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EFFECT OF HEEL RAISE ON SPINAL ALIGNMENT DURING SQUATTING IN NON-ATHLETIC POPULATION: A CROSS-SECTIONAL STUDY

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ABSTRACT:

Background: A sufficient degree of mobility at the ankle is required to facilitate balance and control in both the ascent and descent of the squat. Insufficient ankle mobility is often compensated with the forward trunk angle.

Aim: To determine the effect of heel raise on trunk angle in healthy non-athletic population.

Design: Cross-sectional study

Intervention(s): Study included both male and female, healthy, physically active adults aged 18 years and above, who were not engaged in organized sports activities. Participants were selected based on their consistent engagement in physical activities, practicing a minimum of three sessions per week, each lasting at least 20 minutes. To measure maximum ankle DF-ROM, a weight bearing lunge test (WBLT) was used for each subject. A wooden block was used for the heel raise. The participants were asked to stand on heel wedge, squat and hold the end of squat position for 3 sec at the end to have sufficient time to record the angle. Motion capture was facilitated using a Samsung A9 device, and subsequent angle calculations were performed utilizing the Kinovea software. Adaptive measures were taken to reduce the chance of measurement error by placing the markers over anatomical landmarks and camera held at a distance of 5m from participant at an angle of 90 degrees. Ankle dorsiflexion with WBLT, trunk angle without heel raise and trunk angle with heel raise were the main outcome measures of this study.

Results: Results showed significant differences on trunk angle with and without heel raise ($g = 0.6$, 95% CI [0.1 to 1.2]; $p = 0.02$). The mean and standard deviation was shown to be 3.1 ± 4.6. Hence, trunk angle showed significant differences with and without a heel raise with moderate effect size ($g = 0.6$).

Conclusion: Facilitation of the ankle dorsiflexion movement with the help of heel raise during squat movement decreased forward trunk angle leading to improvement in spinal alignment.

Key Words: Squatting, Heel raise, alignment, trunk angle

INTRODUCTION:

Running, lunging, squatting are some of the fundamental movement patterns necessary for participating in physical activity and reducing the chance of injury, both of which are vital components of long-term health. (Myer et al., 2011; Lubans et al., 2010; Lloyd et al., 2014). Thus, in order to prepare for strenuous physical activity and organized, competitive sport, it is important to gain competency in fundamental movement patterns (Myer et al., 2014). Squatting is a common and popular exercise among athletes and the general public (Escamilla et al., 2001a; Fry et al., 2003; McCurdy et al., 2005). It has biomechanical and neuromuscular similarities to a wide range of athletic movements and thus is included as a fundamental exercise in many sports and training programs to enhance athletic performance (Escamilla et al., 2001; Senter et al., 2006). More specifically, it is also becoming increasingly popular in clinical settings as part of treatment of knee ligament lesions (Cerulli et al., 2002; Fleming et al., 2003; Heijne et al., 2004), patellofemoral pain (Witvrouw et al., 2000), hip and knee total joint replacement (Kuster, 2002), and ankle instability (Hertel, 2000). In particular, it has been used to increase strength of the lower extremity muscles and a more vertical trunk alignment is taught during squatting to minimize lower back shear forces (Kritz et al., 2009; Escamilla et al., 2001c; McCurdy et al., 2005).

The importance of maintaining a neutral lumbar spine and a vertical torso throughout the squat is emphasized by the classic NSCA position paper of 1991. Constraints on achieving the NSCA's 'optimal' spinal posture and knee position may originate from physical limitations such as reduced hip flexion and ankle dorsiflexion range of motion (Sato et al., 2012; Myer et al., 2014). A sufficient degree of mobility at the ankle is required to facilitate balance and control in both the ascent and descent of the squat (Alter, 2004; Sahrmann et al., 2017). Hemmerich et al., found that a dorsiflexion angle of approximately 38° was necessary to keep the heels down during a full squat (Hemmerich et al., 2006). When ankle joint flexibility is compromised, there is a tendency for the heels to rise off the floor which creates compensatory torques about the ankles, knees, hips, and lumbar spine (Kingma et al., 2004; Dionisio et al., 2008). Insufficient anterior translation of the tibia is often compensated with the forward trunk lean. Potential causes of this limitation include decreased mobility of the talocrural joint and shortened lower limb musculature particularly gastrocnemius and soleus (Bishop et al., 2015; Hoch et al., 2011; Macrum et al., 2012).

