hip and Knee Kinetics During a Back Squat and Deadlift. *Journal of Strength and Conditioning Research, 35*(5), 1364–1371. https://doi.org/10.1519/JSC.0000000000002908

31. Clark, D. R., Lambert, M. I., & Hunter, A. M. (2012). Muscle Activation in the Loaded Free Barbell Squat. *Journal of Strength and Conditioning Research, 26*(4), 1169–1178. https://doi.org/10.1519/JSC.0b013e31822d533d

32. Clémenceau, J. -P., & Delavier, F. (2021). *Fitness pro ženy – anatomie* (2. vydání). CPress.

33. *Coda Pelvis*. (2024, June 18). HAS-Motion Software Documentation. Retrieved December 3, 2024, https://www.wiki.has-motion.com/lib/exe/fetch.php?cache=&media=codapelvisscs.gif

34. Comfort, P., & Kasim, P. (2007). Optimizing Squat Technique. *Strength and Conditioning Journal, 29(*6), 10–13. https://journals.lww.com/nsca-scj/abstract/2007/12000/optimizing_squat_technique.1.aspx

35. Comfort, P., McMahon, J. J., & Suchomel, T. J. (2018). Optimizing Squat Technique-Revisited. *Strength and Conditioning Journal, 40*(6), 68–74. https://doi.org/10.1519/SSC.0000000000000398

36. Contreras, B. (2014). *Posilování na anatomických základech*. Grada.

37. Contreras, B., & Schoenfeld, B. (2011). To Crunch or Not to Crunch: An Evidence-Based Examination of Spinal Flexion Exercises, Their Potential Risks, and Their Applicability to Program Design. *Strength and Conditioning Journal, 33*(4), 8–18. https://doi.org/10.1519/SSC.0b013e3182259d05

38. Contreras, B., Vigotsky, A. D., Schoenfeld, B. J., Beardsley, C., & Cronin, J. (2016). A Comparison of Gluteus Maximus, Biceps Femoris, and Vastus Lateralis Electromyography Amplitude in the Parallel, Full, and Front Squat Variations in Resistance-Trained Females. *Journal of Applied Biomechanics, 32*(1), 16–22. https://doi.org/10.1123/jab.2015-0113

39. Čápová, J. (2016). *Od posturální ontogeneze k terapeutickému konceptu*. Repronis.

40. Čihák, R. (2011). *Anatomie 1* (třetí, upravené a doplněné vydání). Grada.

41. Dewberry, M. J., Bohannon, R. W., Tiberio, D., Murray, R., & Zannotti, C. M. (2003). Pelvic and femoral contributions to bilateral hip flexion by subjects suspended from a bar. *Clinical Biomechanics, 18*(6), 494–499. https://doi.org/10.1016/S0268-0033(03)00096-2

42. Diamond-Walker, N. (2019). *501 nejlepších posilovacích cviků*. Euromedia.

43. Doll, M. (2024). *Cvičení s vlastní vahou bez nářadí: 50 tréninkových sestav*. Grada Publishing.

44. Dylevský, I. (2021). *Klinická kineziologie a patokineziologie*. Grada Publishing.

45. Ebrahimi, H., Balouchi, R., Eslami, R., & Shahrokhi, M. (2015). The effect of 8 weeks of core stabilization exercises on disability, abdominal and back muscle strength in patients with chronic low back pain due to disc herniation. *Journal of Practical Studies of Biosciences in Sport, 2*(4), 9–20. https://doi.org/10.22077/jpsbs.2014.18

46. Edington, C. P. (2017). *Lumbar spine kinematics and kinetics during heavy barbell squat and deadlift variations* [Diplomová práce]. University of Saskatchewan.

47. Elborady, A. A., Saleh, O. E., & Abdallah, A. A. A. (2023). Effect of a 6-week core stability training program on active trunk repositioning: a randomised controlled trial. *Physiotherapy Quarterly, 31*(4), 1–6. https://doi.org/10.5114/pq.2023.117222

48. Eliška, O. (2023). *Aplikovaná anatomie pro fyzioterapeuty, maséry a příbuzné obory* (Druhé, přepracované a rozšířené vydání). Galén.

49. Endo, Y., Miura, M., & Sakamoto, M. (2020). The relationship between the deep squat movement and the hip, knee and ankle range of motion and muscle strength. *Journal of Physical Therapy Science, 32*(6), 391–394. https://doi.org/10.1589/jpts.32.391

50. English, N. (2023, August 1). *When Butt Wink Is a Problem (And When It Isn't)*. BarBend. Retrieved November 13, 2024, https://barbend.com/butt-wink-aaron-horschig-squat-university/

51. Erman, B., Vural, F., Dopsaj, M., Ozkol, M. Z., Kose, D. E., Aksit, T., & Cè, E. (2023). The effects of fatigue on linear and angular kinematics during bilateral squat. *PLOS ONE, 18*(11), 1–20. https://doi.org/10.1371/journal.pone.0289089

52. Escamilla, R. F., Fleisig, G. S., Lowry, T. M., Barrentine, S. W., & Andrews, J. R. (2001). A three-dimensional biomechanical analysis of the squat during varying stance widths. *Medicine and Science in Sports and Exercise, 33*(6), 984–998. https://doi.org/10.1097/00005768-200106000-00019

53. Falk, J., Aasa, U., & Berglund, L. (2021). How accurate are visual assessments by physical therapists of lumbo-pelvic movements during the squat and deadlift? *Physical Therapy in Sport, 50*, 195–200. https://doi.org/10.1016/j.ptsp.2021.05.011

54. Filipczyk, P., Filipczyk, K., & Saulicz, E. (2021). Influence of Stabilization Techniques Used in the Treatment of Low Back Pain on the Level of Kinesiophobia. *International Journal of Environmental Research and Public Health, 18*(12), 1–13. https://doi.org/10.3390/ijerph18126393

55. Fry, A. C., Smith, C. J., & Schilling, B. K. (2003). Effect of Knee Position on Hip and Knee Torques During the Barbell Squat. *Journal of Strength and Conditioning*

Research, 17(4), 629–633. https://journals.lww.com/nsca-jscr/abstract/2003/11000/effect_of_knee_position_on_hip_and_knee_torques.1.aspx

56. Gandbhir, V. N., & Cunha, B. (2020, June 7). *Goniometer*. StatPearls - NCBI Bookshelf. https://www.ncbi.nlm.nih.gov/books/NBK558985/

57. Gandolfi, M., Tinazzi, M., Magrinelli, F., Busselli, G., Dimitrova, E., Polo, N., Manganotti, P., Fasano, A., Smania, N., & Geroin, C. (2019). Four-week trunk-specific exercise program decreases forward trunk flexion in Parkinson's disease: A single-blinded, randomized controlled trial. *Parkinsonism & Related Disorders, 64*, 268–274. https://doi.org/10.1016/j.parkreldis.2019.05.006

58. Garcia-Fernandez, A., & Petros, P. E. (2020). A four month squatting-based pelvic exercise regime cures day/night enuresis and bowel dysfunction in children 7–11 years. *Central European Journal of Urology, 73*(3), 307–314. https://doi.org/10.5173/ceju.2020.0044

59. Glass, S. C., & Albert, R. W. (2018). Compensatory Muscle Activation During Unstable Overhead Squat Using a Water-filled Training Tube. *Journal of Strength and Conditioning Research, 32*(5), 1230–1237. https://doi.org/10.1519/JSC.0000000000002000

60. Glassbrook, D. J., Brown, S. R., Helms, E. R., Duncan, S., & Storey, A. G. (2019). The High-Bar and Low-Bar Back-Squats: A Biomechanical Analysis. *Journal of Strength and Conditioning Research, 33*, S1–S18. https://doi.org/10.1519/JSC.0000000000001836

61. Gluppe, S. B., Engh, M. E., & Bø, K. (2020). Immediate Effect of Abdominal and Pelvic Floor Muscle Exercises on Interrecti Distance in Women With Diastasis Recti Abdominis Who Were Parous. *Physical Therapy, 100*(8), 1372–1383. https://doi.org/10.1093/ptj/pzaa070

62. Gordon, R., & Bloxham, S. (2016). A Systematic Review of the Effects of Exercise and Physical Activity on Non-Specific Chronic Low Back Pain. *Healthcare, 4*(2), 1–19. https://doi.org/10.3390/healthcare4020022

63. Gorsuch, J., Long, J., Miller, K., Primeau, K., Rutledge, S., Sossong, A., & Durocher, J. J. (2013). The Effect of Squat Depth on Multiarticular Muscle Activation in Collegiate Cross-Country Runners. *Journal of Strength and*

Conditioning Research, 27(9), 2619–2625. https://doi.org/10.1519/JSC.0b013e31828055d5

64. Graham, J. (2009). Wall Squat With Stability Ball and Dumbbells. *Strength and Conditioning Journal, 31*(1), 48–49. https://doi.org/10.1519/SSC.0b013e318195a278

65. Grant, T. M., Saxby, D. J., Pizzolato, C., Savage, T., Bennell, K., Dickenson, E., Eyles, J., Foster, N., Hall, M., Hunter, D., Lloyd, D., Molnar, R., Murphy, N., O'Donnell, J., Singh, P., Spiers, L., Tran, P., & Diamond, L. E. (2024). Squatting biomechanics following physiotherapist-led care or hip arthroscopy for femoroacetabular impingement syndrome: a secondary analysis from a randomised controlled trial. *PeerJ, 12*, 1–23. https://doi.org/10.7717/peerj.17567

66. Greyling, M. (2013). *Pelvic biomechanics and muscle activation patterns during non-weighted squats in U/19 university-level rugby union players* [Diplomová práce]. Nort-West University.

67. Gross, J. M., Fetto, J., & Rosen, E. (2023). *Vyšetření pohybového aparátu* (4. vydání). Stanislav Juhaňák – Triton.

68. Gullett, J. C., Tillman, M. D., Gutierrez, G. M., & Chow, J. W. (2009). A Biomechanical Comparison of Back and Front Squats in Healthy Trained Individuals. *Journal of Strength and Conditioning Research, 23*(1), 284-292. https://doi.org/10.1519/JSC.0b013e31818546bb

69. Gúth, A. (2020). *Bolesť a škola chrbtice* (6. vydání). Liečreh.

70. Hagovská, M., Kolcunova, P., Mihalečková, N., Bérešová, A., & Repková, Z. (2016). *Praktická kinezioterapia: Vysokoškolská učebnica*. Univerzita Pavla Jozefa Šafárika.

71. Haladová, E., & Nechvátalová, L. (2010). *Vyšetřovací metody hybného systému* (3. vydání). Národní centrum ošetřovatelství a nelékařských zdravotnických oborů.

72. Hamlyn, N., Behm, D. G., & Young, W. B. (2007). Trunk Muscle Activation During Dynamic Weight-Training Exercises and Isometric Instability Activities. *The Journal of Strength and Conditioning Research, 21*(4), 1108–1112. https://doi.org/10.1519/R-20366.1

73. Hara, D., Nakashima, Y., Hamai, S., Higaki, H., Ikebe, S., Shimoto, T., Hirata, M., Kanazawa, M., Kohno, Y., & Iwamoto, Y. (2014). Kinematic Analysis of Healthy Hips during Weight-Bearing Activities by 3D-to-2D Model-to-Image Registration Technique. *BioMed Research International, 2014*, 1–8. https://doi.org/10.1155/2014/457573

74. Harada, S., Hamai, S., Gondo, H., Higaki, H., Ikebe, S., & Nakashima, Y. (2022). Squatting After Total Hip Arthroplasty: Patient-Reported Outcomes and In Vivo Three-Dimensional Kinematic Study. *The Journal of Arthroplasty, 37*(4), 734–741. https://doi.org/10.1016/j.arth.2021.12.028

75. Hardcastle, P., & Nade, S. (1985). The significance of the Trendelenburg test. *The Journal of Bone and Joint Surgery. British volume, 67-B*(5), 741–746. https://doi.org/10.1302/0301-620X.67B5.4055873

76. Hartmann, H., Wirth, K., & Klusemann, M. (2013). Analysis of the Load on the Knee Joint and Vertebral Column with Changes in Squatting Depth and Weight Load. *Sports Medicine, 43*(10), 993–1008. https://doi.org/10.1007/s40279-013-0073-6

77. Havel, Z., Hnízdil, J., Černá, L., Horkel, V., Horklová, H., Kresta, J., Louka, O., Nosek, M., Škopek, M., Valter, L., Vaněčková, J., & Žák, M. (2009). *Rozvoj a diagnostika silových schopností*. Univerzita J. E. Purkyně v Ústí nad Labem.

