JOINT LOADING AT DIFFERENT VARIATIONS OF SQUATS

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The purpose of this study was to identify the effect of squatting in a common, in a knee-shifted position and in an inclined position (3 cm heel lift) on joint loading. 16 male subjects were tested during squatting with an additional mass of 20 kg. Kinematic and kinetic recordings were performed by two force platforms (AMTI) and a ten infrared camera system (VICON). Inverse dynamics were calculated using a recursive multibody algorithm. Results showed significantly higher ankle dorsiflexion moments as well as higher knee varus moments for the knee-shifted performance. Due to the higher load on the ankle and the knee joint the knee-shifted variation should be avoided in squat training. The inclination of 3 cm does not lead to alterations of the joint moments and therefore does not lead to beneficial effects with respect to joint loading.

KEYWORDS: squats, joint loading, weight training.

INTRODUCTION: Due to the high biomechanical and neuromuscular similarity to sportive movements, such as running and jumping, and to daily living tasks, such as walking, getting up from a chair or step up or down stairs (Flanagan et al., 2003), squats are commonly used as exercise in general fitness training and in rehabilitation programs (Escamilla et al., 1998; Gullet et al., 2008). Also for elderly people the exercise is recommended to maintain their functional ability and, hence, help to provide their physical independence (Flanagan et al., 2003; Salem et al., 2003). Another aspect is the training of young athletes, at which muscle training always has to be considered with respect to functional and adequate joint loading. Squats can be conducted in many different ways. Variations include e.g. different squatting angles (Cotter et al., 2009; Salem & Powers, 2001), lifting additional weight (Cotter et al., 2009) as well as foot posture and stance width (Escamilla et al., 2001). Research focusing on these variations mostly shows little effect of the variations on joint loading. Cotter et al. (2009) prove different joint loading situations while performing squats with additional weight for varying squat angles of the knee. Escamilla et al. (2001) assert that a narrow stance for squat is characterized by lower tibio-femoral compressive forces than for a wide stance. No significant effects of variations in squatting angles (Salem & Powers, 2001) and in foot posture (Escamilla et al., 2001) are observed. Depending on the training goal, different effects might be aimed. In rehabilitation or recreational training the loading on the knee joint should be reduced, while in rehabilitating the patella tendinopathy more loading on the patella tendon seems to enhance the rehabilitation outcome. Good results are therefore reported for squatting on a declined surface, which increases the strain loading in the patella tendon (Kongsgaard et al., 2006; Frohm et al., 2007). Besides the different variations, recommendations are given for the common squat not to let the knee move across the virtual vertical line of the toe to minimize knee joint loading. Escamilla et al. (2009a, 2009b) analyzed cruciate ligament forces (2009a) and the patellofemoral joint force (2009b) at a long wall squat (feet farther from the wall - knee behind vertical line of toe) and short wall squat (feet closer to the wall - knee shifted over vertical line of toes). For the long wall squat higher PCL-forces, but lower patellofemoral joint forces compared to the short wall squat are exhibited, while no research is found though to study the effect of an “incorrect” performance of the common squat in weight training. Given the effect these variations might show, the knee-shift performance also might have an impact on joint loading. In case of any effects, however, they are supposed to be in a similar range as squatting on a declined surface.

Therefore, the aim of this study was to analyze joint moments of three squatting variations representing a common squat, a squat with the knee being shifted over the virtual vertical line of the toe (‘knee-shifted’) and a squat with elevated heels by positioning them on a block of 3 cm.

