Original Article

Comparison of ground reaction force during different angle of squatting

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ABSTRACT

Dali, S., Justine, M., Ahmad, H. & Othman, Z. (2013). Comparison of ground reaction force during different angle of squatting. *J. Hum. Sport Exerc., 8*(3), pp.778-787. Squatting is a form of closed kinetic chain movement which commonly being employed in exercise training. However, little is known regarding the amount of force being imposed on the knee at different angles of squat. Thus, the purpose of this study was to compare the vertical ground reaction force (VGRF) at different angles of squatting among the military personnel. Thirty-seven subjects (age=27.1±2.77 years old) participated in this cross-sectional comparative study. The peak of VGRF was identified during squatting at 40º, 70º, and 110 º of knee flexion, which was measured using a force platform. The data were analysed using the one way repeated measure ANOVA and Pairwise Comparisons via Bonferroni adjustment. The VGRF were shown significantly different between the three angles of squatting ($p<0.05$). Since the Mauchly Test of Sphericity was significant ($p>0$ .05), the result was corrected using Greenhouse-Geiser Epsilon and continued to show a significant different [F (1.36, 49.08)=43.56] ($p<0.05$). The effect size was large ($\eta\rho^2=0.55$). This study suggests that the angle of knee flexion during squatting exercise may influence VGRF. Deep squatting was found to generate the highest VGRF compared to semi and half squatting. Thus, it is suggested that squatting may be best performed at smaller angle in order to avoid excessive force that may be detrimental to the joint surface. **Key words**: GROUND REACTION FORCE, KNEE, SQUATTING.

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INTRODUCTION

Squatting is a common movement employed in the athletic training and proven to improve jumping height, peak power output, dynamic strength, sprint performance and horizontal jumping distance (Chelly et al., 2009; Lamont et al., 2009; Ruben et al., 2010). In physical rehabilitation, squatting is usually incorporated in exercise protocols for muscle strengthening in disorders like patellofemoral pain syndrome, arthritis of the knee and hip joints (Baker, & McAlindon, 2000; Grossi et al., 2005; Jan et al., 2009).

Apart from the beneficial effect of squatting on muscle strength, the ground reaction force is one of the major issues that is understudied. The ground reaction force (GRF) is a force of equal magnitude exerted on the opposite direction from the ground up to the foot (DeLee et al., 2010). It consists of vertical ground reaction force (VGRF) and two shear forces: anterior posterior and medial lateral shear forces (DeLee et al., 2010). It has been observed that excessive shear forces can be injurious to the cruciate ligaments, whereas excessive vertical forces can be deleterious to the menisci and articular cartilage (Eckstein et al., 2006; Escamilla, 2001; Herberhold et al., 1999). Increase GRF on the knee also produces discomfort and elicits pain among patients undergoing knee rehabilitation program (Eastlack et al., 2005). In contrast, vertical forces have been demonstrated to be an important factor in knee stabilization whereby it helps to resist shear forces and minimize tibial translation relative to the femur (Escamilla, 2001; Shoemaker, & Markolf, 1985; Markolf et al., 1981).

On the other hand, squatting activity has been shown to contribute to various musculoskeletal problems such as osteoarthritis (Zhang et al., 2004) and deformation of the joint cartilages (Eckstein et al., 1998, 2005). Therefore, it is logical to mention that incorrect technique of squatting that is prescribed in both rehabilitation and athletic training may increase the risk of injury to the performer and reduce its effectiveness.

Although the knee bending activities were thought to produce high loads that increase the risk of injury, Yack et al. (1993) reported that the stress to the anterior cruciate ligament can be minimized by using parallel squat compared to dynamic knee extension exercise. In addition, Lutz et al. (1993) revealed that squatting produced less anterior and posterior shear forces compared to open kinetic chain exercise in all angles. This shows that the GRF is the critical component that may influence the safety of squatting exercise. Therefore, question needs to be raised regarding what degree of squatting angle or knee flexion that may be considered safe and effective. However, there is no documentation that has emphasized on this issue. As such, it is vital to know that how much the human body can sustain the different amount of forces during different types of movement, specifically during squatting. With this information, the squatting exercises can be safely implemented in the rehabilitation program without compromising the effectiveness of the exercise.