78. Havel, Z., Černá, L., Horkel, V., Horklová, H., Kresta, J., Louka, O., Nosek, M., Škopek, M., Valter, L., & Žák, M. (2010a). *Rozvoj a diagnostika koordinačních a pohyblivostních schopností*. Univerzita Mateja Bela, Pedagogická fakulta v Banskej Bystrici.

79. Havel, Z., Hnízdil, J., Horekl, V., Horklová, H., Kresta, J., Lednický, A., Novotný, F., Valter, L., Vaněčková, J., & Žák, M. (2010b). *Rozvoj a diagnostika rychlostních schopností*. Univerzita J. E. Purkyně v Ústí nad Labem.

80. Hayashi, S., Katsuhira, J., Matsudaira, K., & Maruyama, H. (2016). Effect of pelvic forward tilt on low back compressive and shear forces during a manual lifting task. *Journal of Physical Therapy Science, 28*(3), 802–806. https://doi.org/10.1589/jpts.28.802

81. Hebling Campos, M., Furtado Alaman, L. I., Seffrin-Neto, A. A., Vieira, C. A., Costa De Paula, M., & Barbosa de Lira, C. A. (2017). The geometric curvature of the lumbar spine during restricted and unrestricted squats. *The Journal of Sports Medicine and Physical Fitness, 57*(6). https://doi.org/10.23736/S0022-4707.16.06184-3

82. Hellbrügge, T., Šoltés, L., Archalousová, A., & Ilenčíková, D. (2010). *Prvních 365 dní v životě dítěte: psychomotorický vývoj kojence*. Grada.

83. Henoch, Q. (2014, February 6). *The Bottom Position of Your Squat: A Defining Characteristic of Your Human Existence*. Juggernaut Training Systems. Retrieved November 13, 2024, https://www.jtsstrength.com/bottom-position-squat-defining-characteristic-human-existence/

84. Hey, H. W. D., Lau, E. T.-C., Tan, K.-A., Lim, J. L., Choong, D., Lau, L.-L., Liu, K.-P. G., & Wong, H.-K. (2017). Lumbar Spine Alignment in Six Common Postures: An ROM Analysis With Implications for Deformity Correction. *Spine, 42*(19), 1447–1455. https://doi.org/10.1097/BRS.0000000000002131

85. Hirono, T., Kunugi, S., Yoshimura, A., Ueda, S., Goto, R., Akatsu, H., & Watanabe, K. (2023). Effects of home-based bodyweight squat training on neuromuscular properties in community-dwelling older adults. *Aging Clinical and Experimental Research, 35*(5), 1043–1053. https://doi.org/10.1007/s40520-023-02370-6

86. Hlavenka, T. M., Christner, V. F. K., & Gregory, D. E. (2017). Neck posture during lifting and its effect on trunk muscle activation and lumbar spine posture. *Applied Ergonomics, 62*, 28–33. https://doi.org/10.1016/j.apergo.2017.02.006

87. Hoogenboom, B. J., May, C. J., Alderink, G. J., Thompson, B. S., & Gilmore, L. A. (2023). Three-Dimensional Kinematics and Kinetics of the Overhead Deep Squat in Healthy Adults: A Descriptive Study. *Applied Sciences, 13*(12), 1–17. https://doi.org/10.3390/app13127285

88. Horschig, A. (2015, November 5). *How to screen for ankle mobility*. Squat University. Retrieved December 1, 2024, https://squatuniversity.com/2015/11/05/the-squat-fix-ankle-mobility-pt-1/

89. Horschig, A., Sonthana, K., & Neff, T. (2022). *Bible dřepu: Průvodce zvládnutím techniky dřepu a přirozeného pohybu*. Grada Publishing.

90. Huang, T.-Z., & Kim, S.-Y. (2022). Immediate effect of trunk flexion and extension isometric exercise using an external compression device on electromyography of the hip extensor and trunk range of motion of healthy subjects. BMC Sports Science, *Medicine and Rehabilitation, 14*(1), 1–10. https://doi.org/10.1186/s13102-022-00506-1

91. Hwang, Y.-I., & Park, D.-J. (2018). Comparison of lumbar multifidus thickness and perceived exertion during graded superman exercises with or without an abdominal drawing-in maneuver in young adults. *Journal of Exercise Rehabilitation, 14*(4), 628–632. https://doi.org/10.12965/jer.1836296.148

92. Ikezoe, T., Kobayashi, T., Nakamura, M., & Ichihashi, N. (2020). Effects of Low-Load, Higher-Repetition vs. High-Load, Lower-Repetition Resistance Training Not Performed to Failure on Muscle Strength, Mass, and Echo Intensity in Healthy Young Men: A Time-Course Study. *Journal of Strength and Conditioning Research, 34*(12), 3439–3445. https://doi.org/10.1519/JSC.0000000000002278

93. Imai, A., Kaneoka, K., Okubo, Y., & Shiraki, H. (2016). Immediate Effects of Different Trunk Exercise Programs on Jump Performance. *International Journal of Sports Medicine, 37*(03), 197–201. https://doi.org/10.1055/s-0035-1559714

94. Ishida, T., Samukawa, M., Kasahara, S., & Tohyama, H. (2022). The center of pressure position in combination with ankle dorsiflexion and trunk flexion is useful in predicting the contribution of the knee extensor moment during double-leg squatting. *BMC Sports Science, Medicine and Rehabilitation, 14*(127), 1–8. https://doi.org/10.1186/s13102-022-00523-0

95. Janda, V. (1984). *Základy kliniky funkčních (neparetických) hybných poruch*. Ústav pro další vzdělávání středních zdravotnických pracovníků.

96. Janda, V., Herbenová, A., Jandová, J., & Pavlů, D. (2004). *Svalové funkční testy*. Grada.

97. Jarkovská, H., & Jarkovská, M. (2016). *Posilování s vlastním tělem: 494krát jinak* (druhé, rozšířené vydání). Grada Publishing.

98. Jebavý, R., & Zumr, T. (2014). *Posilování s balančními pomůckami* (druhé, doplněné vydání). Grada.

99. Jedličková, J. (2019). *Ošetření svaloviny pánevního dna metodou L. Mojžíšové*. www.kurzmojzisova.cz.

100. Jesenická, R. (2018). *Komplexní kineziologický rozbor: Funkční poruchy pohybového systému*. Grada Publishing.

101. Johansson, D. G., Marchetti, P. H., Stecyk, S. D., & Flanagan, S. P. (2024). A Biomechanical Comparison Between the Safety-Squat Bar and Traditional Barbell Back Squat. *Journal of Strength and Conditioning Research, 38*(5), 825–834. https://doi.org/10.1519/JSC.0000000000004719

102. Kačírková, M., & Rybová, Z. (2022). *Pohybový vývoj dítěte s láskou a respektem: Fyzioterapeutky dětem*. Euromedia Group.

103. Kadono, N., Tsuchiya, K., Uematsu, A., Kamoshita, H., Kiryu, K., Hortobágyi, T., & Suzuki, S. (2017). A Japanese Stretching Intervention Can Modify Lumbar Lordosis Curvature. *Clinical Spine Surgery: A Spine Publication, 30*(7), 297–300. https://doi.org/10.1097/BSD.0000000000000247

104. Kališko, O., & Ježková, A. (2019). *Metody kinezioterapie I: učební text*. Univerzita J.E. Purkyně v Ústí nad Labem, Fakulta zdravotnických studií.

105. Kaminoff, L., & Matthews, A. (2024). *Jóga – anatomie: Váš ilustrovaný průvodce pozicemi, pohyby a dýchacími technikami* (3. vydání). Cpress.

106. Kapandji, A. I. (2019a). *The Physiology of the Joints: 2. The Lower Limb* (7th edition). Handspring Publishing.

107. Kapandji, A. I. (2019b). *The Physiology of the Joints: 3. The Spinal Column, Pelvic Girdle and Head* (7th edition). Handspring Publishing.

108. Kelly, C. F., Gonzalez, A. M., Spitz, R. W., Sell, K. M., & Ghigiarelli, J. J. (2018). Effect of Hip Abduction Maximal Voluntary Isometric Contraction on Lumbar Motion and Power Output During the Back Squat. *International Journal of Kinesiology and Sports Science, 6*(1), 1–6. https://doi.org/10.7575/aiac.ijkss.v.6n.1p.1

109. Kim, S.-H., Kwon, O.-Y., Park, K.-N., Jeon, I.-C., & Weon, J.-H. (2015). Lower Extremity Strength and the Range of Motion in Relation to Squat Depth. *Journal of Human Kinetics, 45*(1), 59–69. https://doi.org/10.1515/hukin-2015-0007

110. Kobayashi, N., Higashihira, S., Kitayama, H., Kamono, E., Yukizawa, Y., Oishi, T., Takagawa, S., Honda, H., Choe, H., & Inaba, Y. (2021). Effect of Decreasing the Anterior Pelvic Tilt on Range of Motion in Femoroacetabular Impingement: A Computer-Simulation Study. *Orthopaedic Journal of Sports Medicine, 9*(4). https://doi.org/10.1177/2325967121999464

111. Kolář, P., Bitnar, P., Horáček, O., Dyrhonová, O., & Kříž, J. (2020). *Rehabilitace v klinické praxi* (druhé vydání). Galén.

112. Kolber, M. J., Feldstein, A. P., Masaracchio, M., Liu, X., & Hanney, W. J. (2018). Influence of Femoral Acetabular Impingement on Squat Performance. *Strength and Conditioning Journal, 40*(2), 47–53. https://doi.org/10.1519/SSC.0000000000000370

113. Komiyama, K., Hamai, S., Hara, D., Ikebe, S., Higaki, H., Yoshimoto, K., Shiomoto, K., Gondo, H., Wang, Y., & Nakashima, Y. (2018). Dynamic hip kinematics during squatting before and after total hip arthroplasty. *Journal of Orthopaedic Surgery and Research, 13*(1), 1–7. https://doi.org/10.1186/s13018-018-0873-3

114. Kongkamol, C., Charoenporn, N., Sungkhapong, A., & Kooncumchoo, P. (2020). Risks of low back pain in four different lumbopelvic movement patterns during two person-lifting in freestyle and recommended lifting method. *Songklanakarin Journal of Science and Technology, 42*(6), 1272–1278. https://doi.org/10.14456/sjst-psu.2020.165

115. Král, J. (2017). *Fitness s Evou Samkovou: účinnost cviků podle EMG*. Grada Publishing.

116. Krčová, D. (2019). *Sportovní výživa na míru*. Erasport.

117. Krucký, V. (2017). *Vojtova metodika 2. generace: s videokompendiem* (2. vydání). SVR – společnost pro vývojovou rehabilitaci.

