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DIFFERENCES IN THE KNEE TORQUE BETWEEN HIGH- AND LOW-BAR BACK SQUAT TECHNIQUES: A PILOT STUDY

Janez LOGAR[1], Matej KLEVA[1], Uroš MARUŠIČ[2], Matej SUPEJ[1, 3], Mitja GERŽEVIČ[2]

[1]University of Primorska, Faculty of Mathematics, Natural Sciences and Information Technologies, Applied Kinesiology, Glagoljaška 8, Koper, Slovenia
[2]University of Primorska, Science and Research Centre, Institute for Kinesiology Research, Garibaldijeva 1, Koper, Slovenia
[3]University of Ljubljana, Faculty of Sport, Department of Biomechanics, Gortanova 22, Ljubljana, Slovenia

Corresponding Author:
Mitja GERŽEVIČ
University of Primorska, Science and Research Centre, Institute for Kinesiology Research, Garibaldijeva 1, Koper, Slovenia
Tel.: +386 5 663 77 30
e-mail: mitja.gerzevic@zrs.upr.si

ABSTRACT

Purpose: *The squat is one of the most frequently used exercises in sports training and competitions. There are several squat variations: i) the front squat (FS), ii) the high-bar back squat (HBS) and iii) the low-bar back squat (LBS). As the biomechanics of the LBS technique have been studied to a lesser extent, therefore the purpose of this pilot study was to analyze the differences in knee joint net muscle torque between the HBS and LBS.* ***Methods:*** *One healthy male subject (180.0 cm, 76.0 kg, 26 years) performed 10 steady paced squats (5 HBS and 5 LBS) with additional weight (40.4 kg) to a 90° knee angle. Kinematic and kinetic data were gathered using a high-speed camcorder and a force plate, respectively. The maximal and average knee joint net muscle torques (*M_{max} *and* M_{avg}*) were then calculated via 2-dimensional inverse dynamics.* ***Results:*** *A significantly greater* M_{avg} *was observed using the HBS technique as* *compared to the LBS, both during the entire range of the squat (M_{avgHBS} = 221.6 ± 5.1 Nm, M_{avgLBS} = 203.3 ± 10.2 Nm; p = 0.026) as well as during the eccentric (M_{avgHBS} = 226.0 ± 5.9 Nm, M_{avgLBS} = 202.0 ± 14.0 Nm; p = 0.043) and concentric (M_{avgHBS} = 216.2 ± 3.6 Nm, M_{avgLBS} = 205.0 ± 7.9 Nm; p = 0.021) phase separately.* ***Conclusions:*** *It can be concluded that the lower M_{avg} during the LBS could be due to the load transfer to the hip joint, most likely because of the greater anterior tilt of the torso, which is a direct response to a lower and more posterior bar placement on the back to finally maintain an unchanged centre of mass. Confirmation of these findings in a larger sample would imply that the LBS could be a more appropriate squat technique when knee joint relief is desired.*

Keywords: *inverse dynamics, force, kinematics, kinetics, weightlifting, powerlifting*

RAZLIKE V NAVORU V KOLENU MED POČEPOM Z VISOKO IN NIZKO POSTAVITVIJO DROGA ZA GLAVO: PILOTNA ŠTUDIJA

IZVLEČEK

Namen: *Počep je ena najpogosteje uporabljenih vaj v sklopu športne vadbe, treninga in tekmovanj. Poznamo več različic počepa: počep z drogom, naloženim i) na sprednjem delu ramen (FS), ii) za glavo na zgornjih vlaknih kapucaste mišice (HBS) in iii) za glavo čez grebena lopatic (LBS). Ker je biomehanika tehnike LBS manj raziskana, je bil namen te pilotne študije analizirati razlike v neto mišičnem navoru v kolenu med tehnikama HBS in LBS.* ***Metode:*** *En zdrav merjenec moškega spola (180,0 cm; 76,0 kg; 26 let) je z dodatnim bremenom (40,4 kg) v enakomernem ritmu opravil 10 počepov (5 HBS in 5 LBS) do kota 90° v kolenu. Kinematični in kinetični podatki so bili zajeti z visokofrekvenčno kamero in s pritiskovno ploščo. S pomočjo inverzne dinamike so bili nato v dvodimenzionalnem prostoru izračunani največji (M_{max}) in povprečni (M_{avg}) neto mišični navori v kolenu.* ***Rezultati:*** *Rezultati so pokazali značilno večje M_{avg} pri tehniki HBS v primerjavi s tehniko LBS tako med celotnim obsegom gibanja (M_{avgHBS} = 221.6 ± 5.1 Nm, M_{avgLBS} = 203.3 ± 10.2 Nm; p = 0.026) kot tudi med ekscentrično (M_{avgHBS} = 226.0 ± 5.9 Nm, M_{avgLBS} = 202.0 ± 14.0 Nm; p = 0,043) in koncentrično (M_{avgHBS} = 216.2 ± 3.6 Nm, M_{avgLBS} = 205.0 ± 7.9 Nm; p = 0,021) fazo počepa ločeno.* ***Zaključek****: Zaključimo lahko, da so nižji M_{avg} pri tehniki LBS posledica prenosa obremenitev na kolčni sklep, najverjetneje zaradi večjega nagiba trupa anteriorno, kar predstavlja neposreden odziv na nižjo in bolj posteriorno postavitev droga za glavo in s tem ohranjanja ustrezne pozicije težišča telesa na podporno površino. Potrditev teh ugotovitev* *na večjem vzorcu bi pomenila, da je tehnika LBS primernejša takrat, ko želimo razbremeniti kolenski sklep.*

