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Analysis of the kinematic parameters of squatting in subjects with different levels of physical activity – A preliminary study

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Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

abstract

Background: Bipedal leg squat is a common rehabilitation exercise. It is used for evaluation of lower limb function and pelvis and core stability. The aim of this study was a comparison of the lower limb, pelvis and spine ranges of motion in subjects with different declared physical activity level during bipedal squat.

Material and methods: Twenty healthy student-volunteers took part in this investigation. Based on the author's questionnaire, they were divided into two groups: "higher" and "lower" physical activity level. Participants performed a two-leg squat with maximal depth, and returned to the standing position. The tridimensional motion of the ankle, knee, hip, pelvis and spine was analysed.

Results: During a bipedal squat the more active subjects demonstrate a greater ankle range of motion (42.585 deg) and smaller pelvis (17.293 deg) and spine (40.228 deg) mobility in the sagittal plane than the less active participants (33.819 deg, 29.178 deg and 63.279 deg respectively). The more active group demonstrate a decreased motion of the ankle in the frontal plane (4.173 deg; 10.839 deg, $p = 0.006$) and an increased motion of the hip in the transverse plane (39.765deg; 27.971 deg, $p = 0.035$) than less the active one.

Conclusions: The level of activity can lead to different movement patterns during multi-joint exercises.

Key words: physical activity, kinematics, squat.

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INTRODUCTION

Closed kinetic chain exercises have become popular and strongly recommended for rehabilitation because they are believed to be safer than exercises in an open kinematic chain. Thus bipedal squats are one of the most common exercises in sport training and rehabilitation practice [1, 2]. They are known as functional, multi-joint tasks and are very important in recovery after lower-limb injuries. They are used to strengthen the quadriceps and gluteal muscles [3]. These exercises are part of physical examination as a functional mobility test (4). They inform about the stability of the lumbo-pelvic complex. Loss of motor control in this area can lead to back disorders [5]. Several factors can cause compensation in lumbo-pelvic movement patterns. Joints of the lower limb, especially the hip, are involved in spinal function and may be involved in back pain. Recent evidence suggests that the role of the lower-limb joints lies in compensation for spinal dysfunction. However, lower-limb abnormalities could also lead to excessive spinal motion that lead to back pain [6, 7].

MATERIAL AND METHODS

Participants

The participants of this investigation were healthy student-volunteers. They were asked to define their weekly time spent on physical activities in hours per week. The activity levels were based on leisure time physical activity (sport and outdoor tasks like walking for pleasure, cycling to work and/or for pleasure) specified in the author's questionnaire based on questions included in the Minnesota Leisure-time Physical Activity Questionnaire [11]. According to the World Health Organisation (WHO) recommendations of physical activity for 18–64-year-old persons, adults should increase their moderate-intensity physical activity to 300 minutes per week for additional health benefits [12]. Thus, participants were divided into two groups in this study. The first group consisted of those subjects who spent less than four hours per week on physical activity (n = 9; 4 men and 5 women). The second group were participants who spent five hours (the 300 min recommended by WHO) or more on physical activity every week (n = 11; 5 men and 6 women). The group characteristics is presented in Table 1.

Table 1. Group characteristics

Group	Age (years)	Body length (cm)	Body weight (kg)	Number of participants
"more" active	22.17	173.67	67.10	11
"less" active	23.67	172.00	62.33	9

Bipedal squat

Participants perform a two-leg squat with maximal depth and return to the standing position maintaining heel contact throughout the movement. For clinical practice, the squat depth and movement speed testing are not standardised. The squatting activity was conducted at the motion analysis laboratory at the Lublin University of Technology. Approval for this research was obtained from both the ethical committee at the Lublin University of Technology (No. 6/2015) and the ethical committee at the Medical University of Lublin (No. KE-0254/331/2015).

In the initial position individuals had to stand with their feet at shoulder width, looking straight ahead. Their upper limbs were positioned parallel to the floor. Participants made a practice trial. After that, they performed a maximal two-leg squat, holding the squat position for 3 seconds. Then they returned to the staring position.