Additionally, increased lumbar flexion from a neutral position amplifies shear forces during squatting (Schoenfeld et al., 2010). Furthermore, in order to lower the risk of injury, technical guidelines concur that the spine and pelvis should be in a neutral position with no relative motion during the squatting motion. (Kathiresan et al., 2010, Kritz et al., 2009, McCurdy et al., 2005). Therefore, when performing these types of movements, maintaining good trunk and pelvic alignment is important to consider.

Accordingly, heel wedges have been recommended for individuals displaying excessive forward trunk flexion (Charlton et al., 2017, Dionisio et al., 2008, Escamilla et al., 2001). When the heel is raised, the ankle is forced into a higher degree of plantarflexion, decreasing the ankle dorsiflexion angle (Damsted et al., 2015, Escamilla et al., 2001, Fuglsang et al., 2017, Turner et al., 2021, Titus et al., 2018), which may indirectly affect the knee or trunk angle (D'Amico et al., 2022). Importantly, no study has explored the impact of heel raise on squatting within non-athletic population. Moreover, essential daily activities, such as ascending and descending stairs, sitting and lifting could potentially benefit from improved ankle mobility through incorporating heel raise (Zhenghui Lu et al., 2022; Moreno D'Amicov et al., 2022; Mark G. L. Sayers et al., 2020; Charlton et al., 2017; Zachary Mestelle et al., 2017). The interplay between ankle mobility and trunk angle during squats necessitates investigation.

Among advanced non-invasive movement evaluation tools, the most common are based on optoelectronic devices (NEGRINI et al., 2016) as well as 3-D motion analysis (Titus et al., 2018). These systems are used in different ways to monitor trunk kinematics, with different aims and different results. New low-cost methods of motion analysis (Mills, 2015) have been developed in recent years. These are based on the use of videos captured by video cameras or mobile smart devices for further analysis. The most commonly used applications are Ubersense®, PostureScreen®, KCapture®, Kinovea®, The Captury®, SimiMotion® for PC as well as mobile phone applications (Mills, 2015, Bertelsen et al., 2013, Damsted et al., 2015, Balsalobre-Fernández et al., 2014, de Almeida et al., 2015).

Hence, the purpose of this study was to investigate how mobility of the ankle i.e. dorsiflexion range of motion (DF-ROM) influence the trunk angle during the squat. The heel wedge will provide an increase in DF excursion, hence favoring ankle DF. This information could be helpful for the general population to work on their ankle mobility and improve performance of functional activities like squats.

INCLUSION CRITERIA:

- Both male and female
- Participants consisted of healthy, physically active adults aged 18 years and above, who were not engaged in organized sports activities. Participants were selected based on their consistent engagement in physical activities, practicing a minimum of three sessions per week, each lasting at least 20 minutes.

EXCLUSION CRITERIA:

- Participants with history of any spinal or lower extremity surgery
- Any history of spinal or lower extremity trauma
- Any neurologic disorder.

PROCEDURE:

To assess the maximal ankle dorsiflexion range of motion (DF-ROM), the weight-bearing lunge test (WBLT) was employed for each participant. Good to Excellent inter-rater reliability (ICC = 0.80 - 0.99) and intra-rater reliability (ICC = 0.65-0.99) scores were reported for this test (Powden et al., 2015).

To measure trunk angles during squatting, reflective markers were used, with their placement executed based on established methodologies (List et al., 2013; Lorenzetti et al., 2012). Markers were affixed to key anatomical landmarks including the trunk, lateral epicondyle, lateral malleolus, and anterior shank. Motion capture was facilitated using a Samsung A9 device, and subsequent angle calculations were performed utilizing the Kinovea software. Kinovea® is a free 2D motion analysis software for computers that can be used to measure kinematic parameters. This software has inter-rater reliability of >0.90 for different joints ROM including hip, knee and ankle (Fernández-González et al., 2020). Adaptive measures were taken to reduce the chance of measurement error by placing the markers over anatomical landmarks and camera held at a distance of 5m from participant at an angle of 90 (Fernández-González et al., 2020)