118. Kushner, A. M., Brent, J. L., Schoenfeld, B. J., Hugentobler, J., Lloyd, R. S., Vermeil, A., Chu, D. A., Harbin, J., McGill, S. M., & Myer, G. D. (2015). The Back Squat: Targeted Training Techniques to Correct Functional Deficits and Technical Factors That Limit Performance. *Strength and Conditioning Journal, 37*(2), 13–60. https://doi.org/10.1519/SSC.0000000000000130

119. Laslett, M. (2008). Evidence-Based Diagnosis and Treatment of the Painful Sacroiliac Joint. *Archives of Physical Medicine and Rehabilitation, 16*(3), 142–152. https://doi.org/10.1179/jmt.2008.16.3.142

120. Lau, M. (2022, September 7). *Pelvic Tilt and Squats: Butt Winking and Posterior Pelvic Tilt*. [P]rehab. Retrieved November 13, 2024, https://theprehabguys.com/pelvic-tilt-and-squat-depth/

121. Le Huec, J. C., & Hasegawa, K. (2016). Normative values for the spine shape parameters using 3D standing analysis from a database of 268 asymptomatic Caucasian and Japanese subjects. *European Spine Journal, 25*(11), 3630–3637. https://doi.org/10.1007/s00586-016-4485-5

122. Lee, B., & McGill, S. (2016). The effect of short-term isometric training on core/torso stiffness. *Journal of Sports Sciences, 35*(17), 1724–1733. https://doi.org/10.1080/02640414.2016.1235791

123. Levitová, A., & Hošková, B. (2015). *Zdravotně-kompenzační cvičení*. Grada Publishing.

124. Lewit, K. (2024). *Manipulační léčba* (6. upravené vydání). Euromedia.

125. Li, X., Zhang, H., Lo, W. L. A., Ge, L., Miao, P., Liu, H., Li, L., & Wang, C. (2022). Sling Exercise Can Drive Cortical Representation of the Transversus Abdominis and Multifidus Muscles in Patients With Chronic Low Back Pain. *Frontiers in Neurology, 13*, 1–11. https://doi.org/10.3389/fneur.2022.904002

126. Liebenson, C. (2019). *Rehabilitation of the Spine: A Patient-Centered Approach* (third edition). Wolters Kluwer.

127. List, R., Gülay, T., Stoop, M., & Lorenzetti, S. (2013). Kinematics of the Trunk and the Lower Extremities During Restricted and Unrestricted Squats. *Journal of Strength and Conditioning Research, 27*(6), 1529–1538. https://doi.org/10.1519/JSC.0b013e3182736034

128. Lorenzetti, S., Ostermann, M., Zeidler, F., Zimmer, P., Jentsch, L., List, R., Taylor, W. R., & Schellenberg, F. (2018). How to squat? Effects of various stance widths, foot placement angles and level of experience on knee, hip and trunk motion

and loading. *BMC Sports Science, Medicine and Rehabilitation, 10*(1). https://doi.org/10.1186/s13102-018-0103-7

129. Lui, T. K. S., Tsang, S. M. H., & Kwok, A. W. L. (2018). Changes in Lumbopelvic Movement and Muscle Recruitment Associated with Prolonged Deep Squatting: A Pilot Study. *International Journal of Environmental Research and Public Health, 15*(5). https://doi.org/10.3390/ijerph15051001

130. Luomajoki, H., Kool, J., de Bruin, E. D., & Airaksinen, O. (2008). Movement control tests of the low back; evaluation of the difference between patients with low back pain and healthy controls. *BMC Musculoskeletal Disorders, 9*(170), 1–12. https://doi.org/10.1186/1471-2474-9-170

131. Lynn, S. K., & Noffal, G. J. (2012). Lower Extremity Biomechanics During a Regular and Counterbalanced Squat. *Journal of Strength and Conditioning Research, 26*(9), 2417–2425. https://doi.org/10.1519/JSC.0b013e31823f8c2d

132. Maclachlan, L., White, S. G., & Reid, D. (2015). OBSERVER RATING VERSUS THREE-DIMENSIONAL MOTION ANALYSIS OF LOWER EXTREMITY KINEMATICS DURING FUNCTIONAL SCREENING TESTS: A SYSTEMATIC REVIEW. *International Journal of Sports Physical Therapy, 10*(4), 482–492. https://pmc.ncbi.nlm.nih.gov/articles/PMC4527195/

133. Mahaffey, K. (2021, August 27). *What is Pelvic Tilt & How Do You Fix it?* National Academy of Sports Medicine. Retrieved November 17, 2024, https://blog.nasm.org/what-is-pelvic-tilt-how-do-you-fix-it

134. Malanga, G. A., & Mautner, K. (2017). *Musculoskeletal Physical Examination: An Evidence-Based Approach* (second edition). Elsevier.

135. Mang, Z., Kravitz, L., & Beam, J. (2022). Transfer Between Lifts: Increased Strength in Untrained Exercises. *Strength and Conditioning Journal, 44*(3), 101–106. https://doi.org/10.1519/SSC.0000000000000667

136. Mansfield, P. J., & Neumann, D. A. (2024). *Essentials of Kinesiology: for the Physical Therapist Assistant* (fourth edition). Elsevier.

137. Marek, J., Benešová, J., Lahuňáková, M., Kačinetzová, A., Kolářová, M., Kračmarová, K., Ryšavá, H., Tichý, M., & Ťupa, F. (2005). *Syndrom kostrče a pánevního dna* (vydání 2.). Triton.

138. Marchetti, P. H., Fioravante, G. Z., Jarbas da Silva, J., Gomes, W. A., Soares, E. G., Pecoraro, S. L., Sisconeto de Freitas, F., Magalhes, R. A., Senaga Miyatake, M. M., & Brown, L. E. (2017). Effects of Squat Amplitude on pelvic tilt and Tibial Inclination. *MOJ Sports Medicine, 1*(1), 6–7. https://doi.org/10.15406/mojsm.2017.01.00002

139. Martínez-Mesa, J., González-Chica, D. A., Duquia, R. P., Bonamigo, R. R., & Bastos, J. L. (2016). Sampling: how to select participants in my research study? *Anais Brasileiros de Dermatologia, 91*(3), 326–330. https://doi.org/10.1590/abd1806-4841.20165254

140. Masi, M. (2020). *Hack Your Squat: Learn how to identify fundamental flaws in the back squat and fix them so you and your clients can get back to safely training and performing at maximum potential!*.

141. Mata, A. J., Hayashi, H., Moreno, P. A., Dudley, R. I., & Sorenson, E. A. (2021). Hip Flexion Angles During Supine Range of Motion and Bodyweight Squats. *International Journal of Exercise Science, 14*(1), 912–918. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8439674/

142. McGill, S. (2021). *Mechanika zad: Tajemství zdravé páteře, jež vám váš lékař zatajil. Návod, jak se zbavit bolesti zad pomocí McGillovy metody* (vydání třetí). Mladá fronta.

143. McKean, M. R., Dunn, P. K., & J. Burkett, B. (2010). The Lumbar and Sacrum Movement Pattern During the Back Squat Exercise. *Journal of Strength and Conditioning Research, 24*(10), 2731–2741. https://doi.org/10.1519/JSC.0b013e3181e2e166

144. Miyachi, R., Deguchi, M., Nishi, Y., Yonekura, S., & Hara, J. (2021). Relationship between iliopsoas muscle thickness and hip angle during squats in different pelvic positions. *Journal of Physical Therapy Science, 33*(4), 351–355. https://doi.org/10.1589/jpts.33.351

145. Moon, M. S., Kim, S. T., Shin, S., & Jeon, S. M. (2021). SQUAT POSTURE AND SPINOPELVIC PARAMETERS — RADIOGRAPHIC ASSESSMENT. *Journal of Musculoskeletal Research, 24*(03), 1–6. https://doi.org/10.1142/S0218957721500019

146. Mun, D.-J., Oh, H.-J., & Lee, S.-H. (2022). Effects of Sling Exercise on Pain, Trunk Strength, and Balance in Patients with Chronic Low Back Pain. *The Journal of Korean Physical Therapy, 34*(3), 110–115. https://doi.org/10.18857/jkpt.2022.34.3.110

147. Murchison, A. (2024). *30denní plán na posílení středu těla: Core trénink*. Grada.

148. Murray, R., Bohannon, R., Tiberio, D., Dewberry, M., & Zannotti, C. (2002). Pelvifemoral rhythm during unilateral hip flexion in standing. *Clinical Biomechanics, 17*(2), 147–151. https://doi.org/10.1016/S0268-0033(01)00115-2

149. Muscolino, J. E. (2023). *Kinesiology: The Skeletal System and Muscle Function* (4th edition). Elsevier.

150. Myer, G. D., Kushner, A. M., Brent, J. L., Schoenfeld, B. J., Hugentobler, J., Lloyd, R. S., Vermeil, A., Chu, D. A., Harbin, J., & McGill, S. M. (2014). The Back Squat: A Proposed Assessment of Functional Deficits and Technical Factors That Limit Performance. *Strength and Conditioning Journal, 36*(6), 4–27. https://doi.org/10.1519/SSC.0000000000000103

151. Naqvi, U., & Sherman, A. L. (2023, August 28). *Muscle Strength Grading*. StatPearls - NCBI Bookshelf. https://www.ncbi.nlm.nih.gov/books/NBK436008/

152. Nelson, A. G., & Kokkonen, J. (2023). *Strečink na anatomických základech* (třetí, doplněné vydání). Grada Publishing.

153. Nielsen, S. R. (2015). *Posterior Pelvic Tilt in Barbell Back Squats: A Biomechanical Analysis* [Diplomová práce]. Norwegian School of Sport Sciences.

154. Nuzzo, J. L., McCaulley, G. O., Cormie, P., Cavill, M. J., & McBride, J. M. (2008). Trunk Muscle Activity During Stability Ball and Free Weight Exercises. *Journal of Strength and Conditioning Research, 22*(1), 95–102. https://doi.org/10.1519/JSC.0b013e31815ef8cd

155. O'Reilly, M. A., Whelan, D. F., Ward, T. E., Delahunt, E., & Caulfield, B. M. (2017). Technology in Strength and Conditioning: Assessing Bodyweight Squat Technique With Wearable Sensors. *Journal of Strength and Conditioning Research, 31*(8), 2303–2312. https://doi.org/10.1519/JSC.0000000000001957

156. Oshikawa, T., Morimoto, Y., & Kaneoka, K. (2018). Lumbar lordosis angle and trunk and lower-limb electromyographic activity comparison in hip neutral position and external rotation during back squats. *Journal of Physical Therapy Science, 30*(3), 434–438. https://doi.org/10.1589/jpts.30.434

157. Oshikawa, T., Takaki, N., Morimoto, Y., Akuzawa, H., & Kaneoka, K. (2021). Front Squat Increases Lumbar Lordosis Compared to Back Squat without Changing Lower Limb and Trunk Muscles Activity at the Same Absolute Barbell Weight. *International Journal of Sport and Health Science, 19*, 39–46. https://doi.org/10.5432/ijshs.202020

158. Palaščáková Špringrová, I. (2024). *Akrální koaktivační diagnostika a terapie* (čtvrté, rozšířené vydání). ACT centrum.

159. Pastucha, D., Botek, M., Cipryan, L., Febbi, M., Gallo, J., Hyjánek, J., Jelínek, L., Konečný, P., Neuls, F., Přidalová, M., Pudil, R., Skalská, M., Sovová, E., Sovová, M., Střítecká, H., Šafář, M., & Turčan, P. (2024). *Tělovýchovné lékařství* (2., přepracované a aktualizované vydání). Grada.

160. Paulsen, F., & Waschke, J. (2018). *Sobotta Atlas of Anatomy: General Anatomy and Musculoskeletal System* (16. ed.). Elsevier.