Data analysis

We collected 3D kinematic data simultaneously with video data using an 8-camera Vicon 2.0 motion capture system (NIR T40S cameras) operating at 100 Hz. Thirty-nine retro-reflective markers were attached to specific anatomic landmarks. Joint centres were defined according to the Plugin-gait Model. We used the filtered marker trajectories to compute the 3D segment and joint angles using the Euler angle method in conjunction with the Nexus software (Vicon, OxfordMetrics). The sagittal plane was represented by the X axis, the frontal one on the Y axis and the transverse one on the Z axis. The ratio of the PSIS marker (posterior superior iliac spine) height during the maximal descent and during the initial standing position expressed in percentage was calculated to demonstrate the depth of the squat.

During a bipedal squat, the motion of the sagittal, frontal and transverse planes of the ankle, knee, hip, pelvis and spine was analysed. Angles were defined by means of the Plugin-gait Model. The ankle angle is a relative angle between the shank and the foot. The knee angle is defined as the angle between the thigh and the shank. The hip angle is the angle between the pelvis and the thigh. Positive values in this model's calculations mean flexion and ankle dorsiflexion, adduction, external rotation, pronation and the negative values of the mean motion in the opposite direction – extension and plantarflexion, abduction, internal rotation and supination. The pelvis angle was calculated as an absolute quantity of the angle between the pelvis and the laboratory coordinate system. Positive values mean forward tilt, elevation and left rotation, while negative values mean backward tilt, drop and right rotation. The spine angle was calculated as the angle between the thorax relative to the pelvis. Positive values mean flexion, side flexion to the left and left rotation, while negative values mean extension, side flexion to the right and right rotation. For joints, the total range of motion (ROM) was calculated as a difference of the maximal and minimal angle reached during the tasks. The Mann-Whitney U test was used for statistical analysis. The significance level was set at 0.05.

Results

The height ratio of the PSIS (posterior superior iliac spine) marker during the maximal descent and maximal marker height in standing position expressed in percent is comparable for both groups ($p>0.05$) and amounts to 60%.

Sagittal plane

More active participants demonstrated increased ankle ROM during a bipedal squat at 42.585 deg in comparison with the less active ones (33.819 deg). The hip and knee motions were comparable in both groups. The less active group had a greater pelvis and spine ROM during a bipedal squat than the more active persons, amounting to 29.178 deg and 63.279 deg for pelvis and spine respectively.

The pelvis and spine ROM in the sagittal plane for the more active ones was 17.293 deg, and 40.228 deg for pelvis and spine respectively (Table 2).

Table 2. Bipedal squat – sagittal, frontal and transverse planes range of motion (deg)

	Less active n=9		More active n=11		U Mann-Whitney test	
	M	SD	M	SD	U	P
Sagittal						
Ankle_ROM	33.819	7.627	42.585	7.447	20.000	0.025
Hip_ROM	105.904	10.362	107.060	8.995	46.000	0.790
Knee_ROM	143.645	11.587	148.213	9.915	34.000	0.254
Pelvis ROM	29.178	10.650	17.293	8.265	20.000	0.025
Spine ROM	63.279	16.719	40.228	8.596	8.000	0.003
Frontal						
Ankle_ROM	10.839	6.032	4.173	2.599	10.000	0.006
Hip_ROM	11.081	3.115	9.869	3.100	34.000	0.438
Knee_ROM	25.370	10.095	28.655	6.868	34.000	0.433
Pelvis ROM	6.271	4.278	4.686	1.447	34.000	0.433
Spine ROM	7.438	3.524	6.551	2.514	32.000	0.505
Transverse						
Ankle_ROM	41.564	19.150	28.059	7.241	26.000	0.148
Hip_ROM	27.271	7.473	39.765	13.133	18.000	0.035
Knee_ROM	35.237	15.969	42.191	11.114	26.000	0.148
Pelvis ROM	8.601	4.971	5.687	1.525	22.000	0.076
Spine ROM	7.442	5.540	5.312	3.438	26.000	0.230