Thus, the objective of this study was to identify the differences in VGRF produced during semi squatting (40º), half squatting (70º) and deep squatting (110º) among military personnel. It was hypothesized that there would be no significant differences in VGRF between semi squatting, half squatting and deep squatting. The military personnel were chosen for the study population because several studies have reported high prevalence of injury during military training and army duty (Bottoni, 2005; Bullock et al., 2010; Ekeland, 1997; Jones et al., 2000; Kaufman et al., 2000) that may require them to undergo long term rehabilitation.

METHODS

Study Design and Participants

The subjects for this cross-sectional comparative study were military personnel who were selected based on a simple random sampling using index card. The sample size was determined by the GPower 3 version 3.0.10 Software using the F test ANOVA for repeated measures. A total of 39 participants were recruited after taking into consideration of 10% drop outs (90% power, with the risk of type 1 error occurrence at 0.05). A few studies that have examined the muscle activity using EMG of lower limb muscles during squatting had sample sizes ranging from five to forty one subjects (Sousa et al., 2007; Salem, & Powell, 2001; Escamilla et al., 2000; Isear et al., 1996).

The criteria for study inclusion were normal body mass index (BMI), no history of ligament injury and knee surgery, and no history of systemic diseases and other medical illnesses as verified by the doctor involved in the medical clearance. An initial ethical application was addressed to the Research Ethics Committee, Universiti Teknologi MARA prior to initiation of the study and was given approval on December 30th, 2010.

Instrumentations

Demographics and anthropometrics data

The demographic data gathered were age (years) and number of years working experience in military service. The anthropometric data included the height, weight, and body mass index (kg/m^2). The body weight was measured using the weight scale (Tanita BC-418 MA, Tanita, Illinois, US) and recorded in the unit of kilogram (kg). The Stadiometer (SECA Vogel & Halke, Hamburg, Germany) was used to measure the height of the subjects.

The vertical ground reaction force

The VGRF was measured using a force platform (The Zebris® FDM-SX Multi forces measuring plate, Noraxon Inc. US). This platform has the capacity to measure the VGRF during weight bearing activity; however, it does not provide recording for the anterior-posterior and medio-lateral forces. The force platform was calibrated each time prior to data collection using the WinFDMS software.

The peak VGRF force was identified during the complete squatting movement performed by the subjects. The force platform in this study was fixed rigidly on the ground. This was necessary in order to ensure the movement was not affected by the platform, and to ensure a valid and reliable reading from the platform (Fritz & Peikenkamp, 2003). The best three data for peak VGRF were documented for each angle of squatting, thus the participants needed to perform at least three movements for each squatting angle. The mean for peak VGRF for each angle was calculated as the average score in Newton (N).

The squatting procedure

The squatting movement implemented in this study mimicked the squatting exercise commonly used in strengthening exercise (Howard, 2005). A knee brace (Telescoping Cool IROM®, DJ Orthopedics, Vista, CA) was used to standardize the restriction of the knee angles. The knee brace has an incremental adjustable angle restriction point by 10 degrees. The brace was positioned with the point of moveable arm (fulcrum) being aligned to the knee joint line. The adjustable angle restriction was set at 40º, 70º and 110º of knee flexion for the establishment of the marker for semi squatting, half squatting and deep squatting respectively. The marker is necessary because the participants referred to these markers as they squat down to the required angle (Howard, 2005). Three horizontal markers were placed on the surface at the finger level for each angle to indicate the three angles of knee flexion.

A warm up session was conducted prior to testing procedures, which was consisted of 10 repetitions of squatting at any angles, followed by cycling on the stationary bicycle for five minutes (Kisner & Colby, 2002). The participants were allowed to take a five-minute rest by walking around the testing area. In this study, only the dominant leg was measured and recorded for data analysis, as determined based on the leg that subjects preferred for kicking a ball (Maior et al., 2009; Stensdotter et al., 2007).