161. Pavlova, A. V., Cooper, K., Meakin, J. R., Barr, R. J., & Aspden, R. (2016). Internal lumbar spine motion during lifting. *Orthopaedic Proceedings, 98-B*(Supp. 6), 19–19. https://doi.org/10.1302/1358-992X.98BSUPP_6.SBPR2015-019

162. Pavlova, A. V., Meakin, J. R., Cooper, K., & Aspden, R. J. (2014). Intrinsic shape of the lumbar spine and its effect on lifting manoeuvres. *Orthopaedic Proceedings, 96-B*(Supp. 4), 17–17. https://doi.org/10.1302/1358-992X.96BSUPP_4.SBPR2013-017

163. Pavluch, L., & Frolíková, K. (2004). *Osobní trenér: Cvičíme ve fitness centru*. Grada.

164. Peterson, D. D. (2018). Periodic Fitness Testing: Not Just for Athletes Anymore. *Strength and Conditioning Journal, 40*(5), 60–76. https://doi.org/10.1519/SSC.0000000000000393

165. Petr, M., & Šťastný, P. (2012). *Funkční silový trénink*. Univerzita Karlova v Praze, Fakulta tělesné výchovy a sportu.

166. Phili, M. (2023, November 28). *How Anterior Pelvic Tilt Influences Your Squat Depth*. PrimalMobility. Retrieved November 13, 2024, from https://www.primalmobility.com/blog/how-anterior-pelvic-tilt-affects-squat-depth

167. Pilný, J., Calábová, N., Štichhauer, R., & Hájek, P. (2018). *Úrazy ve sportu a jak jim předcházet* (Druhé, rozšířené a doplněné vydání). Grada Publishing.

168. Pirola, V. (2024). *Handbook of Kinesiology: Functional anatomy, Biomechanics, Assessment of joints and muscles*. Edra Publishing.

169. Popowychová, K. (2023). *Cvičení pro dva: Společné cvičení pro lepší výsledky*. Grada.

170. Powden, C. J., Hoch, J. M., & Hoch, M. C. (2015). Reliability and minimal detectable change of the weight-bearing lunge test: A systematic review. *Manual Therapy, 20*(4), 524–532. https://doi.org/10.1016/j.math.2015.01.004

171. Rašev, E. (1992). *Škola zad*. Direkta.

172. Reichert, B. (2021). *Palpační techniky: Povrchová anatomie pro fyzioterapeuty*. Grada Publishing.

173. Ribeiro Neto, A., Ferreira Magalhães, L., Gotti Alves, R. R., Flor Bertolini, G. R., Moreira Lobato, D. F., & Bertoncello, D. (2023). Two-dimensional video analysis of the overhead squat: a preliminary study. *Retos, 50*, 50–56. https://doi.org/10.47197/retos.v50.99340

174. Rio, E., Kidgell, D., Purdam, C., Gaida, J., Moseley, G. L., Pearce, A. J., & Cook, J. (2015). Isometric exercise induces analgesia and reduces inhibition in patellar tendinopathy. *British Journal of Sports Medicine, 49*(19), 1277–1283. https://doi.org/10.1136/bjsports-2014-094386

175. Rippetoe, M. (2009). *The Squat, or How I Learned to Stop Leg-Pressing and Use My Ass*. https://startingstrength.com/articles/squat_rippetoe.pdf

176. Rippetoe, M. (2018, August 9). *"Butt Wink"*. StartingStrength. Retrieved November 13, 2024. https://startingstrength.com/training/butt-wink

177. Roubík, L. (2012). *Příprava na soutěž v kulturistice od A do Z*. Grafixon.

178. Rychlíková, E. (2016). *Manuální medicína: průvodce diagnostikou a léčbou vertebrogenních poruch* (5. rozšířené vydání). Maxdorf.

179. Rychlíková, E. (2019). *Funkční poruchy kloubů končetin: diagnostika a léčba* (2. doplněné vydání). Grada Publishing.

180. Rychlíková, E. (2021). *Orientační vyšetření páteře*. Maxdorf.

181. Saraceni, N., Campbell, A., Kent, P., Ng, L., Straker, L., & O'Sullivan, P. (2021). Exploring lumbar and lower limb kinematics and kinetics for evidence that lifting technique is associated with LBP. *PLOS ONE, 16*(7). https://doi.org/10.1371/journal.pone.0254241

182. Sedláková, S. (2023). *Záda, která cvičí, nebolí: Cvičíme podle Ludmily Mojžíšové* (vydání páté). Vyšehrad.

183. Serdar, C. C., Cihan, M., Yücel, D., & Serdar, M. A. (2021). Sample size, power and effect size revisited: simplified and practical approaches in pre-clinical, clinical and laboratory studies. *Biochemia medica, 31*(1), 27–53. https://doi.org/10.11613/BM.2021.010502

184. Shin, H.-H., Yoon, N.-Y., & Lee, J.-H. (2022). The Effects of Taping and Corrective Exercise Program on Spine and Pelvic Balance in University Students. *Annals of Applied Sport Science, 10*(3), 1–10. https://doi.org/10.52547/aassjournal.1053

185. Shumway-Cook, A., & Woollacott, M. (2000). Attentional demands and postural control: the effect of sensorycontext. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 55*(1), M10–M16. https://doi.org/10.1093/gerona/55.1.M10

186. Schlegel, P. (2024). *Hluboký stabilizační systém páteře a bolest zad*. Grada.

187. Schmidt, R. A., & Lee, T. D. (2011). *Motor control and learning: A behavioral emphasis* (5th Edition). Human Kinetics.

188. Schoenfeld, B. J. (2010). Squatting Kinematics and Kinetics and Their Application to Exercise Performance. *Journal of Strength and Conditioning Research, 24*(12), 3497–3506. https://doi.org/10.1519/JSC.0b013e3181bac2d7

189. Schwanbeck, S., Chilibeck, P. D., & Binsted, G. (2009). A Comparison of Free Weight Squat to Smith Machine Squat Using Electromyography. *Journal of Strength and Conditioning Research, 23*(9), 2588-2591. https://doi.org/10.1519/JSC.0b013e3181b1b181

190. Schwarzenegger, A., & Dobbins, B. (2018). *Encyklopedie moderní kulturistiky* (druhé, upravené a doplněné vydání). Beta.

191. Sikorová, L. (2009). *Cvičení a pohybové aktivity v těhotenství: Zdravý pohyb pro těhotné* (2. aktualizované vydání). Computer Press.

192. Sinclair, J., Brooks, D., & Atkins, S. (2017). An examination of the hamstring and the quadriceps muscle kinematics during the front and back squat in males. *Baltic Journal of Health and Physical Activity, 9*(1), 4, 37–45. https://doi.org/10.29359/BJHPA.09.1.04

193. Sint Jan, S. V. (2007). *Color atlas of skeletal landmark definitions: Guidelines for reproducible manual and virtual palpations*. Churchill Livingstone.

194. Smejkal, J. (2015). *Základy tréninku a sportovní výživy: Průvodce prvními 8 týdny v posilovně*. Erasport.

195. Snarr, R. L., & Esco, M. R. (2014). Electromyographical Comparison of Plank Variations Performed With and Without Instability Devices. *Journal of Strength and Conditioning Research, 28*(11), 3298–3305. https://doi.org/10.1519/JSC.0000000000000521

196. Snášel, M. (2017, September 19). *RETROVERZE PÁNVE/ BUTT WINK U DŘEPU – JAKÁ JE PŘÍČINA A JE TO NEBEZPEČNÉ?* CoreTraining.cz. Retrieved October 27, 2024. http://coretraining.cz/2017/09/retroverze-panve-butt-wink-u-drepu-jaka-je-pricina-a-je-to-nebezpecne/

197. Southwell, D. J., Petersen, S. A., Beach, T. A. C., & Graham, R. B. (2016). The effects of squatting footwear on three-dimensional lower limb and spine kinetics. *Journal of Electromyography and Kinesiology, 31*, 111–118. https://doi.org/10.1016/j.jelekin.2016.10.005

198. Stackeová, D. (2011). *Relaxační techniky ve sportu*. Grada.

199. Stackeová, D. (2014). *Fitness programy z pohledu kinantropologie* (třetí, doplněné a přepracované vydání). Galén.

200. Stackeová, D. (2018). *Cvičení na bolavá záda* (druhé, rozšířené a doplněné vydání). Grada Publishing.

201. Stackeová, D. (2023). *Jak porozumět bolestem zad: Psychosomatika z pohledu fyzioterapeuta*. CPress.

202. Stahl, C. A., Regni, G., Tanguay, J., McElfresh, M., Trihy, E., Diggin, D., & King, D. L. (2024). A Biomechanical Comparison of the Back Squat and Hexagonal Barbell Deadlift. *Journal of Strength and Conditioning Research, 38*(5), 815–824. https://doi.org/10.1519/JSC.0000000000004729

203. Standring, S. (2020). *Gray's Anatomy: The Anatomical Basis of Clinical Practice* (42nd edition). Elsevier.

204. Stoppani, J. (2016). V*elká kniha posilování: Tréninkové metody a plány. 381 posilovacích cviků* (druhé, přepracované a rozšířené vydání). Grada Publishing.

205. Straub, R. K., & Powers, C. M. (2024). A Biomechanical Review of the Squat Exercise: Implications for Clinical Practice. *International Journal of Sports Physical Therapy, 19*(4), 490–501. https://doi.org/10.26603/001c.94600

206. Striano, P. (2022). *Cvičení pro zdravá záda – anatomie: Aby záda nebolela, ilustrovaný praktický průvodce* (2. vydání). CPress.

207. Strusková, O., & Novotná, J. (2020). *Metoda Mojžíšové v praxi*. XYZ.

208. Stuchlá, L. (2024). *Přehled anatomie a fyziologie člověka: pro nelékařské zdravotnické obory*. Grada Publishing.

209. Styles, W. J., Matthews, M. J., & Comfort, P. (2016). Effects of Strength Training on Squat and Sprint Performance in Soccer Players. *Journal of Strength*

and Conditioning Research, 30(6), 1534–1539. https://doi.org/10.1519/JSC.0000000000001243

210. Sung, P. S. (2013). A compensation of angular displacements of the hip joints and lumbosacral spine between subjects with and without idiopathic low back pain during squatting. *Journal of Electromyography and Kinesiology, 23*(3), 741–745. https://doi.org/10.1016/j.jelekin.2013.02.003

211. Suresh, K., Thomas, S. V., & Suresh, G. (2011). Design, data analysis and sampling techniques for clinical research. *Annals of Indian Academy of Neurology, 14*(4), 1–4. https://doi.org/10.4103/0972-2327.91951

212. Swinton, P. A., Lloyd, R., Keogh, J. W. L., Agouris, I., & Stewart, A. D. (2012). A Biomechanical Comparison of the Traditional Squat, Powerlifting Squat, and Box Squat. *Journal of Strength and Conditioning Research, 26*(7), 1805–1816. https://doi.org/10.1519/JSC.0b013e3182577067

213. Švejcar, P., & Šťastný, M. (2013). *Moderní fyziotrénink*. Plot.

214. Tichý, M. (2014). *Dysfunkce kloubu: Podstata konceptu Funkční manuální medicíny* (druhé, přepracované a doplněné vydání). Miroslav Tichý.