METHOD: 16 healthy male physically active students (25.1 ± 2.2 years, 183.0 ± 5.8 cm, 80.3 ± 7.6 kg) with no lower extremity injuries participated in this study. Kinematic and kinetic recordings were collected simultaneously by a 10 camera, three-dimensional motion analysis system (VICON, MX camera system, Oxford Metrics Ltd, UK; 200 Hz)[a] and two force platforms (AMTI, model ORG 6; Advanced Mechanical Technology, Watertown, MA, 1000 Hz) embedded in the floor. Reflective markers were placed according to the Vicon Plug In Gait (PIG) markerset[a] including additional markers on the medial epicondyles of the knee and on the barrel. Subjects were instructed to perform 3 different types of squats standing in a natural position. Each foot was standing on one force platform and an additional mass of 20 kg was lifted. The three variations consisted of a common performance (“common” - knees stay behind a virtual vertical line of the toes), a knee anterior shifted performance (“knee-shift” - knee moves across the vertical line of the toes) and a performance, where the subjects position their heels on a wooden block of 3 cm (“block” - block positioned under each heel). Squats were performed to a knee angle of 90°. Tactile feedback was given by a pole, which was positioned horizontally according to the subject’s body height. 8 repetitions were performed for each condition, with each repetition taking 4 seconds and 5 min resting period between each condition.
Sagittal and frontal plane moments were calculated for the hip, knee and ankle using the recursive multibody algorithm MkdTools (Simonidis & Seemann, 2010) and a model based on Zatsiorsky / Seluyanov Parameters (de Leva, 1996). Movements were filtered with a 4 Hz Butterworth filter. Maximum joint moments were identified for each repetition. Ensemble averages of the eight trials were calculated for each parameter. Peak moments are identified in sagittal plane as flexion moments of the hip and knee and as dorsiflexion moment at the ankle. In the frontal plane peak moments are identified as hip abduction moment, knee varus moment and ankle adduction moment (Figure 1) and are presented in Table 1.

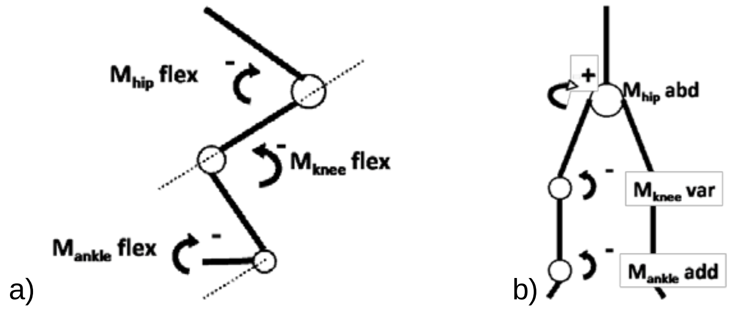

Figure 2. Peak moments of the ankle dorsiflexion moment (a), the hip adduction moment (b), the knee varus moment (c) and the ankle adduction moment (d).

Only the data of the right leg were considered for statistical analysis. The differences between the variations were statistically tested using an ANOVA with repeated measurements ($p < 0.05$).

RESULTS: Regarding the sagittal plane the ‘knee-shifted’ squat leads to a significant increase of the dorsiflexion moment in the ankle. This is indicated by an increase of 78% compared to the ‘common’ condition and an increase of 104 % compared to the ‘block’ condition (Figure 2.a). No other effects on the joint kinetics have been identified in the sagittal plane. In the frontal plane significant differences are observed at the knee for the ‘knee-shifted’ condition. Compared to the ‘common’ squat the knee varus moment is 127%

increased and compared to the ‘block’ condition it is increased by 94% (Figure 2.c). The variation of the squat also leads to alterations in the ankle abduction moment, with the least abduction moment for the ‘knee-shifted’ squat and the highest abduction moment for the ‘block’ condition (Figure 2.d).

Table 1. Mean maximum moments of hip, knee and ankle joint in sagittal and frontal plane of the right leg; mean (SD)

	common [Nm/BW]	block [Nm/BW]	knee-shift [Nm/BW]
Hip flexion moment	-0.92 (0.25)	-0.90 (0.28)	-0.93 (0.26)
Knee flexion moment	-0.70 (0.23)	-0.76 (0.26)	-0.75 (0.28)
Ankle dorsiflexion moment	-0.32 (0.14)	-0.28 (0.15)	-0.57 (0.2)
Hip abduction moment	0.19 (0.08)	0.17 (0.09)	0.16 (0.09)
Knee varus moment	-0.30 (0.27)	-0.36 (0.27)	-0.69 (0.51)
Ankle adduction moment	-0.03 (0.07)	-0.08 (0.07)	0.00 (0.06)