Ključne besede: *inverzna dinamika, sila, kinematika, kinetika, dvigovanje uteži, powerlifting*

INTRODUCTION

The squat is one of the most widely used resistance exercises in the field of strength and conditioning (Schoenfeld, 2010) as it activates the largest, most powerful muscles in the body and is often regarded as the greatest test of lower-body strength (Escamilla, 2001; McCaw & Melrose, 1999).

The most studied variations of the squat are: the front squat (FS) with the bar held in front of the chest at the clavicle, the high-bar back squat (HBS) with the bar slightly above the level of the acromion across the upper trapezius muscles and the low-bar back squat (LBS) with the barbell positioned slightly below the level of the acromion across the spinae scapulae (Donnelly, Berg, & Fiske, 2006). Different variations of the squat are also an integral component in some sports. For example, in competitive weightlifting the FS is an essential component in the performance of the clean, whereas the HBS is most frequently used by athletes during strength training in various sports and by persons concerned with fitness (Gullett, Tillman, Gutierrez, & Chow, 2009). Conversely, the LBS technique is typical of competitive powerlifting (Schoenfeld, 2010).

In comparison with back squats, the FS has been found to produce lower maximal joint compressive forces on the knee and lower back, with little differences in shear forces and without compromising overall muscle recruitment in the quadriceps and hamstrings (Diggin et al., 2011; Gullett et al., 2009). However, due to flexibility limitations front squats are not as commonly used as back squats in training protocols. It must also be noted that for individuals untrained in the FS, this exercise should be eased into in order to maximize the loading stress on the target muscles while decreasing unnecessary stress to the relevant (particularly knee) joints via developing and exercising with proper techniques (Gullett et al., 2009).

As opposed to the upright posture while performing the FS, back squats require a more forward lean of the trunk in order to maintain balance and thus increase the load on the hip and back extensors (Braidot, Brusa, Lestussi, & Parera, 2007; Diggin et al., 2011; Fry, Smith, & Schilling, 2003). Several studies compared the biomechanics of front and back squats, however, the majority of previous studies focused mostly on 2D or 3D kinematics and / or kinetics of the front- vs. (high-bar) back-squat technique with different foot positions and squat depths, with (Gullett et al., 2009; Stuart et al., 1996) or without (Braidot et al., 2007; Diggin et al., 2011; Escamilla, Fleisig, Lowry, Barrentine, & Andrews, 2001; Russell & Phillips, 1989) muscle activation analysis. Swinton, Lloyd, Keogh, Agouris and Stewart (2012) performed a biomechanical comparison of the traditional HBS with a self-selected narrow stance and the powerlifting style squat, where they only took into account a wider stance and greater forward lean of the trunk during the powerlifting squat execution, but failed to consider the lower placement of the bar on the back.

Since no research has been performed comparing the load on the knee joint between the HBS and the LBS it is believed, but not yet demonstrated, that the LBS technique produces greater hip and back extensor torque and less knee extensor torque than HBS, which translates into reduced patellofemoral compression and anterior cruciate ligament (ACL) strain in the LBS (Watkins, 1999, in Schoenfeld, 2010). In order to evaluate one of these assumptions, the purpose of this pilot study was to analyze knee joint net muscle torque differences between the HBS and LBS technique, hypothesizing lower maximal / peak and average net muscle torques during the LBS. This knowledge has an important practical value for coaches and therapists when dealing with specific training goals or with acutely or chronically injured athletes and patients.