215. Tichý, M. (2017). *Funkční diagnostika pohybového aparátu* (2. vydání). Stanislav Juhaňák – Triton.

216. Tlapák, P. (2022a). *Tvarování těla pro muže a ženy* (11. vydání). ARSCI.

217. Tlapák, P. (2022b). *Posilování kloubní kondice: Centračně-stabilizační cvičení* (2. vydání, dotisk). ARSCI.

218. Todoroff, M. (2017). Dynamic Deep Squat: Lower-Body Kinematics and Considerations Regarding Squat Technique, Load Position, and Heel Height. *Strength and Conditioning Journal, 39*(1), 71–80. https://doi.org/10.1519/SSC.0000000000000278

219. Usui, S., Maeo, S., Tayashiki, K., Nakatani, M., & Kanehisa, H. (2016). Low-load Slow Movement Squat Training Increases Muscle Size and Strength but Not Power. *International Journal of Sports Medicine, 37*(04), 305–312. https://doi.org/10.1055/s-0035-1564255

220. van der Wurff, P., Buijs, E. J., & Groen, G. J. (2006). A Multitest Regimen of Pain Provocation Tests as an Aid to Reduce Unnecessary Minimally Invasive Sacroiliac Joint Procedures. *Archives of Physical Medicine and Rehabilitation, 87*(1), 10–14. https://doi.org/10.1016/j.apmr.2005.09.023

221. Vančura, M. (2024). *Dysbalance v bojových sportech: Box, zápas, MMA – problémy, zranění, náprava*. Grada.

222. Vařeka, I., & Vařeková, R. (2009). *Kineziologie nohy*. Univerzita Palackého v Olomouci.

223. Vašíčková, L. (2024). *Sezení ve vozíku: zvýšení pohybového potenciálu a prevence komplikací*. Grada.

224. Vazirian, M., Van Dillen, L., & Bazrgari, B. (2016a). Lumbopelvic rhythm during trunk motion in the sagittal plane: A review of the kinematic measurement methods and characterization approaches. *Physical Therapy and Rehabilitation, 3*(1), 1–9. https://doi.org/10.7243/2055-2386-3-5

225. Vazirian, M., Van Dillen, L. R., & Bazrgari, B. (2016b). Lumbopelvic rhythm in the sagittal plane: A review of the effects of participants and task characteristics. *International Musculoskeletal Medicine, 38*(2), 51–58. https://doi.org/10.1080/17536146.2016.1241525

226. Véle, F. (2006). *Kineziologie: Přehled klinické kineziologie a patokineziologie pro diagnostiku a terapii poruch pohybové soustavy* (2. rozšířené a přepracované vydání). Triton.

227. Véle, F. (2012). *Vyšetření hybných funkcí z pohledu neurofyziologie: Příručka pro fyzioterapeuty pracující v neurorehabilitaci*. Triton.

228. Vigotsky, A. D., Bryanton, M. A., Nuckols, G., Beardsley, C., Contreras, B., Evans, J., & Schoenfeld, B. J. (2019). Biomechanical, Anthropometric, and Psychological Determinants of Barbell Back Squat Strength. *Journal of Strength and Conditioning Research, 33*(1), S26–S35. https://doi.org/10.1519/JSC.0000000000002535

229. Vilímová, V. (2009). *Didaktika tělesné výchovy* (2., přepracované vydání). Masarykova univerzita.

230. Vojta, V., & Peters, A. (2010). *Vojtův princip: svalové souhry v reflexní lokomoci a motorické ontogenezi* (překlad 3., zcela přepracovaného vydání). Grada.

231. Walsh, J. C., Quinlan, J. F., Stapleton, R., FitzPatrick, D. P., & McCormack, D. (2007). Three-dimensional Motion Analysis of the Lumbar Spine during "Free Squat" Weight Lift Training. *The American Journal of Sports Medicine, 35*(6), 927–932. https://doi.org/10.1177/0363546506298276

232. Weeks, B. K., Carty, C. P., & Horan, S. A. (2015). Effect of sex and fatigue on single leg squat kinematics in healthy young adults. *BMC Musculoskeletal Disorders, 16*(1). https://doi.org/10.1186/s12891-015-0739-3

233. Yanagisawa, O., Oshikawa, T., Adachi, G., Matsunaga, N., & Kaneoka, K. (2021). Acute effects of varying squat depths on lumbar intervertebral disks during high-load barbell back squat exercise. *Scandinavian Journal of Medicine & Science in Sports, 31*(2), 350–357. https://doi.org/10.1111/sms.13850

234. Yavuz, H. U., & Erdag, D. (2017). Kinematic and Electromyographic Activity Changes during Back Squat with Submaximal and Maximal Loading. *Applied Bionics and Biomechanics, 2017*, 1–8. https://doi.org/10.1155/2017/9084725

235. Yoo, W. G. (2016). Effect of the single-leg, lateral oblique, decline squat exercise on sacroiliac joint pain with knee pain. *Journal of Physical Therapy Science, 28*(9), 2688–2689. https://doi.org/10.1589/jpts.28.2688

236. Yoshiko, A., & Watanabe, K. (2021). Impact of home-based squat training with two-depths on lower limb muscle parameters and physical functional tests in older adults. *Scientific Reports, 11*(1), 1–10. https://doi.org/10.1038/s41598-021-86030-7

237. Yoshimoto, K., Hamai, S., Higaki, H., Gondo, H., Ikebe, S., & Nakashima, Y. (2018). Pre- and post-operative evaluation of pincer-type femoroacetabular impingement during squat using image-matching techniques: A case report. *International Journal of Surgery Case Reports, 42*(2018), 121–127. https://doi.org/10.1016/j.ijscr.2017.12.007

238. Zarei, H., & Norasteh, A. A. (2021). Effects of core stability training program on trunk muscle endurance in deaf children: A preliminary study. *Journal of Bodywork and Movement Therapies, 28*, 6–12. https://doi.org/10.1016/j.jbmt.2021.07.014

9 APPENDICES

9.1 LIST OF APPENDICES

Appendix A – Approval of the Ethics Committee of Faculty of Physical Education and Sport at Charles University in Prague

Appendix B – Approval of the Faculty of Health Studies at the Jan Evangelista Purkyně University in Ústí nad Labem

Appendix C – Informed consent template

Appendix D – Qualisys marker locations

Appendix E – Descriptive statistics of hip joint range of motion

Appendix F – Descriptive statistics of ankle joint range of motion

Appendix G – Frequency distribution of pelvic ligaments examination

Appendix H – Frequency distribution of muscle length assessment

Appendix I – Frequency distribution of muscle strength testing

Appendix J – Frequency distribution of deep stabilization system testing

APPENDIX A

UNIVERZITA KARLOVA
FAKULTA TĚLESNÉ VÝCHOVY A SPORTU
José Martího 31, 162 52 Praha 6-Veleslavín

Žádost o vyjádření Etické komise UK FTVS

k projektu výzkumné, kvalifikační či seminární práce zahrnující lidské účastníky

Název projektu: Retroverze pánve při dřepu, její objektivizace a možné řešení pomocí pohybové intervence

Forma projektu: doktorská

Období realizace: leden 2022 – červen 2023

Předkladatel: Mgr. Ondřej Kališko (UK FTVS Katedra fyziologie a biochemie)

Hlavní řešitel: Mgr. Ondřej Kališko (UK FTVS Katedra fyziologie a biochemie)

Místo výzkumu (pracoviště): Fakulta zdravotnických studií (FZS) Univerzity J. E. Purkyně (UJEP) v Ústí nad Labem, Katedra fyzioterapie a Laboratoř pro studium pohybu

Spoluřešitel(é):

Vedoucí práce (v případě studentské práce): James Tufano, Ph.D.

Finanční podpora: 1. část projektu – bude podána žádost GAUK; 2. a 3. část projektu je finančně podpořena: Interní grantová soutěž Fakulty zdravotnických studií Univerzity J. E. Purkyně v Ústí nad Labem, název projektu: Vliv fyzioterapie na výskyt retroverze pánve při provádění dřepu (číslo projektu: IG2019-72141-01-0025)

Popis projektu: Projekt se zabývá objektivizací specifického pohybu pánve (retroverze, v žargonu silového sportu tzv. butt wink) při provádění dřepu. Cílem projektu je tento pohyb pánve objektivizovat a pokusit se jej napravit pomocí pohybové intervence (zjišťován bude primárně okamžitý efekt intervence ale i efekt s odstupem 1, 2 a 3 týdnů). Projekt je rozdělen do tří částí.
První částí je online dotazníkové šetření, jehož cílem je zjistit názor odborné veřejnosti (fyzioterapeuti, osobní trenéři, učitelé tělesné výchovy, sportovci a studenti uvedených oborů) na tuto problematiku, resp. jestli výskyt tohoto specifického pohybu pánve považují za problém či nikoliv a jak jej řeší. Otázky nebudou zjišťovat žádná citlivá data.
Druhá část projektu je pilotní fáze, kde bude zjišťováno, u kolika procent lidí se tento pohyb pánve vyskytuje a při jakém zatížení se vyskytuje. Probandi budou v této části provádět dřepy, nejprve s vlastní vahou a poté s velkou činkou (váha činky 20 kg) kde bude postupně zvyšována zátěž až k 80 % maximální zátěže (1 RM). S každou úrovní zatížení provedou probandi 5 opakování dřepu s pauzou 120 sekund mezi jednotlivými úrovněmi. Zde poslouží pro sběr dat videozáznam (proband bude snímán z boku, aby byla viditelná stehna, trup a páteř) a 3D kinematická analýza.
Do hlavní části výzkumu pak bude zařazeno minimálně 10 probandů, u kterých se vyskytne retroverze již při nízkém zatížení (dřep s vlastní vahou, zátěž odpovídající 20 % 1 RM a zátěž odpovídající 40 % 1 RM). Výběr probandů provede řešitel projektu na základě toho, kdy se u nich objeví retroverze pánve (viz výše). Tito probandi budou dále vyšetřeni na možné příčiny retroverze – palpační vyšetření pánve (zjištění polohy spina iliaca anterior superior, spina iliaca posterior superior a crista iliaca), vyšetření zkrácených struktur dle Jandy, změření rozsahu pohybu v hlezenním a kyčelním kloubu pomocí goniometru, provedení Neurac testu v závěsném systému Redcord pro pánev, kyčelní a kolenní kloub (Neurac test testuje sílu svalů v uzavřeném kinematickém řetězci). Podle výsledku vyšetření bude každému probandovi stanovena individuální terapie (využity budou např. tyto metody: Neurac, strečink, mobilizace kloubů, postizometrická relaxace svalů) s cílem zjištění okamžitého účinku této terapie (ale i efektu s odstupem 1, 2 a 3 týdnů) na výskyt retroverze pánve – proband bude opět provádět dřepy s výše uvedeným zatížením a pro sběr dat opět poslouží videozáznam a 3D kinematická analýza. Všechny metody sběru dat jsou neinvazivní, vyžadují však spolupráci probanda. Ve výsledku se pak bude jednat spíše o kvalitativní výzkum s daným množstvím případových studií.
2. a 3. část výzkumu byla schválena EK FZS v rámci projektu: IG2019-72141-01-0025. Při výzkumu se budu řídit oběma žádostmi.

Charakteristika účastníků výzkumu:
Předpokládaný počet účastníků pro dotazníkové šetření: 100 (dotazník bude zveřejněn na webových stránkách FZS UJEP a dotazník bude také odeslán na emaily studentů. Řešitel nebude mít emailové adresy k dispozici, dotazník bude odeslán jako „Info" email přes Centrum informatiky UJEP)
Předpokládaný počet účastníků do pilotní fáze projektu: 50, věkové rozmezí: 18-40 let (probandi budou rekrutováni z řad studentů FZS UJEP)
Předpokládaný počet účastníků do 3. fáze výzkumu: minimálně 10 (maximálně 20), věkové rozmezí: 18-40 let
Předpoklady pro účast do druhé a třetí fáze výzkumu – zkušenost se silovým tréninkem alespoň jeden rok, zařazení dřepů do tréninku alespoň 1x týdně.
Kontraindikace pro zařazení do druhé a třetí fáze výzkumu – bolesti zad v posledních třech měsících, akutní onemocnění, infekční onemocnění, úraz a rekonvalescence po onemocnění či úrazu. Zjištění kontraindikací: zeptání se probanda. Probandi musí mít platnou lékařskou prohlídku se závěrem: bez omezení k silovým disciplínám. Výběr probandů bude zajišťovat řešitel projektu. Řešitel projektu je fyzioterapeut a v případě potřeby bude stav probanda konzultován s lékařem.