The starting position for the squatting was in the upright position with the hip and knees were fully extended. The dominant leg was placed on the force plate while the other leg was placed outside as shown in Figure 1. The stance width for each squatting movement was positioned based on the width of the subject's shoulder (Escamilla et al., 2001). The subjects were instructed to squat down until the end of the available range of motion that was set for the pin-stops with the shoulder flexion maintained at 90º, 15cm from the surface of the marker placement surface (Dionisio et al., 2008).

Figure 1. *The position for determining the specific angle of squatting.*

The participants performed the squatting movement until the fingers were parallel to the desired marker (desired squat depth), then, in a continuous motion back to the starting position (Escamilla, 2001). The subjects were instructed to perform the squatting movement for each angle as fast as they can within one second. The participants were also instructed to keep the upper arm elevated to 90º at the shoulder joint, without moving the elbow, wrist and hand which was determined by the researcher through observation (Dionisio et al., 2008). Participants were told to inform the researcher for any discomforts that they might experience during the procedure. The data collection for each angle was conducted with at least 24 hours lapse after the previous session in order to reduce the risk of muscle fatigue and injury (Eckstein et al., 1999).

Statistical Analysis

The data in this study were analyzed using the PASW (Predictive Analytics Software) Statistic 18 package. The one way repeated measures ANOVA within factors were used to analyze the significant difference of VGRF, while the multiple pairwise comparisons between the three angles of squatting were assessed using the Bonferroni adjustment. The level of significance was set at $p < 0.05$. All sets of data were reportedly normal since the Shapiro-Wilk test showed non significant result ($p > 0 .05$).

RESULTS

The demographic and anthropometric characteristics of the study population are tabulated in Table 1.

Table 1. *Participants Characteristics*

Characteristics	Range				
	N	%	Min	Max	Mean±SD
Age (years)			23	34	27.1 ± 2.77
Working experience					
(years)	4	10.8	3	13	7.32 ± 2.44
< 5	29	78.4			
5 – 10	4	10.8			
>10					
Anthroprometric					
Height (m)			1.59	1.82	1.69 ± 0.06
Weight (kg)			50.4	72.2	60.42 ± 6.37
BMI (kg/m^2)			18.5	22.9	21.25 ± 1.13

The range and mean score of VGRF for semi squatting, half squatting, and deep squatting are presented in Table 2. The analysis of the mean value showed that the VGRF increased by 20.43 N or 6.61% to the mean score of 329.46 ± 14.85 N when compared between semi squatting and half squatting. The VGRF continued to show an increment when the angle of squatting increased from half squatting to deep squatting with 53.76 N or 16.32% to the mean score of 383.22 ± 52.63 N. When the mean of VGRF during semi squatting was compared with deep squatting, the VGRF increased by 74.19 N or 24%.

Table 2. *The Pairwise Comparison of VGRF between different angles of squatting*

Angle of Squatting		Mean Difference	Percentage Difference (%)	p^a
SS	HS	-24.11*	-7.42	.000
	DS	-31.73*	-9.76	.000
HS	SS	24.11*	7.42	.000
	DS	-7.62	-2.18	1.000
DS	SS	31.73*	9.76	.000
	HS	7.62	2.18	1.000

*. The mean difference is significant at the .05 level.
a. Adjustment for multiple comparisons: Bonferroni
SS: semi squatting,
HS: half squatting
DS: deep squatting
VGRF: Vertical ground reaction force

The result of repeated measures ANOVA revealed that there was a significant difference in VGRF produced between semi squatting, half squatting and deep squatting. Since the Mauchly Test of Sphericity was significant ($p > 0.05$), the result was corrected using Greenhouse-Geiser Epsilon and continued to show a significant different [F (1.36, 49.08) = 43.56] ($p < 0.05$). Therefore, the null hypothesis was rejected. The effect size was large (partial eta squared = 0.55). The Pairwise comparisons were conducted via Bonferroni adjustment between semi squatting and half squatting; half squatting and deep squatting and between semi squatting and deep squatting and all showed significant differences at $p < 0.05$.