It is noteworthy that despite Kinovea being deemed a marker-less motion capture system, the integration of markers served as salient focal points during motion tracking via video playback using Kinovea. The camera was situated on a leveled tripod, strategically capturing tape markers and spinal movements. The characterization of trunk angle entailed the determination of the angle between the trunk and the ground, consistent with prior investigations (Charlton et al., 2017; Fuglsang et al., 2017; Lee et al., 2019). Participants engaged in a warm-up regimen of 5–10 minutes, incorporating dynamic stretching, followed by a familiarization phase involving squat practice. To ensure the consistency of foot positioning across both conditions, a marking tape was utilized to demarcate the foot placement. A wooden block served as a heel raise, which placed the participant's foot in a 20° plantar-flexed position. Subsequently, participants executed squats while positioned on the heel wedge, sustaining the terminal squat position for 3 seconds to facilitate adequate angle recording. Participants performed three squats with each squat lasting approximately 5 seconds, interspersed by a 1-minute rest interval.

DATA ANALYSIS:

Normality of the data was checked by using Shapiro-wilk test. The absolute data was used for ankle dorsiflexion with WBLT, trunk alignment without heel raise and trunk alignment with heel raise. The data were represented as mean and standard deviation. Paired-sample T-test was conducted to analyse the differences in trunk angle before and after the heel raise.

Hedge's g effect sizes (EF) with 95% confidence intervals were calculated to interpret the magnitude of these differences with the following classifications: standardized mean differences of 0.2, 0.5, and 0.8 for small, moderate, and large effect sizes, respectively (Turner et al., 2021). Significance was set at $p < 0.05$. All data were computed through Microsoft Excel. Data was analyzed using SPSS version 27.

RESULTS:

The data were normally distributed for all variables to be assessed i.e. ankle dorsiflexion with WBLT, trunk alignment without heel raise and trunk alignment with heel raise. Table 1 shows mean standard deviation, minimum value, and maximum value of the variables age and ankle dorsiflexion WBLT.

Table 1: Descriptive of Age and Ankle Dorsiflexion WBLT

Variable	N	Minimum	Maximum	Mean ± Std. Deviation
Age	15	23	49	33.9±8.1
Ankle Dorsiflexion WBLT	15	33.4	59.1	46.7±7.6

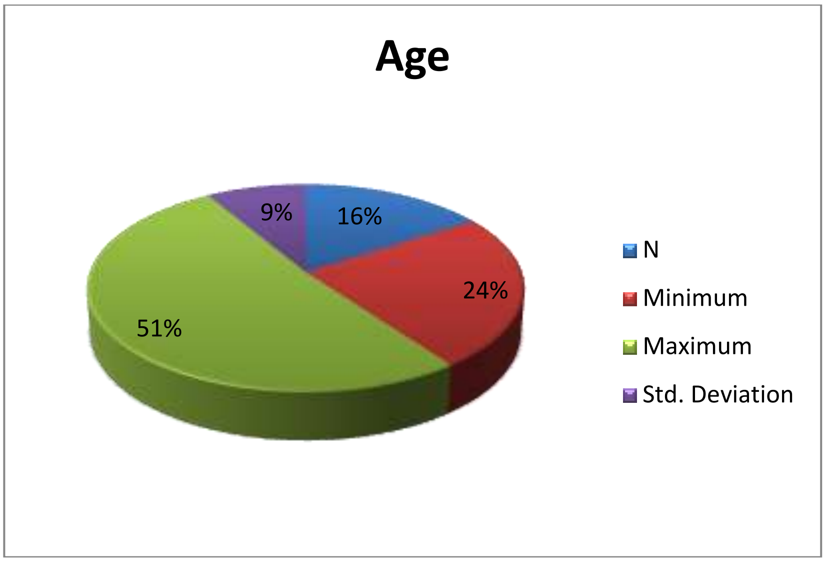

Figure 1: Pie Chart Showing Age frequency

EFFECT OF HEEL RAISE ON TRUNK ANGLE:

Table 2 shows the differences on trunk angle with and without a heel raise. There was a moderate significant difference on trunk angle with and without heel raise (g= 0.6, 95% CI [0.1 to 1.2]; p= 0.02).