METHODS

Subjects

One healthy male subject (height 180.0 cm, weight 76.0 kg, BMI 23.5 kg·m^{-2}, age 26 years old), a student with five years of resistance training experience voluntarily participated in this pilot study. The study was performed according to the Helsinki declaration, while a written consent was not obtained since the measurements were performed within the framework of the study program at the University of Primorska.

Procedures

Six spherical reflective markers were placed over the 5th lumbar vertebra, spina iliaca anterior superior, greater trochanter, lateral knee, lateral malleolus and fifth metatarsal head on the subject's right leg. Two additional markers on the floor were used for space calibration. The subject was wearing dark, fitting clothes in order for the markers to be visible and stable (Figure 1).

After the marker placement, the subject performed a standardized 6-minute warm-up (stepping on 25-cm high bench, tempo 120 min^{-1}, changing the leading leg each minute) and three to five practice squats without weight plates on the barbell for each squat type to get familiar with the pace of execution and range of motion. Verbal, tactile and audio feedback was given to the subject before, during, and after each familiarization set of squats, as well as during the main measurements. To guarantee the same pace of each repetition of each squat technique, a metronome was used and set so that the eccentric as well as the concentric phase of the squat was performed in 2 seconds – totaling at 4 seconds. Each repetition was performed to the knee angle of approximately 90° in order to descend to the same depth. To ensure the same depth and the same knee angle at the lowest point of the squats, a box/case on the top of a chair was used (at a height of 57 cm). During the execution of the task the subject had to reach and touch it with his buttocks, thus ensuring a tactile feedback (Figure 1). The subject then performed a total of 10 squat repetitions with additional load (barbell with weight plates weighing 40.4 kg (53.2 % BM)), five of which were performed in the HBS and five in the LBS technique using a self-selected stance width in order to achieve the subject's most natural feet position. Each repetition was performed separately, starting with five sequential repetitions using the HBS technique, followed by five sequential repetitions using the LBS technique (without randomization). Before each repetition, the force plate was recalibrated. In order to prevent fatigue, one- to two-minute rest periods were provided between repetitions.

Figure 1: High-bar back squat (HBS; left picture) and low-bar back squat (LBS, right picture) technique and the measurement setup.

Measurements

The movement was captured at the frequency of 120 Hz in a sagittal plane using a high-speed camcorder (FUJI FINEPIX HS10, Fujifilm Corporation, Tokyo, Japan). Two reflectors (LOWELPRO-LIGHT, Lowel-Light Manufacturing, Inc., Hauppauge, NY, USA) with the power of 250 W were placed next to the video camera. A force plate (AMTI HE600600-2k, Advanced Mechanical Technology, Inc., Watertown, MA, USA) was used to collect 3D ground-reaction forces with the sampling frequency set at 1200 Hz. The video camera and the force plate were synchronized before the subject executed each repetition.

Each reflective marker was automatically recognized, digitized and scaled using AviMes AD 2.4 (ISC Matej Supej s.p., Kranjska Gora, Slovenia) software (Holmberg, Lund Ohlsson, Supej, & Holmberg, 2013; Rasmussen et al., 2012). 2D data (x, y coordinates) were then smoothed using a 2-pass second-order critically damped low-pass Butterworth filter with the cut-off frequency of 6 Hz. The position and magnitude of the lower-extremity segmental masses, their velocities, accelerations and moments of inertia for each movement repetition were estimated using mathematical models and the subject's anthropometric data according to Winter (2009). Using Matlab R2013a software (The Mathworks, Inc., Natick, MA, USA) the ground-reaction force data were first synchronized with video data and reduced to 120 Hz, and then the net joint reaction forces and joints' net muscle torques were calculated for the lower extremity using an inverse dynamic analysis that combined the anthropometric, kinematic, and ground-reaction force data (Winter, 2009). Due to the differences in the duration among the squat repetitions (ranging from 3.59 – 3.92 s for HBS and from 3.69 – 4.17 s for LBS), each repetition was normalized in the time domain to 100 %. For each repetition of each squat technique minimum knee angles (α_{minHBS}, α_{minLBS}), maximal/peak (M_{maxHBS}, M_{maxLBS}) and average (M_{avgHBS}, M_{avgLBS}) knee joint net muscle torques were calculated as dependent variables. This was done for the entire range of motion for each squat (descending and ascending phase together), as well as for the eccentric (descending) and concentric (ascending) phase separately. The calculations were performed in the range of motion from 160° to the lowest angle in the knee joint and back to 160°. Due to an error in the ground-reaction force data capture during the first HBS measurement, the first repetition of each squat technique was excluded from the analysis.