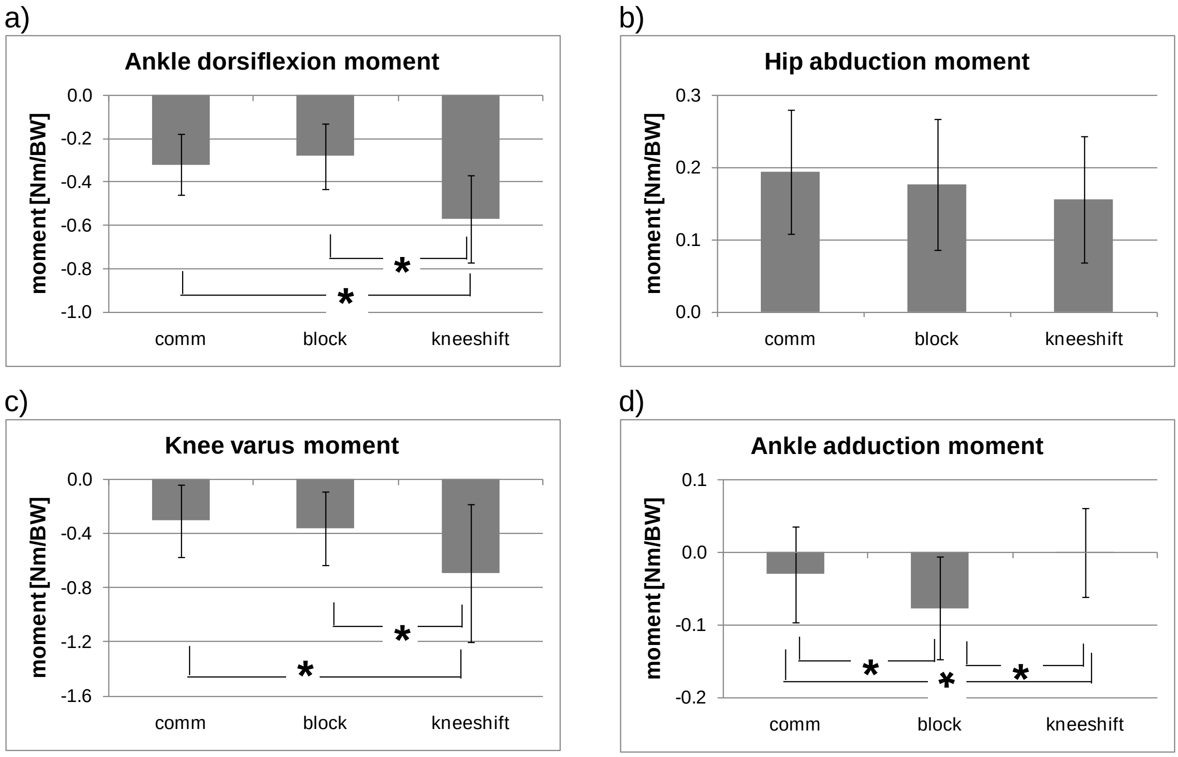

Figure 2. Peak moments of the ankle dorsiflexion moment (a), the hip adduction moment (b), the knee varus moment (c) and the ankle adduction moment (d).

DISCUSSION: The ‘knee-shifted’ condition with a relatively low additional weight does not affect the knee joint loading in the sagittal plane as one might expect. The only effect in the sagittal plane is a higher dorsiflexion moment at the ankle due to the extended anterior shift of the knee. In the frontal plane the maximum knee varus moment increases significantly. Due to the anterior movement the stabilisation of the knee might be reduced. Furthermore, this positioning leads to higher joint loading. The squat on a block does not lead to alterations in the joint kinetics in this study. Konsgaard et al. (2006) used a declined surface of 25° inclination, while the inclination at this study was ~10°. This inclination seems to be too low to lead to an alteration in the joint kinetics. At the ankle joint significant differences regarding the adduction moment are observed in each condition. Considering the relatively low values of these moments the relevance of these alterations might be neglected. Calculating the knee joint moments is the first step in understanding the forces in the knee joint. By producing a knee flexor moment a quadriceps extensor moment is also needed to hold the subject in equilibrium. Hence, a quadriceps force will be needed to generate this moment, which further has effects on single subcomponents of the knee such as tibiofemoral and patellofemoral compression forces or the forces on the anterior and posterior cruciate ligament (Escamilla, 2001). Therefore this paper only can give a first indication of the effects of variation in squatting technique. For further insight more specific knee models need to be applied to the present data.

CONCLUSION: The 'knee-shifted' squat does lead to higher ankle dorsiflexion moments and higher knee varus moments and should, consequently, not be recommended especially for the fitness training in juvenile and elderly athletes. No effect was found in squatting with the heel standing on a block of 3 cm height, despite a higher, but still very low adduction moments at the ankle joint. The chosen heel elevation seems to be too low to lead to signifcant alterations of joint loading. Most likely, however, the stress on the Achilles tendon might be reduced. Alterations in the ankle adduction angle at the three variations exist, but the relevance of these alterations has to be investigated more specifically.

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