M – mean; SD – standard deviation; U – Mann-Whitney test; P – P-value

Interestingly, we have found that the main difference in pelvic motion was observed in minimal values (backward tilt) achieved during a squat not in maximal values (forward tilt), (Table 3). Less active participants reached -4.055 versus 5.188 deg as an minimal value (p = 0.048). More active participants had more flexed spine (maximal value) during a squat than the less active ones (46.525 versus 28.200 deg, p = 0.006). During a squat, the more active persons held the pelvis anteriorly (or forward) tilted, the less active ones first tilted it forward and then backward and again forward during the return from the squat position (Fig. 1).

Frontal plane

There was a significant difference between groups in the ankle frontal plane motion. The less active subjects had more ROM in this plane than the more active participants (10.839 deg versus 4.173 deg, p = 0.006). The motion of other joints in this plane was comparable in both groups.

TRANSVERSE PLANE

In the transverse plane the less active participants had less ROM of the hip than the more active ones (27.971 deg versus 39.765 deg, p = 0.035). There were no other significant differences in this plane between groups.

Table 3. Peak pelvis angles (minimal and maximal) achieved during a squat

	M	SD	M	SD	U	P
pelvis min	5.188	4.008	-4.055	9.370	23.000	0.048
pelvis max	22.481	6.729	25.123	9.290	41.000	0.543
spine min	-12.027	6.466	-16.754	7.159	26.000	0.130
spine max	28.200	6.200	46.525	14.641	11.000	0.006

Positive values mean forward pelvis tilt and spine flexion and negative values mean backward pelvic tilt and spine extension.