Statistical Analysis

Statistical analysis was performed with IBM SPSS Statistics 20 package (IBM Corporation, Armonk, NY, USA). Homogeneity of variances using the Levene's test and normality of data distribution using the Shapiro-Wilk's test were performed first. To test the differences between maximal and average net muscle torques between the HBS and the LBS technique, a Paired-Samples T-test was used. Statistical significance for all analyses was set at p-level < 0.05 (2-tailed).

RESULTS

All parameters were normally distributed ($p > 0.05$) and had homogeneous variances ($p > 0.05$). The average knee joint net muscle torques and angles during the whole movement for four repetitions with each squat technique (HBS and LBS) are presented in Figure 2. The results of the Paired-samples T-test showed no significant differences between minimum knee angle ($\alpha_{minHBS} = 98.1 \pm 0.3°$, $\alpha_{minLBS} = 96.7 \pm 1.1°$; $p = 0.064$; $\alpha = 180°$ means maximally extended knee) and a significantly greater average net muscle torque at the knee joint during the squats using the HBS technique compared to the LBS, both during the entire range of the squat ($M_{avgHBS} = 221.6 \pm 5.1$ Nm, $M_{avgLBS} = 203.3 \pm 10.2$ Nm; $p = 0.026$) as well as during the eccentric ($M_{avgHBS} = 226.0 \pm 5.9$ Nm, $M_{avgLBS} = 202.0 \pm 14.0$ Nm; $p = 0.020$) and concentric ($M_{HBSavg} = 216.2 \pm 3.6$ Nm, $M_{LBSavg} = 205.0 \pm 7.9$ Nm; $p = 0.041$) phase respectively (Figure 3). However, there were no differences in maximal knee joint net muscle torque values during the eccentric and concentric phase respectively, not even if the entire range of motion was considered ($p > 0.05$).

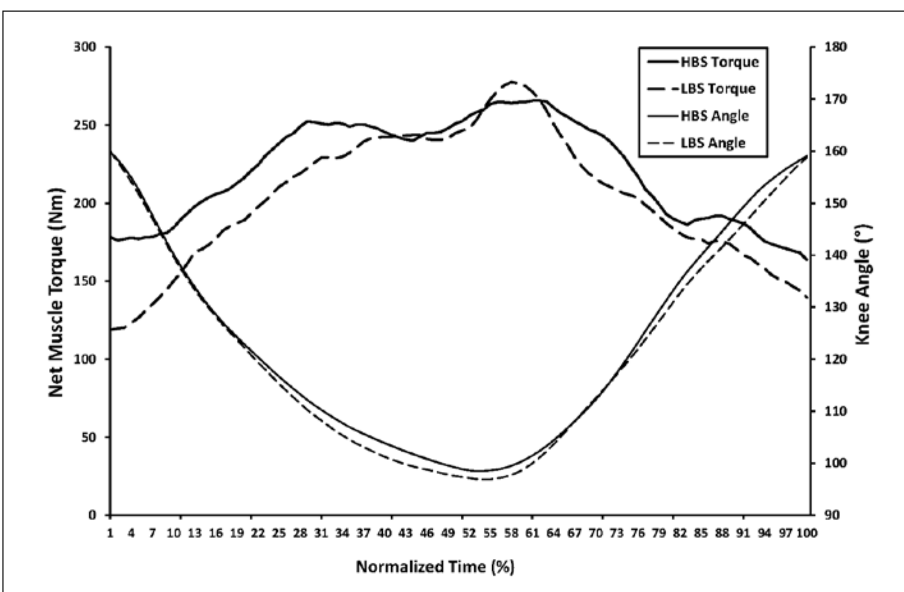

Figure 2: Knee joint net muscle torque and angle (average of 4 repetitions) during the high-bar back squat (HBS) and low-bar back squat (LBS).