Zajištění bezpečnosti: Rizika mohou nastat při 2. a 3. části výzkumu. Jedná se o riziko zranění a pádu činky.
Minimalizace rizika zranění: probandi před sběrem dat absolvují rozcvičení, které se bude skládat ze 4 sérií dřepů po 15 opakování s vlastní vahou. Na rozcvičení bude dohlížet řešitel projektu a vedoucí Laboratoře pro studium pohybu při FZS UJEP Mgr. Marek Jelínek, Ph. D.
Minimalizace rizika pádu činky: činka bude zajištěna ve speciálním stojanu na dřepy a s nakládáním činky budou pomáhat POMVĚDi z řad studentů fyzioterapie. Na celý proces bude opět dohlížet řešitel projektu a vedoucí Laboratoře pro studium pohybu při FZS UJEP Mgr. Marek Jelínek, Ph. D.
Sběr dat je neinvazivní.
Rizika prováděného průzkumu nebudou vyšší než rizika běžně očekávaná u tohoto typu výzkumu.
Etické aspekty výzkumu: Do výzkumu nebudou zařazeni vulnerabilní skupiny a jednotlivci.
Potenciální střet zájmů: Já ani nikdo z výzkumného týmu nemáme soukromý zájem na výsledku výzkumu, výzkum nevede k mému osobnímu prospěchu ani k prospěchu žádného z řešitelů ani účastníků výzkumu.
Ochrana osobních dat: Osobní údaje nebudou předány k dalšímu zpracování. Během dotazníkového šetření budou sbírána pouze následující data: věk, pohlaví, povolání a odpovědi na otázky v dotazníku. Během 2. a 3. fáze výzkumu budou sbírána následující data: věk, pohlaví, výška, hmotnost, maximální silový výkon v dřepu pro jedno opakování (1 RM). Tato data poslouží pouze k popisné statistice výzkumného souboru. Veškerá sbíraná data budou bezpečně uchována na heslem zajištěném počítači v uzamčené kanceláři řešitele, přístup k nim bude mít pouze řešitel. Každý účastník bude mít přidělen číselný kód.
Uvědomuji si, že text je anonymizován, neobsahuje-li jakékoli informace, které jednotlivě či ve svém souhrnu mohou vést k identifikaci konkrétní osoby – budu dbát na to, aby jednotliví účastníci nebyli rozpoznatelní v textu práce. Osobní data, která by vedla k identifikaci účastníků výzkumu, budou do 1 dne po testování anonymizována. Získaná data budou zpracovávána, bezpečně uchována a publikována v anonymní podobě v disertační práci, v odborných časopisech, případně v úložištích dat, monografiích a prezentována na konferencích, případně budou využita při další výzkumné práci na UK FTVS.
Pořizování fotografií/videí/audio nahrávek účastníků:
Během výzkumu budou pořizovány fotografie a videozáznam pro účely názorné ukázky provedeného testování a terapie s probandy a také pro porovnání pohybu pánve před intervencí a po intervenci.
Fotografie: Anonymizace osob na fotografiích bude provedena začerněním/rozmazáním obličejů či částí těla, znaků, které by mohly vést k identifikaci jedince. Neanonymizované fotografie budou bezpečně uchovány na heslem zajištěném počítači v uzamčené kanceláři řešitele, přístup k nim bude mít pouze řešitel a budou do 1 dne po pořízení smazány. Publikovány budou pouze anonymizované fotografie.
Videa: Videa nebudou nikde publikována, budou využita pouze pro účely řešitele projektu, videa budou následně smazána. Neanonymizovaná videa budou bezpečně uchována na heslem zajištěném počítači v uzamčené kanceláři řešitele, přístup k nim bude mít pouze řešitel řešitel a budou do 1 dne po skončení výzkumu smazána.
V maximální možné míře zajistím, aby získaná data nebyla zneužita.
Text informovaného souhlasu (IS): přiložen, zjednodušený IS ve formě úvodu k dotazníku přiložen.

Povinností **všech účastníků výzkumu na straně řešitele** je chránit život, zdraví, důstojnost, integritu, právo na sebeurčení, soukromí a osobní data zkoumaných subjektů, a podniknout k tomu veškerá preventivní opatření. Odpovědnost za ochranu zkoumaných subjektů leží vždy na účastnících výzkumu na straně řešitele, nikdy na zkoumaných, byť dali svůj souhlas k účasti na výzkumu. Všichni účastníci výzkumu na straně řešitele musí brát v potaz etické, právní a regulační normy a standardy výzkumu na lidských subjektech, které platí v České republice, stejně jako ty, jež platí mezinárodně.
Potvrzuji, že tento popis projektu odpovídá návrhu realizace projektu a že při jakékoli změně projektu, zejména použitých metod, zašlu Etické komisi UK FTVS revidovanou žádost.

V Praze dne: 2.11. 2021 Podpis předkladatele:

Vyjádření Etické komise UK FTVS

Složení komise: **Předsedkyně:** doc. PhDr. Irena Parry Martínková, Ph.D.
Členové: prof. MUDr. Jan Heller, CSc., prof. PhDr. Pavel Slepička, DrSc., PhDr. Pavel Hráský, Ph.D., Mgr. Eva Prokešová, Ph.D., Mgr. Tomáš Ruda, Ph.D., MUDr. Simona Majorová

Projekt práce byl schválen Etickou komisí UK FTVS pod jednacím číslem: ......245/2021......

dne: ......8. 11. 2021......

Etická komise UK FTVS zhodnotila předložený projekt a **neshledala rozpory** s platnými zásadami, předpisy a mezinárodní směrnicemi pro provádění výzkumu zahrnujícího lidské účastníky.

Řešitel projektu splnil podmínky nutné k získání souhlasu Etické komise UK FTVS.

UNIVERZITA KARLOVA
Fakulta tělesné výchovy a sportu
José Martího 31, 162 52, Praha 6
– 20 –

razítko UK FTVS podpis předsedkyně EK UK FTVS

APPENDIX B

UNIVERZITA KARLOVA
FAKULTA TĚLESNÉ VÝCHOVY A SPORTU
José Martího 31, 162 52 Praha 6-Veleslavín

Dokument č. 1 k žádosti o vyjádření Etické komise UK FTVS:

Potvrzení pracoviště o možnosti realizace výzkumného projektu z hlediska bezpečnosti účastníků projektu a o možnosti publikace názvu pracoviště

Dokument pro Etickou komisi UK FTVS

Název pracoviště/obchodní firma: Fakulta zdravotnických studií (FZS)
Univerzity J. E. Purkyně (UJEP) v Ústí nad Labem

Odpovědná osoba na pracovišti/statutární zástupce: doc. PhDr. Zdeněk Havel, CSc.

Funkce odpovědné osoby: děkan FZS UJEP

Svým níže uvedeným vlastnoručním podpisem potvrzuji, že na výše uvedeném pracovišti lze realizovat projekt s názvem *„Retroverze pánve při dřepu, její objektivizace a možné řešení pomocí pohybové intervence"*, jemuž bylo Etickou komisí UK FTVS přiděleno *j. č. 245/2021* a jehož hlavním řešitelem je *Mgr. Ondřej Kališko* , přičemž tento projekt lze na výše uvedeném pracovišti provést s adekvátním zajištěním bezpečnosti pro všechny účastníky projektu, neboť dané pracoviště bude v průběhu realizace projektu adekvátně vybaveno jak po materiální, tak po odborné stránce, a dále zajistí, aby byly dodrženy etické aspekty výzkumu během realizace výzkumu. Dále potvrzuji, že **souhlasím/~~nesouhlasím~~** (*nehodící se škrtněte*) s tím, aby byl název pracoviště/obchodní firmy zveřejněn v rámci publikování výsledků tohoto výzkumu a to i v případě, pokud by měl výsledek výzkumu negativní dopad na pověst pracoviště/obchodní firmy.

V Ústí nad Labem, dne 10. 11. 2021

Podpis odpovědné osoby/statutárního orgánu na pracovišti:.....................................

Razítko:

UNIVERZITA J. E. PURKYNĚ
v ÚSTÍ NAD LABEM -1-
Fakulta zdravotnických studií
Velká hradební 13
400 96 Ústí nad Labem
doc. PhDr. Zdeněk Havel, CSc.

APPENDIX C

UNIVERZITA KARLOVA
FAKULTA TĚLESNÉ VÝCHOVY A SPORTU
José Martího 31, 162 52 Praha 6-Veleslavín

INFORMOVANÝ SOUHLAS

Vážený pane, vážená paní,

v souladu se Všeobecnou deklarací lidských práv, nařízením Evropské Unie č. 2016/679 a zákonem č. 110/2019 Sb. – o zpracování osobních údajů a dalšími obecně závaznými právními předpisy *(jakož jsou zejména Helsinská deklarace, přijatá 18. Světovým zdravotnickým shromážděním v roce 1964 ve znění pozdějších změn (Fortaleza, Brazílie, 2013); Zákon o zdravotních službách a podmínkách jejich poskytování (zejména ustanovení § 28 odst. 1 zákona č. 372/2011 Sb.) a Úmluva o lidských právech a biomedicíně č. 96/2001, jsou-li aplikovatelné),* Vás žádám o souhlas s Vaší účastí ve výzkumném projektu na UK FTVS v rámci dizertační práce s názvem Retroverze pánve při dřepu, její objektivizace a možné řešení pomocí pohybové intervence prováděné na Fakultě zdravotnických studií (FZS) Univerzity J. E. Purkyně (UJEP) v Ústí nad Labem, Katedře fyzioterapie a Laboratoři pro studium pohybu.

1. Projekt bude probíhat v období od října 2021 do května 2023
2. Projekt je financován z Interní grantové soutěže Fakulty zdravotnických studií Univerzity J. E. Purkyně v Ústí nad Labem, název projektu: Vliv fyzioterapie na výskyt retroverze pánve při provádění dřepu
3. Cílem výzkumného projektu je objektivizovat specifický pohyb pánve (retroverze) při dřepu a pokusit se jej napravit pomocí pohybové intervence (zjišťován bude primárně okamžitý efekt intervence ale i efekt s odstupem 1, 2 a 3 týdnů)
4. Způsob zásahu bude neinvazivní. Budete provádět dřepy s různým zatížením (dřepy s vlastní vahou až po dřepy s opakováním, kdy maximální zátěží bude 80 % maximálního silového výkonu v dřepu), vždy provedete 5 dřepů, budete odpočívat 2 minuty a poté se zvýší zátěž. Pro sběr bude využito pořízení videozáznamu a 3D kinematická analýza, jejíž princip spočívá v nalepení kuliček (markerů) na Vaše tělo, které vysílají signál do kamer a lze tak sledovat pohyb těla v prostoru. Pokud budete následně zařazeni do další fáze výzkumu, tak zde bude prováděno fyzioterapeutické vyšetření – palpační vyšetření pánve (zjištění polohy spina iliaca anterior superior, spina iliaca posterior superior a crista iliaca), vyšetření zkrácených struktur dle Jandy, změření rozsahu pohybu v hlezenním a kyčelním kloubu pomocí goniometru, provedení Neurac testu v závěsném systému Redcord pro pánev, kyčelní a kolenní kloub (Neurac test testuje sílu svalů v uzavřeném kinematickém řetězci.) Podle výsledku vyšetření Vám bude stanovena individuální terapie s cílem zjištění okamžitého účinku této terapie (ale i efektu s odstupem 1, 2 a 3 týdnů) na výskyt retroverze pánve – budete opět provádět dřepy s výše uvedeným zatížením a pro sběr dat opět poslouží videozáznam a 3D kinematická analýza.
5. Časová náročnost projektu: provádění dřepů a sběr dat pomocí videa a 3D kinematické analýzy cca 60-90 minut. Pokud bude zařazeni do další fáze výzkumu tak vyšetření zabere cca 60 minut. Terapie 30-60 minut a nové měření při provádění dřepů 60-90 minut. Měření s odstupem 1, 2 a 3 týdnů zabere opět 60-90 minut.
6. Během výzkumu mohou nastat dvě rizika – riziko zranění a pádu činky. Minimalizace rizika zranění: účastníci před sběrem dat absolvují rozcvičení, které se bude skládat ze 4 sérií dřepů po 15 opakování s vlastní vahou. Na rozcvičení bude dohlížet řešitel projektu (Mgr. Ondřej Kališko) a vedoucí Laboratoře pro studium pohybu při FZS UJEP Mgr. Marek Jelínek, Ph. D. Minimalizace rizika pádu činky: činka bude zajištěna ve speciálním stojanu na dřepy a s nakládáním činky budou pomáhat POMVĚDi z řad studentů fyzioterapie. Na celý proces bude opět dohlížet řešitel projektu a vedoucí Laboratoře pro studium pohybu při FZS UJEP Mgr. Marek Jelínek, Ph. D. Sběr dat je neinvazivní a bezbolestný.
7. Projektu se nemohou účastnit osoby, které v posledních třech měsících trpěli bolestmi zad nebo stále trpí
8. O bezpečnost při výzkumu se bude starat řešitel projektu – Mgr. Ondřej Kališko, vedoucí Laboratoře pro studium pohybu – Mgr. Marek Jelínek, Ph. D. a studenti oboru fyzioterapie.

