INFLUENCE OF THE STEP LENGTH AND POSITION OF THE FRONT KNEE ON THE LOAD CONDITIONS OF THE KNEE AND HIP DURING LUNGES

Pascal Schütz[1], Renate List[1], Roland Zemp[1] and Silvio Lorenzetti[1]

Institute for Biomechanics, ETH Zurich, Switzerland[1]

The aim of this study was to quantify the differences in the loading conditions of the lunge strength exercise at different step lengths and different tibia angles of the front leg. Eleven subjects performed lunges with 25 % body mass (BM) barbell extra load on two force plates. The movement was recorded with a motion capture system. The angles and the forces were calculated using inverse dynamics. A larger tibia angle led to a smaller ROM of the front knee, a larger ROM of the rear knee and hip, whereas a larger step length decreased the ROM of the rear knee and hip. A larger tibia angle resulted in a decreased moment in the front knee, front and rear hip and an increased moment in the rear knee. This possibility for varying the angles and corresponding moments allows coaches and therapists to adapt the lunge to an efficient exercise for strength training.

KEY WORDS: strength exercise, lunges, loading conditions, movement analysis.

INTRODUCTION: Besides squats, lunges are the most common exercise for the legs. Lunges are mainly an exercise to dynamically strengthen the gluteus maximus, the quadriceps, the hamstrings and the muscles of the lower leg. It is a multijoint, closed kinetic chain and weight bearing exercise (Flanagan, Wang, Greendale, Azen & Salem, 2004). The benefits for the hamstring strength and the sprint performance were shown for walking forward lunges and jumping forward lunges, respectively (Jönhagen, Ackermann & Saartok, 2009). Lunges are often used in athletics (especially for sports with single leg movements), rehabilitation (for example after anterior cruciate ligament (ACL) injuries) and for elderly people maintaining their fitness for daily life activities.
Based on a fitness centre accident report (Müller, 1999), most injuries occur due to misbehaviour of the customers, 21 % are due to wrong exercise execution and 45.6 % due to overload. There are multitudes of guidelines how to perform lunges. They especially focus on the knee position and the step length.
Therefore the aim of this work is to study the influence of the step length and the tibia angle of the front leg on the angles and moments of the knees and hips.

METHODS: Kinematics and kinetics of the lunge movement were evaluated using a 12 camera 3D Vicon (Oxford, UK) system. The eleven healthy subjects were all students of movement science with experiences in weight lifting. The average age was 24.9 ±2.5 y, the leg length 90.3 ±4.5 cm and the weight 68.1 ±8.8 kg. This study was approved by the Swiss Federal Institute of Technology Zurich ethics committee. The subjects performed lunges with 25% body mass (BM) extra load using a barbell. The barbell was positioned on the trapecius muscle. To control the tibia angle in the sagittal plane, the side view of the subject was recorded with a video camera and projected on a screen (Figure 1). The execution types differed in the tibia angle (60º, 75º, 90º and 105º, a larger angles means more plantarflexion) and the step length (55%, 70% and 85% of the leg length). With a tibia angle of 105°, only the 85% step length lunges were possible to be performed. The subjects were instructed to keep the spine in an upright normal lordotic position. To determine the force of each foot, two Kistler force plates (Winterthur, CH) were used. The marker set consisted of 53 skin markers for the body (Bachmann, Gerber & Stacoff, 2008) and two for the barbell. The sagittal plane angles and moments were calculated with inverse dynamics based on functional defined joint centres using Matlab (Lorenzetti, Stoop, Ukelo, Gerber, Stacoff & Stüssi, 2009). The moments were normalized to BM for each subject, the ROM was defined as the maximal joint angle minus the minimal joint angle during the repetition.

Differences between the execution type for the ROM of the knee and hip as well as the corresponding moment were tested with a Wilcoxon-test. The significance level was set at $p<0.05$.

RESULTS: In general, dependent on the execution type, the moments and the angles in the knee and hip can be influenced (Figure 2). Comparing the loading conditions of the front and the rear leg, the moments in the front hip were larger than in the rear hip and the moments in the front knee were smaller than in the rear knee.

The ROM of the knee in the front leg was dependent on the tibia angle for all step lengths (p<0.003), but not dependent on the step length (p>0.182). With smaller tibia angles, the ROM of the front knee increased. The rear leg showed a different behaviour of the ROM of the knee. At 70 % and 85 % step length, the ROM decreased with a smaller tibia angle (p<0.003), whereas at 55 % step length no changes of the ROM were observed (p>0.11). At the rear leg, the ROM of the knee increased with a smaller step length (p<0.003). Only little changes were observed in the ROM of the hip of the front leg. At a tibia angle of 75º and 90º, a larger step length reduced the ROM (p<0.026, except at 75º, the ROM for 70% and 85% were the same). Nevertheless, the tibia angle as well as the step length changed the ROM of the rear hip (p<0.021 respectively p<0.008). A larger tibia angle led to a smaller ROM of the front knee, a larger ROM of the knee and hip of the rear leg, whereas a larger step length reduced the ROM of the rear knee and hip.