Table 2: Comparison of trunk angle with and without a heel raise

Variable	without Heel Raise	with Heel Raise	Differences	Effect Size (95% CI) and P Value
Trunk Angle	41.3±8.5	38.2±8.2	3.1±4.6	0.6 (0.1 to 1.2) p = 0.02

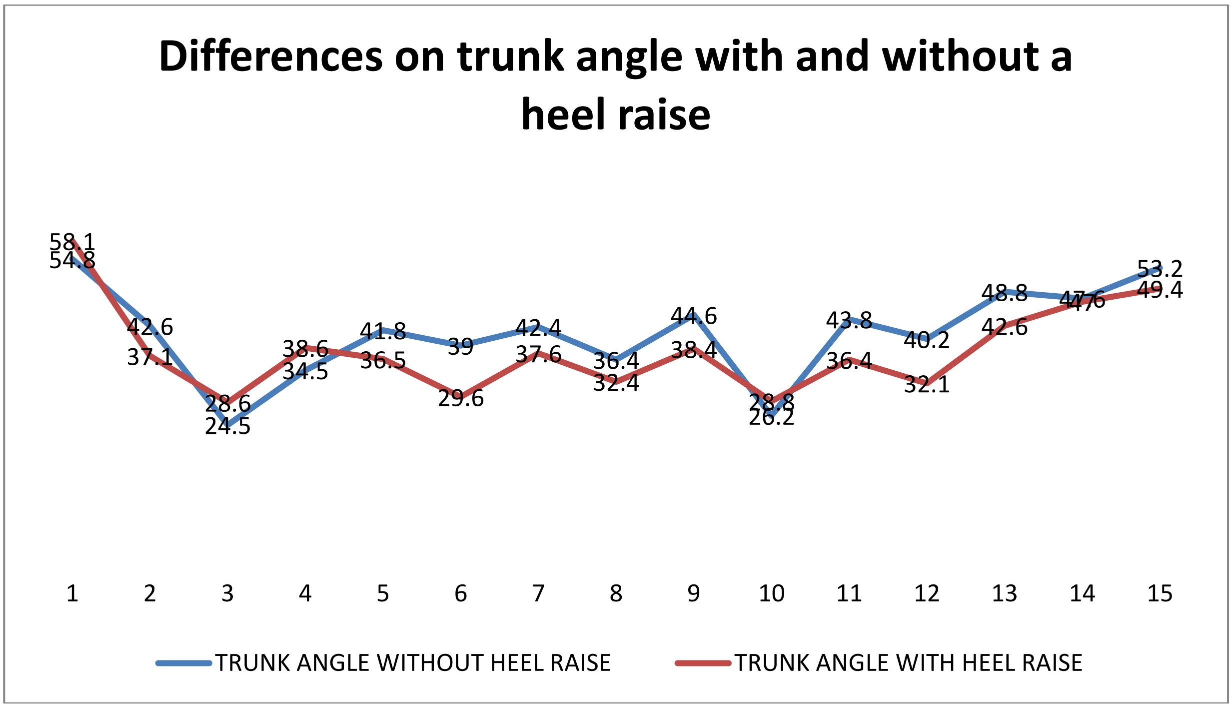

Figure 2: Line Chart showing Differences on trunk angle with and without a heel raise

DISCUSSION:

The objective of our study was to investigate the trunk alignment during squatting with and without heel raise within a healthy non-athletic population. The present study investigated the effects of a heel raise intervention on trunk angle, utilizing Kinovea software for measurement. The results revealed a noteworthy 3-degree reduction in trunk angle, accompanied by a moderate effect size. Differences in joint position less than five degrees after an intervention may be due to system or observer error. Kinovea software, although widely used for motion analysis, is susceptible to measurement errors arising from factors such as marker placement, camera resolution, and processing algorithms (Fernández-González et al., 2020).

While the findings offer insights into the potential influence of heel raise on trunk angle, the possibility of the observed 3-degree decrease being attributed to the normal measurement error inherent to Kinovea must be acknowledged. It is debatable whether such a small increase in trunk angle can significantly impact general population in their functional activities like squats.

The observed 3-degree reduction in trunk angle following the heel raise intervention suggests a biomechanical alteration in the body's alignment. This effect size, classified as moderate, signifies a meaningful change in trunk angle due to the intervention. However, the reliability of this change is called into question given the potential impact of measurement error.