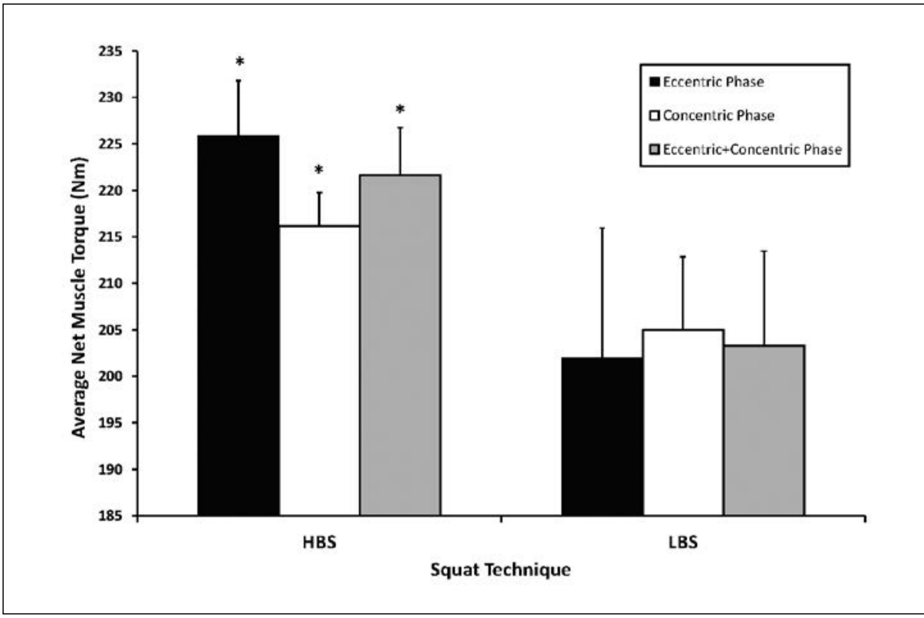

Figure 3: Average knee joint net muscle torques (M_{avg}) during the eccentric (black bars) and concentric (white bars) phase separately and during both eccentric and concentric phase together (grey bars). The asterisks (*) denote significant ($p < 0.05$) differences between the high-bar back squat (HBS) and low-bar back squat (LBS) technique. Averages and SDs of four repetitions of one subject are presented.

DISCUSSION AND CONCLUSIONS

The purpose of this pilot study was to analyze knee joint net muscle torque differences during the execution of two different squat techniques, the HBS and the LBS. The main finding was a significantly greater average net muscle torque at the knee joint while performing the HBS compared to LBS during the whole range of the squat as well as during the concentric and eccentric phase separately. However, there were no differences in maximal / peak net muscle torques.

Similarly to this study, Swinton et al. (2012) compared the HBS with a powerlifting style squat. However, they compared the HBS technique with a self-selected narrow stance to a powerlifting style squat, executed with a wider foot stance and a deliberate greater anterior inclination of the trunk. Moreover, Swinton and his colleagues (2012) failed to consider the lower position of the bar on the back while performing the powerlifting technique. Thus, they kept the high bar position constant during both squat variations and reported significantly greater peak torques at the hip and ankle joints during the HBS compared to the powerlifting style squat, while there were lower or no different peak torques at the lumbar spine as well as at the knee joint. This is in contrast to the findings of the present study, where greater knee joint net muscle torque was observed during the HBS, which is most likely due to differences in the study design, its protocols and observed techniques. Additionally, the subject maintained a constant squat depth as well as stance width during both techniques while only the bar position on the back was manipulated.

Based on the results of the present study it can be concluded that the lower net muscle torques at the knee joint could be due to load transfer to the hip joint and lumbar spine when the LBS technique was adopted. This is most likely due to greater anterior tilt of the torso, which was not measured but is evident from Figure 1. This is most probably a direct response to a lower and more posterior bar placement on the back to finally maintain the centre of mass unchanged and potentially translating into reduced patellofemoral compression and ACL strain during the LBS, as also proposed by Schoenfeld (2010). Thus, we can assume that the knee joint forces over the entire range of motion during the LBS are lower compared to the HBS.

On the other hand, in this study other joints' net muscle torques were not considered, which in addition to single subject measurements is one of the main limitations. Moreover, future research should examine 3D kinematic and kinetic as well as muscle activation differences at the ankle, knee, hip and lumbar spine with different foot position.

In conclusion, it has to be emphasized that the performed study represents a small, pilot scientific work, whose results are valid and entirely applicable solely for the subject taken into consideration and at present they cannot be generalized. However, a confirmation of these findings on a larger sample would imply that the LBS could be more appropriate when knee joint relief is desired. This could prove to be useful for coaches and therapists when dealing with specific training goals (i.e. precise localization of the training effects) or with acutely or chronically injured athletes and patients, such as patellofemoral problems, ACL or collateral ligament injuries.

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