The moment of the front knee increased for a smaller step length at a tibia angle of 60º and 75º (p<0.05, except for 70% and 85% at 60º). A larger tibia angle resulted in a smaller moment of the front leg (p<0.041). This conditions resulted in a larger moment at the rear leg (p<0.041). The influence of the step length on the moment of the knee in the rear leg showed no uniform shape. The observed changes were smaller than 4.3%. Although not all changes of the conditions were significant, the moment in the front and rear hip seemed to increase with step length. A similar behaviour was observed for the variation of the tibia angle. A larger tibia angle resulted in smaller moments for the front and rear hip. A larger angle of the tibia leads to a smaller moment in the front knee, front and rear hip and a larger moment in the rear knee.

The angle moment profiles (AMP) of lunges are given in Figure 3. The maximal moments in the front and rear knee occur at the maximal knee angle, at the deepest point of the movement. Due to the start position of the lunges, the moment in the knee changes the algebraic sign during the movement. In the beginning, the hamstring muscle have to prevent the knee from extending, at the end of the movement, the quadriceps has to extend the knee. This is not the case for the rear leg.

The largest changes of the angle and the moment for the studied execution types were observed in the rear hip. The ROM and the moment are highly dependent on the tibia angle and the step length.

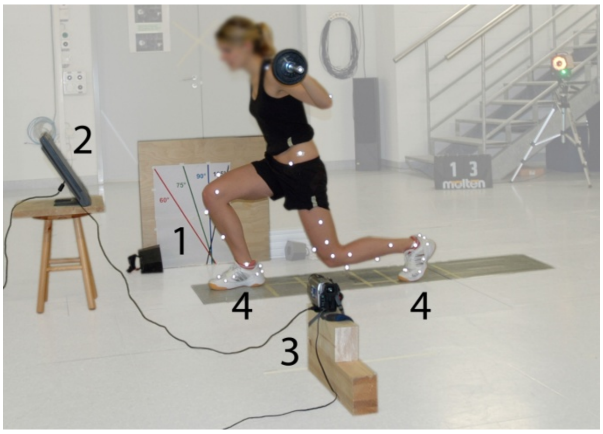

Figure 1: Experimental set up. 1 protractor, 2 screen with the sagittal view, 3 video camera, 4 force plates.