9. Přínosem tohoto výzkumného projektu pro Vás bude to, že budete znát svůj pohybový stereotyp dřepu, jestli je či není patologický.
10. Odměna za Vaši účast v projektu bude diagnostika Vašeho způsobu provedení dřepu a případná náprava pomocí pohybové intervence (fyzioterapie). Účastníkům výzkumu nenáleží finanční odměna.
11. Během výzkumu budou sbírána následující data: věk, pohlaví, výška, hmotnost, maximální silový výkon v dřepu pro jedno opakování (1 RM). Tyto data poslouží pouze k popisné statistice výzkumného souboru. Veškerá sbíraná data budou bezpečně uchována na heslem zajištěném počítači v uzamčené kanceláři řešitele, přístup k nim bude mít pouze řešitel. V průběhu výzkumu budou pořizovány fotografie a videozáznam pro účely názorné ukázky provedeného testování a terapie s probandy a také pro porovnání pohybu pánve před intervencí a po intervenci.
    - Fotografie: Anonymizace osob na fotografiích bude provedena začerněním/rozmazáním obličejů či částí těla, znaků, které by mohly vést k identifikaci jedince. Neanonymizované fotografie budou bezpečně uchovány na heslem zajištěném počítači v uzamčené kanceláři řešitele, přístup k nim bude mít pouze řešitel a budou do 1 dne po pořízení smazány. Publikovány budou pouze anonymizované fotografie.
    - Videa: Anonymizace osob na videích bude provedena začerněním/rozmazáním obličejů či částí těla, znaků, které by mohly vést k identifikaci jedince. Neanonymizovaná videa budou bezpečně uchována na heslem zajištěném počítači v uzamčené kanceláři řešitele, přístup k nim bude mít pouze řešitel a budou do 1 dne po pořízení smazány. Publikovány budou pouze anonymizovaná videa.
12. S celkovými výsledky a závěry výzkumného projektu se můžete seznámit na emailové adrese ondrej.kalisko@ujep.cz a po úspěšném obhájení dizertační práce i v elektronické verzi práce, která bude zveřejněna v Digitálním repozitáři UK, odkaz zde: https://dspace.cuni.cz/
13. V maximální možné míře zajistím, aby získaná data nebyla zneužita.

Jméno a příjmení předkladatele projektu .... Podpis: ....

Jméno a příjemní hlavního řešitele a spoluřešitelů ....

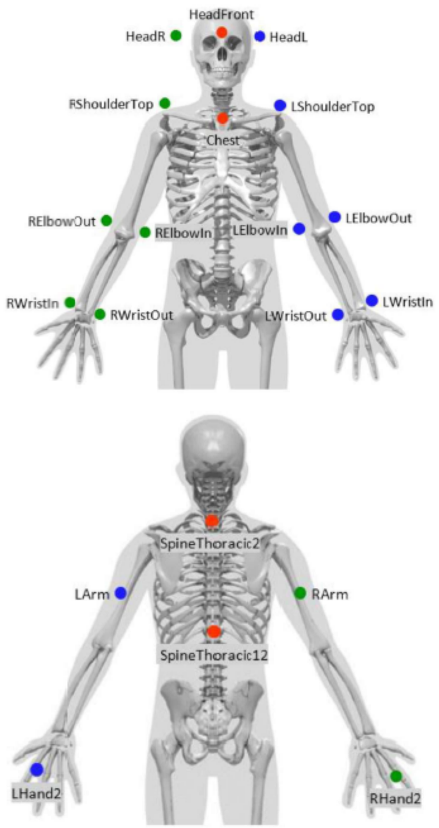
Prohlašuji a svým níže uvedeným vlastnoručním podpisem potvrzuji, že dobrovolně souhlasím s účastí ve výše uvedeném projektu a že jsem měl(a) možnost si řádně a v dostatečném čase zvážit všechny relevantní informace o výzkumu, zeptat se na vše podstatné týkající se účasti ve výzkumu a že jsem dostal(a) jasné a srozumitelné odpovědi na své dotazy. Byl(a) jsem poučen(a) o právu odmítnout účast ve výzkumném projektu nebo svůj souhlas kdykoli odvolat bez represí, a to písemně Etické komisi UK FTVS, která bude následně informovat předkladatele projektu. Dále potvrzuji, že mi byl předán jeden originál vyhotovení tohoto informovaného souhlasu.

Místo, datum ....

Jméno a příjmení účastníka .... Podpis: ....

APPENDIX D

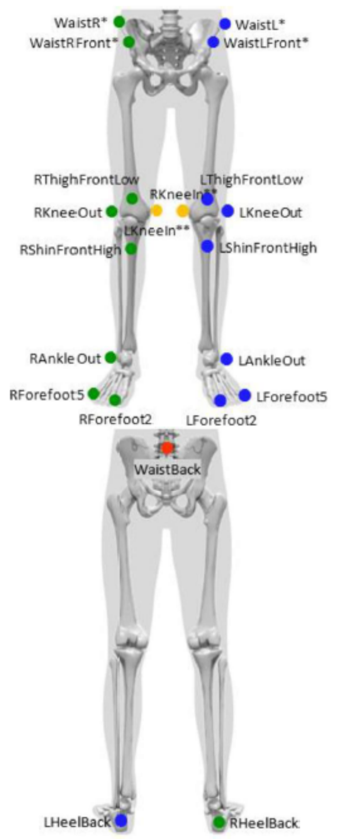
Qualisys Sports Marker Set – Functional Assessment



Name	Ref. [1]	Location	Static (20)	Dyn. (20)
HeadL		On headband, just above ear	X	X
HeadR		On headband, just above ear	X	X
HeadFront	SGL	On headband, Forehead	X	X
Chest	SME	Sternum	X	X
SpineThoracic2	TV2	Spine, 2nd Thoracic Vertebra	X	X
SpineThoracic12	TV12	Spine, 12th Thoracic Vertebra	X	X
LShoulderTop	SAE	Shoulder	X	X
LArm		Posterior on upper arm	X	X
LElbowOut	HLE	Elbow (outside)	X	X
LElbowIn	HME	Elbow (inside)	X	X
LWristIn	RSP	Wrist (thumb side)	X	X
LWristOut	USP	Wrist (pinkie side)	X	X
LHand2	HM2	Hand (basis of Forefinger)	X	X
RShoulderTop	SAE	Shoulder	X	X
RArm		Posterior on upper arm	X	X
RElbowOut	HLE	Elbow (outside)	X	X
RElbowIn	HME	Elbow (inside)	X	X
RWristIn	RSP	Wrist (thumb side)	X	X
RWristOut	USP	Wrist (pinkie side)	X	X
RHand2	HM2	Hand (basis of Forefinger)	X	X

[1] Sint Jan, S. Van (2007). Color Atlas of Skeletal Landmark Definitions. Guidelines for Reproducible Manual and Virtual Palpations. Edinburgh : Churchill Livingstone.

Qualisys Sports Marker Set – Functional Assessment



Name	Ref. [1]	Location	Static (21)	Dyn. (19)
WaistL*	ICT	Ilium – Crest Tubercle	X	X
WaistR*	ICT	Ilium – Crest Tubercle	X	X
WaistLFront*	IAS	Pelvis (Anterior Superior Iliac Spine)	X	X*
WaistBack	(IPS)	Sacrum	X	X
WaistRFront*	IAS	Pelvis (Anterior Superior Iliac Spine)	X	X*
LThighFrontLow		Patella (above knee)	X	X
LKneeOut	FLE	Knee – Lateral epicondyle	X	X
LKneeIn **	FME	Knee – Medial epicondyle	X	
LShinFrontHigh	TTC	Shin	X	X
LAnkleOut	FAL	Ankle	X	X
LHeelBack	FCC	Heel	X	X
LForefoot2	FM2	2nd Toe	X	X
LForefoot5	FM5	5th Toe	X	X
RThighFrontLow		Patella (above knee)	X	X
RKneeOut	FLE	Knee – Lateral epicondyle	X	X
RKneeIn **	FME	Knee – Medial epicondyle	X	
RShinFrontHigh	TTC	Shin	X	X
RAnkleOut	FAL	Ankle	X	X
RHeelBack	FCC	Heel	X	X
RForefoot2	FM2	2nd Toe	X	X
RForefoot5	FM5	5th Toe	X	X

* WaistR and WaistR are optional. If they exist, WaistLFront and WaistRFront become static only.
** KneeIn is optional if functional trial is collected.

[1] Sint Jan, S. Van (2007). Color Atlas of Skeletal Landmark Definitions. Guidelines for Reproducible Manual and Virtual Palpations. Edinburgh : Churchill Livingstone.

APPENDIX E

Table 1

Experimental group hip joint range of motion – Descriptive Statistics – Part 1

	Flexion with extended knee		**Flexion with flexed knee**		**Extension**	
	L	R	L	R	L	R
Mean	84.13	82.61	116.52	117.39	14.35	14.13
Standard error	2.72	2.84	1.87	1.75	0.65	0.68
Median	90.00	85.00	120.00	120.00	15.00	15.00
Mode	90.00	90.00	120.00	120.00	15.00	15.00
Standard deviation	13.03	13.64	8.97	8.38	3.13	3.25
Minimum	55.00	55.00	100.00	100.00	10.00	10.00
Maximum	110.00	110.00	130.00	130.00	20.00	20.00
Count	23	23	23	23	23	23

Notes:
All values are in degrees
L = left side
R = right side

Table 2

Experimental group hip joint range of motion – Descriptive Statistics – Part 2

	Abduction		**Adduction**		**External rotation**		**Internal rotation**	
	L	R	L	R	L	R	L	R
Mean	34.13	32.17	20.00	18.48	28.70	26.30	35.00	38.04
Standard error	1.65	1.40	0.99	0.66	1.64	1.38	1.66	1.85
Median	35.00	35.00	20.00	20.00	30.00	25.00	35.00	40.00
Mode	35.00	35.00	20.00	20.00	35.00	20.00	40.00	40.00
Standard deviation	7.93	6.71	4.77	3.17	7.86	6.61	7.98	8.89
Minimum	20.00	15.00	15.00	15.00	15.00	15.00	15.00	20.00
Maximum	50.00	45.00	35.00	25.00	40.00	40.00	50.00	55.00
Count	23	23	23	23	23	23	23	23

Notes:
All values are in degrees
L = Left side
R = Right side

Table 3

Control group hip joint range of motion – Descriptive Statistics – Part 1

	Flexion with extended knee		Flexion with flexed knee		Extension	
	L	R	L	R	L	R
Mean	88.42	87.89	120.00	121.84	13.68	13.16
Standard error	1.09	1.29	1.71	1.80	1.07	1.03
Median	90.00	90.00	120.00	125.00	15.00	10.00
Mode	90.00	90.00	120.00	125.00	10.00	10.00
Standard deviation	4.73	5.61	7.45	7.85	4.67	4.48
Minimum	75.00	75.00	100.00	95.00	5.00	5.00
Maximum	95.00	95.00	130.00	130.00	20.00	20.00
Count	19	19	19	19	19	19