DISCUSSION

The VGRF showed significant differences between the three angles (semi squatting, half squatting, deep squatting) of knee flexion. These study findings show the means of VGRF increased as the angles of squatting were increased from semi to deep squatting. The VGRF increased ranging from 309.03 N to 383.22 N (approximately 52.08% to 64.57% mean of Body Weight). To date, there were no other studies that have measured the VGRF during various angle of squatting. The VGRF in the same movement can be explained in relation to the Newton’s third law.

The Newton's third law states that, for every action or force, there is an equal but opposite reaction. Forces of action and reaction are equal in magnitude but in the opposite direction. This is crucial when upholding the principle of equilibrium and using tools that assess forces being applied to the body of interest. Reaction forces act to constrain motion by reacting to an applied force. The GRF acts simultaneously due to the weight of the body which is exerted in the opposite direction from the ground. As such, based on this concept, the different types of activity may produce different GRF to the body.

Although there was a different in the angle of squatting, the body does not receive any additional force since the body mass is not influenced by the position of the body without any external force such as acceleration of the movement. As such, when performing the same movement, with the same acceleration, although the angle of the movement was different, it will never produce different amount of VGRF on the body. Therefore, the increment of the VGRF as shown in this finding violated the Newton's third law and this condition was not possible without any other factors such as acceleration of the movement and external load from the exercise modalities such as dumb bell or bar bell.

The acceleration was identified as the main factors that cause the findings of this study violate the Newton's third law. The significant increment of the VGRF produced during different angle of squat exercise may be due to the movement cadence since the subjects were instructed to squat down until the desired angle and back to the starting position as fast as they can within 1 second. Considering that the distances of the squat movement increase with the increment of the angle of squatting, therefore, the subjects were needed to accelerate the movement more in the deeper squat exercise in order to fulfill the requirements based on the instruction given to squat as fast as they can within 1 second.

The Newton's second law supported these findings. According to the law, the force acting on the body is parallel and directly proportional to the acceleration and mass (F = ma) (DeLee et al., 2010; Luttgens & Wells, 1982). In other words, the force produced was influenced by the mass of the object and the acceleration of the movement. Since this study did not use or apply external load to the subjects, the acceleration is the best explanation for the findings. This finding is consistent with Bentley et al. (2010), which explained that the acceleration is a vector quantity that can alter the inertial force whether to decrease or increase during movement. Moreover, the force experienced by the musculoskeletal system is influenced by the inertial force. They also reported that the GRF was significantly higher in the faster acceleration of squatting (one second ascend and one second descend) compared to a slower acceleration of squatting. In recent studies, Jason (2011) and Yang (2011) have shown an agreement with the present study findings, using the different type of closed kinetic chain exercises in which acceleration was one of the components that can affect the force production during weight bearing activities.

Therefore, the result from this present study is consistent with the theory of Newton's 2nd Law (F= ma). Although the current finding showed a significant difference in VGRF at different angles of squatting, the increased in VGRF as the subjects moved into the deeper squat may be influenced by the acceleration of the movement. The findings indicated that in the rehabilitation program that involves squatting activity, the angle of squat exercise does not influence the VGRF acted on the foot.

CONCLUSION

This study suggests that the angle of knee flexion during squatting exercise may influence VGRF. Deep squatting was found to generate the highest VGRF compared to semi and half squatting. Thus, it is suggested that squatting may be best performed at smaller angle in order to avoid excessive force that may be detrimental to the joint surface.

Finally, the population that was used in the current study was healthy subjects. As such, the findings cannot be generalized to other population since the data for this study were gathered from military personnel who presented with different level and pattern of physical activity. Thus, it is recommended that for rehabilitation purposes, further study should be conducted using subjects with specific injuries or diseases. This will provide evidence that can be used to examine the effectiveness of the squat exercise in improving muscle strength.

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