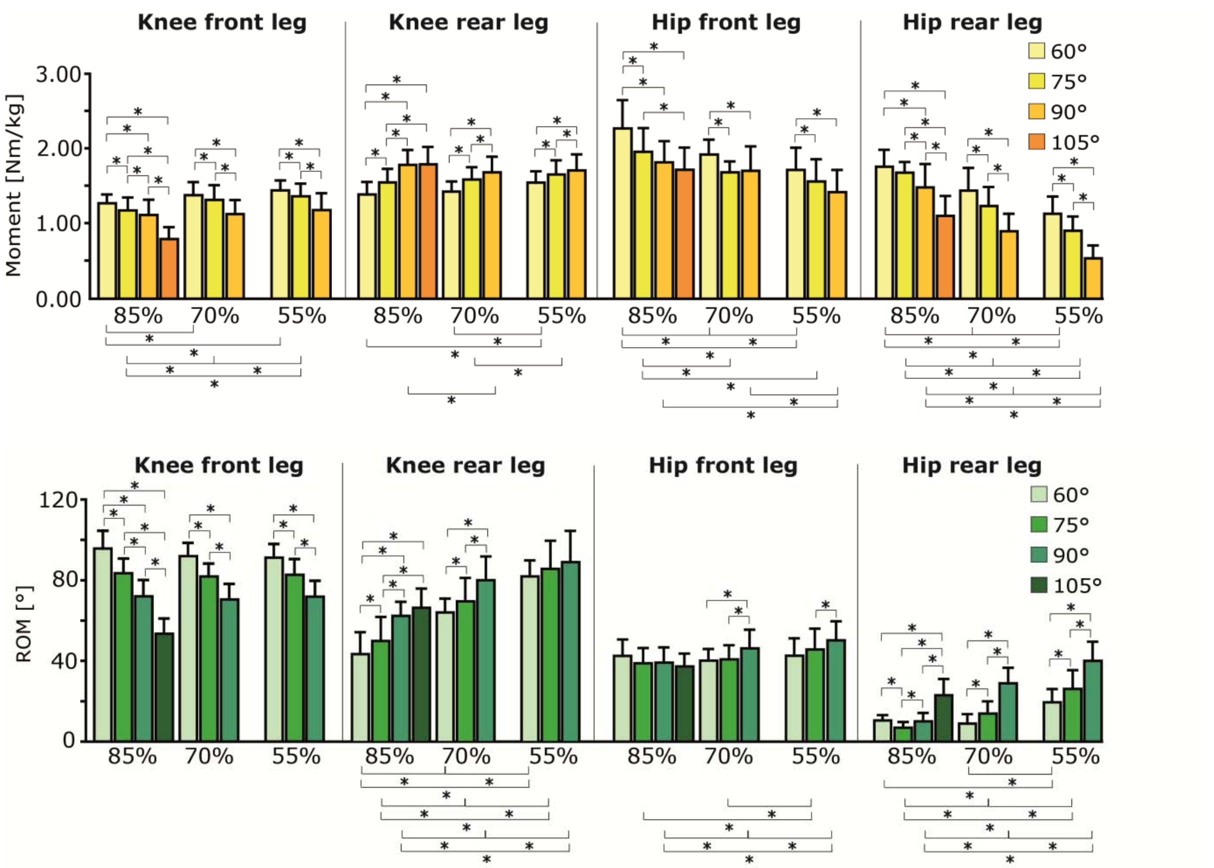

Figure 2: Sagittal plane ROM and moments of the knees and hips for different step lengths and different tibia angle of the front leg.

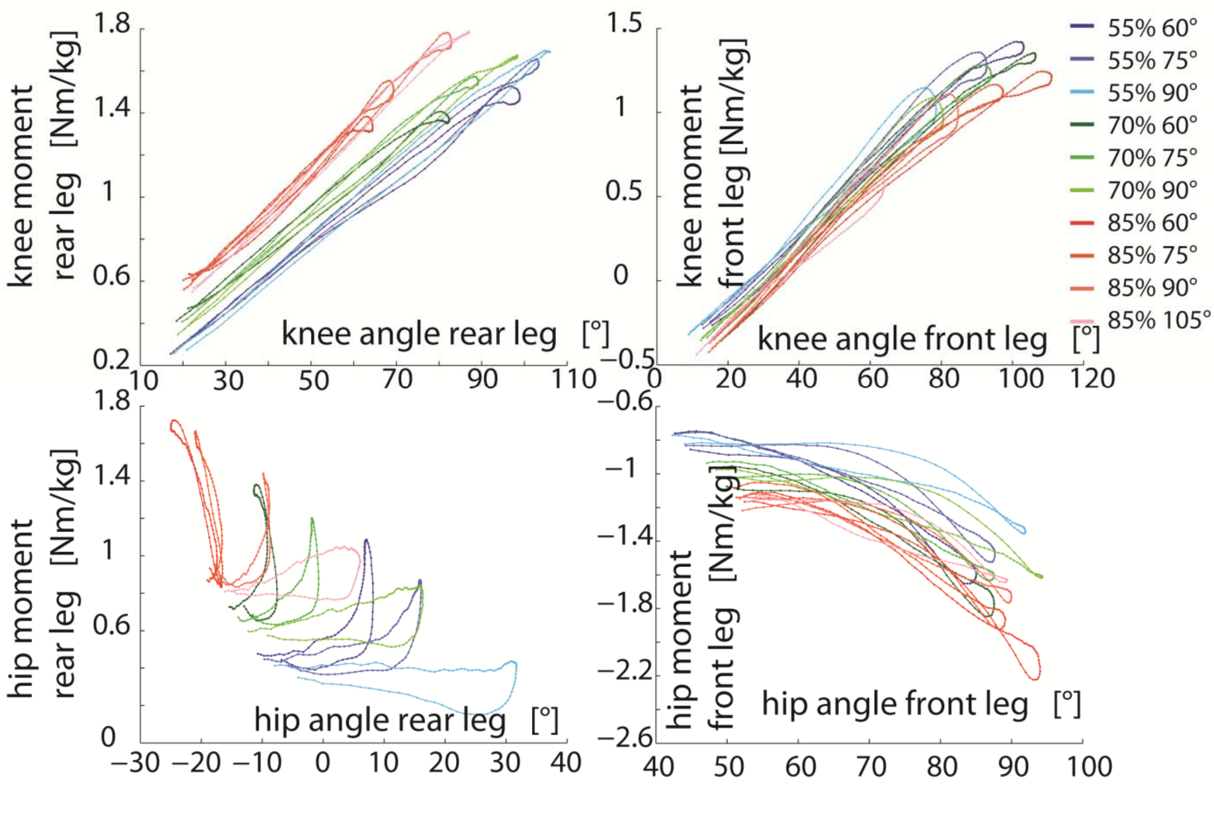

Figure 3: AMP. Left top: Rear knee angles (º) vs. moments (Nm/kg) for the different conditions. Left bottom: Rear hip angles (º) vs. moments (Nm/kg). Right top: Front knee angles (º) vs. moments (Nm/kg). Right bottom: Front hip angles (º) vs. moments (Nm/kg).