M – mean; SD – standard deviation; U – Mann-Whitney test; P – P-value

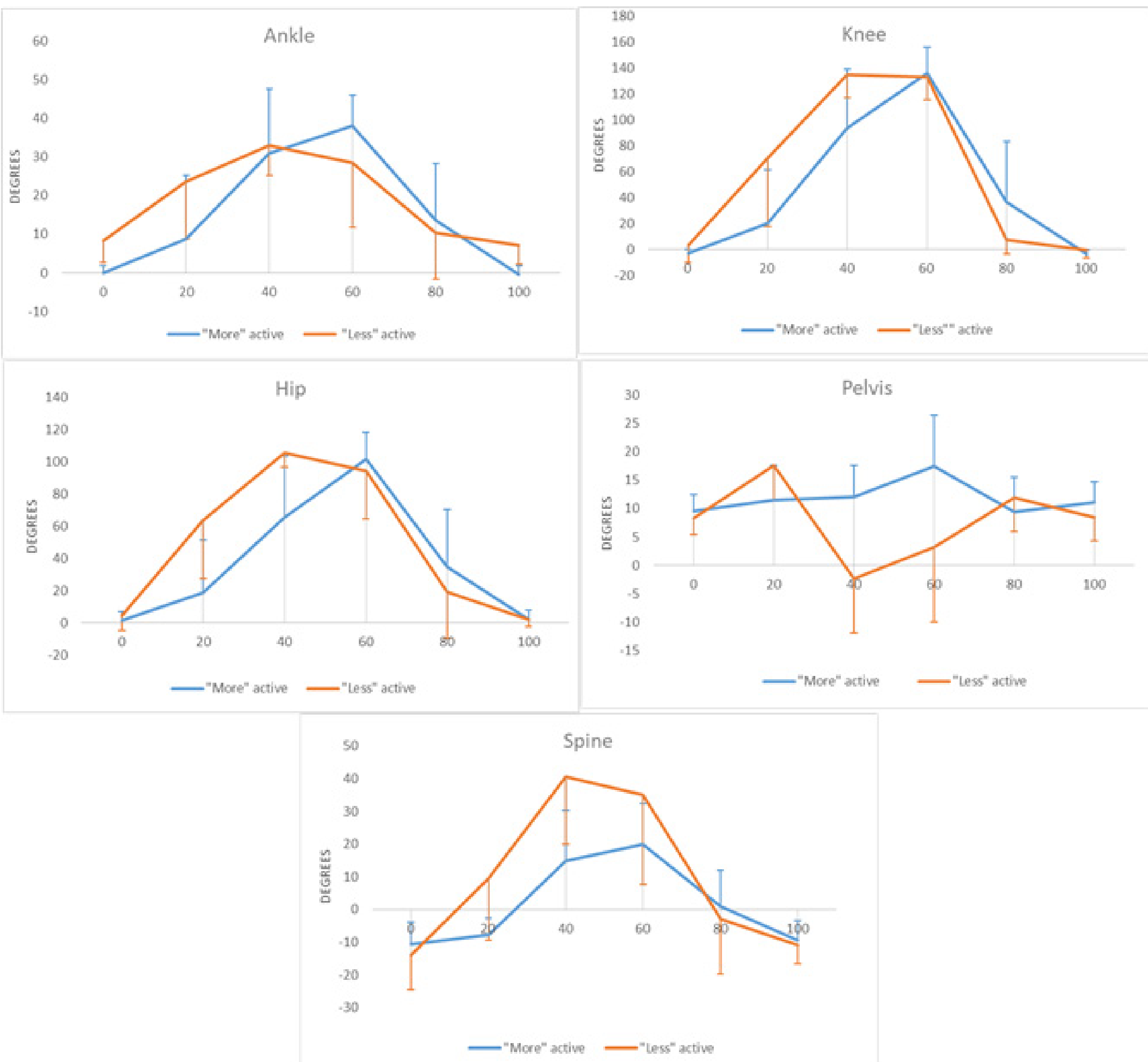

Fig. 1. Averages of the joints angles of every 20 percent of movement time. Error bars (single-sided) represent standard deviation

Discussion

Sagittal plane

The aim of this study was a comparison of the lower limb, pelvis and spine ranges of motion in subjects with different physical activity level. Preserving an optimal range of motion is one of the purposes of physical activity. The squat is defined as a sitting posture with dorsiflexed ankles, a deeply flexed knee and hip and is one of the multiple joint movements performed in a closed kinetic chain [2]. The ankle plays an important role in the closed kinematic chain during the deep squat. Ankle dorsiflexion is significantly associated with squat depth [13] and deep squatting posture [14]. As Macrum et al. report [15], the compensatory changes associated with limiting ankle-dorsiflexion motion may have clinical relevance as decreased knee flexion or increased knee valgus. Decreased dorsiflexion has implications for the body posture [15]. In contrast to Macrum's findings, we did not observe differences in the motion of the knee in the sagittal plane, nor in the hip motion.

If ankle mobility is decreased, people may use the trunk flexion strategy to achieve the desired squat depth and move their centre of gravity forward to stay balanced. This strategy may contribute to an increase in lumbar stress due to more shear forces transferred to passive tissues [16,17]. That is why we believe that range-of-motion limitations in one segment of a closed kinematic chain contribute to compensatory increases in one or more joints to maintain the functional value of the movement task. Interestingly, more active subjects use a motor pattern with increased ankle range of motion and decreased spine and pelvis ROM. The limited ankle-dorsiflexion range of motion may result from gastrocnemius and soleus tightness. More active persons may have more stretched Achilles tendons and for this reason a greater range of ankle motion. Moreover, they may also have a more stable lumbo-pelvic complex with improved proprioception abilities. Altered lumbosacral proprioception and postural control are common in persons suffering from low back pain [18]. Because the depth of the squat in both groups was similar, it was inferred that the deficit of ankle motion is compensated by spine and pelvis motion to provide an optimal squat depth. We investigated young healthy persons, so that compensation is probably possible because of the lack of low back dysfunction. However, repetition of that movement pattern could lead to lumbar passive tissue injuries.