Notes:
All values are in degrees
L = Left side
R = Right side

Table 4

Control group hip joint range of motion – Descriptive Statistics – Part 2

	Abduction		Adduction		External rotation		Internal rotation	
	L	R	L	R	L	R	L	R
Mean	34.21	34.21	17.63	18.16	30.53	28.68	38.16	42.63
Standard error	1.10	1.10	0.89	0.78	2.02	2.02	1.92	1.29
Median	35.00	35.00	20.00	20.00	30.00	30.00	40.00	45.00
Mode	35.00	30.00	20.00	20.00	30.00	30.00	45.00	45.00
Standard deviation	4.79	4.79	3.86	3.42	8.80	8.79	8.37	5.62
Minimum	25.00	30.00	5.00	10.00	10.00	10.00	15.00	30.00
Maximum	45.00	45.00	20.00	25.00	45.00	45.00	50.00	50.00
Count	19	19	19	19	19	19	19	19

Notes:
All values are in degrees
L = Left side
R = Right side

APPENDIX F

Table 1

Experimental group ankle joint range of motion – Descriptive Statistics

	Dorsiflexion		**Plantar flexion**		**Knee to wall**	
	L	R	L	R	L	R
Mean	22.17	21.30	36.09	33.26	13.78	13.78
Standard error	1.88	1.41	2.43	2.10	0.60	0.58
Median	25.00	20.00	35.00	30.00	14.00	14.00
Mode	25.00	20.00	30.00	30.00	13.00	14.00
Standard deviation	9.02	6.78	11.67	10.07	2.86	2.78
Minimum	5.00	5.00	20.00	15.00	8.00	8.00
Maximum	50.00	40.00	60.00	50.00	18.00	18.00
Count	23	23	23	23	23	23

Notes:
All values are in degrees, only Knee to wall test is in centimeters
L = Left side
R = Right side

Table 2

Control group ankle joint range of motion – Descriptive Statistics

	Dorsiflexion		**Plantar flexion**		**Knee to wall**	
	L	R	L	R	L	R
Mean	23.68	23.42	38.42	37.89	14.37	14.58
Standard error	1.75	1.71	2.51	2.55	0.54	0.50
Median	25.00	20.00	40.00	40.00	15.00	15.00
Mode	20.00	20.00	40.00	40.00	14.00	14.00
Standard deviation	7.61	7.46	10.94	11.10	2.34	2.17
Minimum	5.00	10.00	20.00	20.00	8.00	9.00
Maximum	35.00	40.00	60.00	60.00	18.00	18.00
Count	19	19	19	19	19	19

Notes:
All values are in degrees, only Knee to wall test is in centimeters
L = Left side
R = Right side

APPENDIX G

Table 1

Experimental group – Pelvic ligaments assessment – Frequency distribution

	Sacroiliac ligament – Left side			**Sacroiliac ligament – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	23	100.00	100.00	20	86.96	86.96
1	0	0.00	100.00	3	13.04	100.00
Count	23			23		
	Iliolumbar ligament – Left side			**Iliolumbar ligament – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	22	95.65	95.65	21	91.30	91.30
1	1	4.35	100.00	2	8.70	100.00
Count	23			23		
	Sacrotuberous ligament – Left side			**Sacrotuberous ligament – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	22	95.65	95.65	22	95.65	95.65
1	1	4.35	100.00	1	4.35	100.00
Count	23			23		

Notes:
Value 0 = Correct execution
Value 1 = Poor execution

Table 2

Control group – Pelvic ligaments assessment – Frequency distribution

	Sacroiliac ligament – Left side			**Sacroiliac ligament – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	18	94.74	94.74	17	89.47	89.47
1	1	5.26	100.00	2	10.53	100.00
Count	19			19		
	Iliolumbar ligament – Left side			**Iliolumbar ligament – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	18	94.74	94.74	18	94.74	94.74
1	1	5.26	100.00	1	5.26	100.00
Count	19			19		
	Sacrotuberous ligament – Left side			**Sacrotuberous ligament – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	19	100.00	100.00	19	100.00	100.00
1	0	0.00	100.00	0	0.00	100.00
Count	19			19		

Notes:
Value 0 = Correct execution
Value 1 = Poor execution

APPENDIX H

Table 1

Experimental group muscle length – Frequency distribution

	Hamstrings – Left side			**Hamstrings – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	5	21.74	21.74	4	17.39	17.39
1	3	13.04	34.78	5	21.74	39.13
2	15	65.22	100.00	14	60.87	100.00
Count	23			23		
	Hip adductors – Left side			**Hip adductors – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	22	95.65	95.65	22	95.65	95.65
1	1	4.35	100.00	1	4.35	100.00
2	0	0.00	100.00	0	0.00	100.00
Count	23			23		
	Iliopsoas muscle – Left side			**Iliopsoas muscle – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	19	82.61	82.61	21	91.30	91.30
1	4	17.39	100.00	2	8.70	100.00
2	0	0.00	100.00	0	0.00	100.00
Count	23			23		
	Rectus femoris muscle – Left side			**Rectus femoris muscle – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	4	17.39	17.39	8	34.78	34.78
1	9	39.13	56.52	6	26.09	60.87
2	10	43.48	100.00	9	39.13	100.00
Count	23			23		
	Tensor fasciae latae muscle – Left side			**Tensor fasciae latae muscle – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	14	60.87	60.87	12	52.17	52.17
1	9	39.13	100.00	11	47.83	100.00
2	0	0.00	100.00	0	0.00	100.00
Count	23			23		
	Piriformis muscle – Left side			**Piriformis muscle – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	16	69.57	69.57	17	73.91	73.91
1	6	26.09	95.65	6	26.09	100.00
2	1	4.35	100.00	0	0.00	100.00
Count	23			23		

	Triceps surae muscle – Left side			Triceps surae muscle – Right side		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	22	95.65	95.65	23	100.00	100.00
1	1	4.35	100.00	0	0.00	100.00
2	0	0.00	100.00	0	0.00	100.00
Count	23			23		

Notes:
Value 0 = No shortening
Value 1 = Mild shortening
Value 2 = Severe shortening

Table 2

Control group muscle length – Frequency distribution

	Hamstrings – Left side			Hamstrings – Right side		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	3	15.79	15.79	3	15.79	15.79
1	7	36.84	52.63	7	36.84	52.63
2	9	47.37	100.00	9	47.37	100.00
Count	19			19		
	Hip adductors – Left side			**Hip adductors – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	19	100.00	100.00	18	94.74	94.74
1	0	0.00	100.00	1	5.26	100.00
2	0	0.00	100.00	0	0.00	100.00
Count	19			19		
	Iliopsoas muscle – Left side			**Iliopsoas muscle – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	17	89.47	89.47	16	84.21	84.21
1	2	10.53	100.00	3	15.79	100.00
2	0	0.00	100.00	0	0.00	100.00
Count	19			19		
	Rectus femoris muscle – Left side			**Rectus femoris muscle – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	3	15.79	15.79	5	26.32	26.32
1	13	68.42	84.21	12	63.16	89.47
2	3	15.79	100.00	2	10.53	100.00
Count	19			19		
	Tensor fasciae latae muscle – Left side			**Tensor fasciae latae muscle – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	12	63.16	63.16	12	63.16	63.16
1	6	31.58	94.74	6	31.58	94.74

2	1	5.26	100.00	1	5.26	100.00
Count	19			19		
	Piriformis muscle – Left side			**Piriformis muscle – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	17	89.47	89.47	19	100.00	100.00
1	2	10.53	100.00	0	0.00	100.00
2	0	0.00	100.00	0	0.00	100.00
Count	19			19		
	Triceps surae muscle – Left side			**Triceps surae muscle – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	19	100.00	100.00	19	100.00	100.00
1	0	0.00	100.00	0	0.00	100.00
2	0	0.00	100.00	0	0.00	100.00
Count	19			19		

Notes:
Value 0 = No shortening
Value 1 = Mild shortening
Value 2 = Severe shortening

APPENDIX I

Table 1

Experimental group muscle strength – Frequency distribution

	Hip flexion – Left side			**Hip flexion – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
4	0	0.00	0.00	0	0.00	0.00
4+	15	65.22	65.22	15	65.22	65.22
5	8	34.78	100.00	8	34.78	100.00
Count	23			23		
	Hip extension – Left side			**Hip extension – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
4	0	0.00	0.00	0	0.00	0.00
4+	17	73.91	73.91	17	73.91	73.91
5	6	26.09	100.00	6	26.09	100.00
Count	23			23		
	Trendelenburg – Left side			**Trendelenburg – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	23	100.00	100.00	21	91.30	91.30
1	0	0.00	100.00	2	8.70	100.00
Count	23			23		
	Trendelenburg + – Left side			**Trendelenburg + – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	11	47.83	47.83	11	47.83	47.83
1	12	52.17	100.00	12	52.17	100.00
Count	23			23		

Notes:
Value 4 = Full ROM actively against some resistance
Value 4+ = Full ROM actively against some resistence (but not strong enough to reach level 5)
Value 5 = Full ROM actively against strong resistance
Trendelenburg + = Trendelenburg sign difficult variant
Value 0 = Correct execution
Value 1 = Poor execution

Table 2

Control group muscle strength – Frequency distribution

	Hip flexion – Left side			**Hip flexion – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
4	0	0.00	0.00	0	0.00	0.00
4+	7	36.84	36.84	6	31.58	31.58
5	12	63.16	100.00	13	68.42	100.00
Count	19			19		
	Hip extension – Left side			**Hip extension – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
4	1	5.26	5.26	1	5.26	5.26
4+	9	47.37	52.63	9	47.37	52.63
5	9	47.37	100.00	9	47.37	100.00
Count	19			19		
	Trendelenburg – Left side			**Trendelenburg – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	18	94.74	94.74	18	94.74	94.74
1	1	5.26	100.00	1	5.26	100.00
Count	19			19		
	Trendelenburg + – Left side			**Trendelenburg + – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	10	52.63	52.63	5	26.32	26.32
1	9	47.37	100.00	14	73.68	100.00
Count	19			19		

Notes:
Value 4 = Full ROM actively against some resistance
Value 4+ = Full ROM actively against some resistence (but not strong enough to reach level 5)
Value 5 = Full ROM actively against strong resistance
Trendelenburg + = Trendelenburg sign difficult variant
Value 0 = Correct execution
Value 1 = Poor execution

APPENDIX J

Table 1

Experimental group Deep Stabilization System tests – Frequency distribution

	Hip flexion test – Left side			**Hip flexion test – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	4	17.39	17.39	4	17.39	17.39
1	19	82.61	100.00	19	82.61	100.00
Count	23			23		
	Hip extension test – Left side			**Hip extension test – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	12	52.17	52.17	13	56.52	56.52
1	11	47.83	100.00	10	43.48	100.00
Count	23			23		
	Diaphragm test – Left side			**Diaphragm test – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	13	56.52	56.52	12	52.17	52.17
1	10	43.48	100.00	10	43.48	95.65
Count	23			23		

Notes:
Value 0 = Correct execution
Value 1 = Poor execution

Table 2

Control group Deep Stabilization System tests – Frequency distribution

	Hip flexion test – Left side			**Hip flexion test – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	3	15.79	15.79	6	31.58	31.58
1	16	84.21	100.00	13	68.42	100.00
Count	19			19		
	Hip extension test – Left side			**Hip extension test – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	14	73.68	73.68	14	73.68	73.68
1	5	26.32	100.00	5	26.32	100.00
Count	19			19		
	Diaphragm test – Left side			**Diaphragm test – Right side**		
Value	Frequency	Percent	Cumulative percent	Frequency	Percent	Cumulative percent
0	12	63.16	63.16	8	42.11	42.11
1	7	36.84	100.00	11	57.89	100.00
Count	19			19		

Notes:
Value 0 = Correct execution
Value 1 = Poor execution