DO FUNCTIONAL PERTURBATIONS AFFECT ROTATIONAL KNEE JOINT KINEMATICS?

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The purpose of this study was the assessment of rotational knee joint kinematics following a functional perturbation. Perturbations were applied at different phases of the gait cycle with the subjects (n=18) running on a treadmill. During half of the trials a dual task was applied. A statistical comparison took place between strides with and without perturbations applied, showing significant differences. Therefore, the method presented in this study of the application of perturbations to mimic situations in which knee injuries are known to occur, resulted in changed rotational knee joint kinematics.

KEY WORDS: joint stability, dual task, stance phase.

INTRODUCTION: Knee joint injuries account for up to 36% of all athletic injuries and were found to have an increasing incidence rate (Steinbrück, 1999). Up to 60% of all sports-related surgeries are performed on the knee joint (Powell & Barber-Foss, 2000) and traumata to the anterior cruciate ligament (ACL) are estimated to account for half of these knee surgeries. Although different studies agree that an impulsive load on the lower extremity during landing leads to ACL injuries, there is still dispute whether this is combined with a forcefully rotated tibia in external (Harmon & Ireland, 2000) or internal direction (McLean, Huang, Su & Van Den Bogert, 2004). Knee joint injuries are frequently related to perturbations (pert.), leading to injurious motions. Rotational moment pert. may therefore be of specific importance and have not yet been dynamically applied in a functional setting. Hence, in the present study we assessed the degree of maximal internal rotation (MIR) and maximal external rotation (MER) of the knee joint following an internal and external moment pert. First, we expected an increased MIR with perturbations towards the front while those towards the back were expected to cause increased MER. Second, as joint moments and therefore stiffness is expected to vary over the single leg support, we applied perturbations at the beginning and at the end of the single leg stance phase. Since Dixon et al. (2010) found knee joint stiffness to be higher at early stance phase, we anticipated that MIR and MER in response to the perturbations would be larger at the beginning of the stance phase. Third, we applied a cognitive dual task during half of the trials, to mimic dynamic situations that require mental demands. Athletes simultaneously make use of their cognitive and physical capabilities. As Swanik et al. (2007) found significant differences in reaction time, processing speed, visual and verbal memory between a group of ACL injured subjects and healthy controls, we expected an increase in MIR and MER to occur during trials with DT compared to those without dual task (no DT). Finally, we investigated differences between gender, as females have been shown to sustain ACL injuries more often than males.

METHODS: Participants included in the present study were 18 healthy active subjects (9 male, 9 female, age: 24.63.7). Subjects were asked to run on a treadmill, wearing a belt around the pelvis with two ropes attached to it. A custom-made device, which is described in more detail by Bruijn, Meijer, Beek, & van Dieën (2010), was used to apply pert. with the ropes pulling either towards the front or the back of the subject. This way a rotational moment of the pelvis and femur relative to the tibia was produced (Figure 1). Pert. were given at 10% and 50% of the GC, reflecting the beginning and the end of the single leg support phase (Bogey, Gitter, & Barnes, 2010). Subjects performed a DT in form of a Stroop-test during half of the trials to challenge neurocognitive capacities (Stroop, 1935). The name of a color was presented on a large screen in front of them. It was either printed in a congruent or incongruent color. The printed color had to be announced. All conditions were performed in a randomized order. A 3D kinematic analysis of the right leg was conducted using a 6-camera motion capture system (Optotrak, Northern Digital Inc., Waterloo, Canada) at a sampling frequency of 100 Hz. Marker clusters, consisting of three infrared light emitting diodes (IRED) each, were applied to the pelvis, femur, calf and feet. The cluster affixed to the femur was attached to an epicondylar frame around the knee joint. The frame used was identical to the one described by Zürcher Wolterbeek, Harlaar, & Pöll, (2008). Anatomical landmarks were chosen according to Cappozzo, Catani, Croce, & Leardini (1995) to construct local coordinate systems. A reference posture was recorded to define the neutral position of the joints. Offline all data were digitally low pass filtered (Butterworth, cut off frequency 6 Hz). The kinematic data were analyzed using Matlab software (Matlab 7.7, Mathworks, Natick, MA, USA). Peak angular displacement of the knee joint between the onset of the pert. and 200 ms following it was determined. To clarify, the knee motions described in the present paper are defined as followed: Knee internal/external rotation as tibia internal/external rotation relative to the femur in the transverse plane. All values are given in degrees.

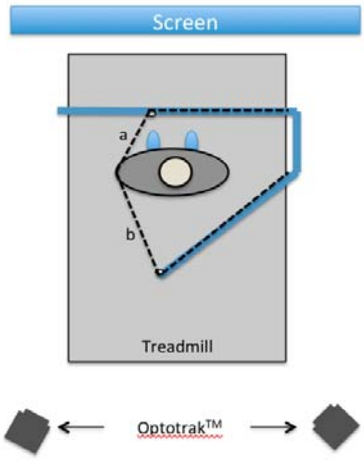

Figure 15: Experimental set-up (top view). Dotted lines represent the ropes connected to the subject's pelvis. a: rope pulling forward, causing an internal rotation, b: rope pulling backward, causing an external rotation. Optotrak cameras were mounted on bars, 3 cameras vertically in a row.