DISCUSSION: The change of the angle of the front tibia is in fact mainly due to a change of the load distribution between the front and the rear leg. The direction of the spine is chosen, such that the load of the lower back is minimized. Hence a shift of the centre of mass during lunges requires changes of the knee and hip angles. At a certain depth of the execution, this results directly in a change of the angle of the frontal tibia. Hence this angle can be taken as a precursor of the mass distribution between the front and the rear leg.

The observed linear behaviour of the rise of the moment in the knee with the flexion of the knee is well known from the squat movement (Gülay, List & Lorenzetti, 2011). It is also consistent with the rise of the retro patellar force with the knee angle (Escamilla, Zheng, MacLeod, Edwards, Hreljac, Fleisig, Wilk, Moormann & Imamura, 2008). The maximal moments during lunges are in general larger than for the squat exercise. This is mainly due to larger moment arms. Furthermore, the maximal knee angles are also larger for the lunge exercise. These two factors are showing that lunges can result in higher moments in the lower extremities with lower extra load of the barbell resulting in a larger challenge for the lower body and a decrease of the load of the back.

The given AMP allows a coach to adapt the sport specific demand on the leg performance to the training. The possibility to vary the execution type opens an individual lead condition at a certain angle. This increases the efficiency of a work out. For therapeutic strength training, the AMP allows to avoid painful hip and knee angles. Furthermore, the load on a certain joint can be estimated and guided in a favourable range for the rehabilitation. As example for practical purposes, a subject that should reduce the moment of the rear hip choses a step length of 55% and an angle of the tibia of 90°, this results in a moment <0.6 Nm/kg whereas a subject that has to avoid a hip extension of -15° should not choose a step length of 85% of the leg length.

CONCLUSION: This study showed the influence of step length and angle of the frontal tibia on the ROM of the knees and hips and on the load distribution of the lower extremities. A larger angle of the tibia leads to a smaller ROM of the front knee, a larger ROM of the knee and hip of the rear leg, whereas a larger step length decreases the ROM of the rear knee and hip. A larger angle of the tibia leads to a smaller moment in the front knee, front and rear hip and a larger moment in the rear knee. The ROM of the knee and the moments are larger compared to the squat exercise. The gained knowledge about the nature of lunges allows coaches and therapists to adapt the lunge exercise to the demand of the customers to prevent them from under- or overloading the body.

REFERENCES:

Bachmann, C., Gerber, H., & Stacoff, A. (2008). Messsysteme, Messmethoden und Beispiele zur instrumentierten Ganganalyse. *Schweizerische Zeitschrift für Sportmedizin und Sporttraum*. 2, p.29-34.

Escamilla, R.F., Zheng, N., MacLeod, T.D., Edwards, W.B., Hreljac, A., Fleisig, G.S., Wilk, K.E., Moorman, C.T. 3rd & Imamura, R. (2008). Patellofemoral compressive force and stress during the forward and side lunges with and without a stride. *Clinical Biomechanics*. 23(8) 1026-1037.

Flanagan, S. P., Wang, M-Y., Greendale, G. A., Azen, S. P. & Salem, G. J. (2004). Biomechanical attributes of lungeing activities of older adults. *Journal of Strength and conditioning research,* 18(3), 599-605.

Gülay, T., List, R., & Lorenzetti, S. (2011). Moments in the knee and hip during descent and ascent of squats. Proceedings 29th ISBS 2011, Porto, P.

Jönhagen, S., Ackermann, P., & Saartok, T. (2009). Forward lunge: a training study of eccentric exercises of the lower limbs. *Journal of Strength and conditioning research,* 23(3), 972/978.

Lorenzetti S., Stoop, M., Ukelo, T., Gerber, H., Stacoff, A., & Stüssi, E. (2009). Comparison of angles and the corresponding moments in knee and hip during restricted and unrestricted squats. Proceedings 27th ISBS 2009, Limerick UK.

Müller R. (1999) Fitness-Center – Verletzungen und Beschwerden beim Training. *BFU Report.* Switzerland.