Although, measures were taken to reduce the chance of measurement error by placing the markers over anatomical locations and positioning the camera at a set distance, the chance of error still exists. Therefore, it is plausible that the 3-degree decrease in trunk angle might, to some extent, reflect the inherent measurement variability of Kinovea rather than a true physiological change.

Although there is limited data to support the use of heel wedges, some researchers have proposed that by limiting forward trunk flexion, heel wedges may enhance trunk and pelvic posture during squatting motions (Charlton et al., 2017, Dionisio et al., 2008, Escamilla et al., 2001). These studies shows that participants' trunk and pelvic positions were more vertically oriented when squatting with a heel wedge, which is consistent with findings of Sato et al., who proposed that less forward trunk flexion occurred when squatting in weightlifting shoes as opposed to running shoes (Sato et al.,2012). This reduction might lead to a favorable spinal alignment, which is necessary for proper squat technique.

When the heel is raised, the ankle is forced into a higher degree of plantarflexion, decreasing the ankle dorsiflexion angle (Damsted et al., 2015, Escamilla et al., 2001, Fuglsang et al., 2017, Turner et al., 2021, Titus et al., 2018), which may indirectly affect the knee or trunk angle (D'Amico et al., 2022).

In contrast, Lee et al. showed that that the heel-raised foot postures do not significantly affect spinal and knee extensor muscle activations as well as trunk and knee kinematics. This difference in results may be due to the experimental design. The thoracic and lumbar angles were evaluated separately in this study utilizing a more direct method that permitted to trace the motions of the thoracic and lumbar segment individually, using a 3D motion capture system and electrogoniometer (Lee et al., 2019).

This effect size of this study indicates a discernible magnitude of change. It is important to recognize and emphasize that although the effect size is moderate which holds substantial clinical significance and warrants careful consideration, however, basis of clinical significance cannot be established while upholding with the scenario of only few degrees of change in trunk angle.

Although our study contributes to the growing body of knowledge surrounding squat mechanics and highlights the practical applications of optimizing ankle mobility for improved trunk alignment with specific emphasis on non-athletic population, however, it is clearly mentioned that our results showed only 3 degrees decline in trunk angle that can probably be attributed to the technical error that corresponds to the reliability and validity of the assessment tool. Furthermore, the significant changes observed in our study in alignment with all supportive literature; might affect musculoskeletal adaptations, essential for training and rehabilitation. Nevertheless, the results might vary between individuals with difference in how they perform the squat.

Moreover, highlighting the encountered limitations; trunk angles were not assessed using 3-D motion analysis due to limited resources. Data were analyzed in 2D, some subjects tended to externally rotate their feet slightly, which caused little frontal plane movement to occur. Even though the effect size of the study was moderate, but we cannot generalize our results on the basis of only 3 degrees changes in trunk angle that ,might be attributed to technical error; hence showing no clinical relevant significance. Further studies should be conducted with more valid resources on a large number of populations so that a clear picture for effectiveness of the technique can be depicted. Results in this study were established for non- athletic population, all of whom had 20 min duration of physical activity atleast 3 days a week. These results might be transferable only to subjects of same age, gender, and similar training status. Hence, results cannot be generalized.

CONCLUSION:

Elevating the heel in the squat is widely thought to be an efficient means of keeping the trunk more upright during the squat. This could be related to the ankle's increased ROM, which allows the shank to move closer to horizontal.

In conclusion, this study underscores the effects of heel raise on trunk angle, with a 3-degree decrease observed through Kinovea software. Despite the moderate effect size, the plausibility of the observed change being a consequence of measurement error must be acknowledged. Further research employing refined methodologies and robust measurement techniques will be pivotal in corroborating and building upon these findings, potentially shedding more light on the intricate relationship between heel raise and trunk angle. This information could be helpful for the general population to work on their ankle mobility and improve performance of functional activities like squats.

RECOMENDATIONS:

Only single variable in terms of trunk angle was analyzed, future studies should endeavor large population sizes to measure other variables like lower limb biomechanics during squats in non-athletic population. Without a more thorough understanding of the changes that occur as a result of using heel raise, recommendations may be appropriately made. More research is needed to determine if the use of a heel raise will elicit changes in trunk and pelvis kinematics during squatting movements.

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