It is interesting to note that the less active group tilted their pelvis backwards during a squat, when the more active one held it anteriorly tilted throughout the whole movement. When the pelvis is tilted backwards, it causes more flexion of the spine. This result can be explained by the better squat technique of the more active participants, who keep their trunk more straight. The present findings seem to be consistent with other research, which found that restricted squat (knees are not allowed beyond toes) leads to a more flexed trunk posture, which in turn leads to increased stresses in the back [19]. The restriction in our study seems to be natural and results from limited ankle dorsiflexion, which does not allow the knees to go beyond the toes.

Frontal plane

We have noted increased ankle motion in the frontal plane in the less active persons. This can suggest that the limited motion of the ankle in the sagittal plane contributes to the increased motion in the frontal plan. Previous researchers suggested that limited ankle dorsiflexion contributes to excessive rear-foot pronation and calcaneal eversion [20, 21]. The more frontal plane motion can be a result of compensation.

Transverse plane

In the transverse plane the more active participants demonstrated increased motion of hips. We had expected more differences in knee rotation or in the hip adduction/abduction motion. Greater hip adduction and knee mediolateral displacement are related with poor squat technique [22]. However, no significant differences were found between groups in these respects. The increased transverse plane motion may be related to more external rotation. We are of the opinion that it is part of the movement pattern that allows keeping the trunk in a more straight position.

Physical activity is one of the strongest health determinants [18]. However, the relationship between the physical activity level and motor skills or the range of motion of the joints remains unclear. Blaes et al. [23] investigated physical activity using accelerometry and physical performance assessed by means of EUROFIT tests in children. They found no relationship between physical activity and physical performance [23]. Ronsky et al. [24] suggest that the level of physical activity does not have a significant effect on the maximal ankle joint range of motion in the gait of elderly people [24]. Wrotniak et al. [25] indicate that motor proficiency is positively associated with physical activity and inversely associated with sedentary activity in children [25]. In our study, the declared physical activity level seems to be related to the range of motion of the ankle, spine and pelvis in the sagittal plane as well as ankle frontal plan motion and hip rotation, but these results need confirmation in further studies using more accurate tools.

Previous studies have shown that squat exercises are useful for motor learning/ control or strengthening evaluation in clinical practice and sport training [26,27]. It may be interesting for further research whether or not there is any correlation between pelvic-spine mobility and the range of motion of lower-limb joints during activities in a closed kinematic chain in reference to physical activity level. It seems to be clear that, as part of one chain, elements are related and thus dysfunction in one of them results in compensatory changes in another.

Limitation

There are a few limitations in this work. First of all, division into “more” and “less” active participants is based on the authorial survey questionnaire. Because of that, these results need confirmation in broader research using objective tools or at least more reliable objective questionnaires. In our investigation, we measure the range of motion only during the exercise (squat) as a “functional range of motion”; we do not measure mobility in other positions, more isolated for each joint. According to Dill et al. [28], compared with nonweight-bearing passive measures, ankle-dorsiflexion ROM during the weight-bearing exercises may better identify those at risk for dysfunctional movement patterns during functional tasks. Further investigations in this direction can clarify if the difference in motion was due to compensation or other reasons like technique pattern.

Moreover, our research has a small sample, without division by sex. Previous studies reported that there are differences in movement patterns between sexes [29,30]. Comparison between sexes can probably clarify our results. All the same, we consider that the influence of physical activity level on kinematic parameters, such as range of motion, may be very important and needs to be explored further.

CONCLUSIONS

In comparison to less active subjects, more active participants demonstrate increased ankle ROM and decreased spine and pelvis ROM in the sagittal plane during a squat. They also demonstrate decreased motion of the ankle in the frontal plane and increased motion of the hip in the transverse plane compared to the less active equivalents. The level of activity can lead to different movement patterns during multi-joint exercises. The relationship between physical activity level and exercise performance needs further exploration.

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