To test for differences between the conditions or between gender for MER and MIR in the knee joint kinematics following a pert., the data were submitted to two 2 x 2 (gender [male, female] x measurement conditions [DT, no DT; 10% GC, 50% GC]) mixed design ANOVAs. One ANOVA was performed using the data collected for MER and the other for MIR. ηp2 was used to determine the effect size and. Absolute values were used for the calculations meaning the difference between the data before a pert. and the data following a pert.. A one-way between subjects ANOVA was calculated to examine interaction effects. The intercept of the statistical model was used as a primary test of the effect of a pert. As a specific test of the effect of the pert. per condition, we subsequently applied paired t-tests to determine whether there was a significant difference between the kinematic data before and following a pert. within each condition. 95% confidence intervals (CI) were calculated. For all statistical tests α was set at 0.05.

RESULTS: The calculated intercepts for MER ($F(1,16) = 6.65$, $p = 0.02$, $\eta_p^2 = 0.29$) and MIR ($F(1,16) = 11.34$, $p < 0.01$, $\eta_p^2 = 0.42$) were found to be significant which suggests an effect of the pert. on knee kinematics. In agreement with those findings, the significant t-test results support the hypothesis of changed knee kinematics following a pert. (Table 1). None of the conditions investigated had a significant main effect on the kinematics of the knee joint.

However, a clear trend was proven for gender to have a main effect on MIR ($F(1,16) = 4.15$, $p = 0.06$, $\eta_p^2 = 0.21$). Males ($M = 7.21$, SD = 11.69) showed an increased effect of the pert. compared to females ($M = 1.77$, SD = 9.2).

Table 8: Paired t-test results comparing steps with pertuerbation to steps without perturbation.

	NoDT 10% GC	NoDT 50% GC	DT 10% GC	DT 50% GC
MER	M = -0.15 ±9.5, p = 0.95, 95% CI[-4.57, 4.88]	M = -3.15 ±4.69, p = 0.01, 95% CI[-5.49, 0.82]	M = -6.16 ±10.41, p = 0.02, 95% CI[-0.99, 11.34]	M = -2.2 ±4.7, p = 0.06, 95% CI [0.14, -4.54]
MIR	M = 7.87 ±10.63, p = 0.01, 95% CI [2.58, 13.15]	M = 5.31 ±10.65, p = 0.05, 95% CI [0.02, 10.61]	M = 1.06 ±9.57, p = 0.65, 95% CI[-2.26, 5.82]	M = 3.71 ±11.75, p = 0.2, 95% CI [9.56, -2.13]

A significant interaction was proven for DT*GC in MER ($F(1,16) = 4.78$ $p = 0.04$ $\eta_p^2 = 0.23$). If pert were applied at 50% GC a decrease in external rotation was found in trials without DT compared to those with DT. If pert. were applied at 10% GC, an increase in external rotation appeared (Figure 3). No further significant interactions were found. In agreement with our hypothesis we found MIR to increase when pert. were applied towards the front and MER to increase when pert. were applied to the back of the subject during running. A clear trend can be seen for trials at which pert. were applied towards the back at 50% GC while a DT was performed.

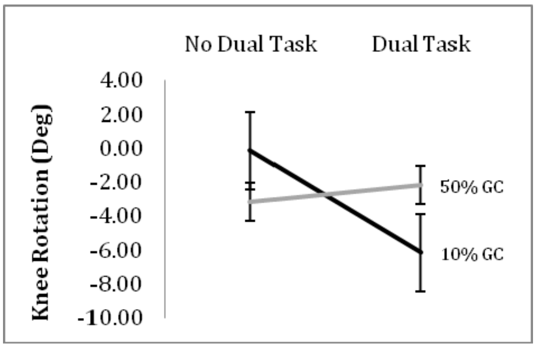

Figure 2: Interaction effect in MER. Data is presented as mean, error bars represent SE.

DISCUSSION: Within the current study differences were found in knee joint kinematics before and after the application of a pert. To interpret the practical significance of the results, 95% CIs were calculated. No explicit clinically relevant data is presented in the literature on excessive rotational kinematics (Shimokochi & Shultz, 2008). Markolf, Gorek, Kabo, & Shapiro (1990) state that tibia rotation in either direction highly increases strains at the ACL with internal rotation generating higher forces. Therefore even a small increase in rotation of 2° is considered a potentially harmful effect of a pert. In some measurement conditions pert. did not have an effect if a DT was performed. According to the findings of the present study conscious movement control may not be used when regulating knee joint kinematics following a pert. Our findings are in agreement with the results by Resch, May, Tomporowski, & Ferrara (2011) who revealed that postural balance was either maintained or improved if a DT was performed. Maintaining the intended trajectory in the knee joint is therefore assumed to be of higher priority than accomplishing a DT. The stance phase at which pert. were applied had a varying effect on the kinematics, also in interaction with the performance of the DT. Differing information can be found in the literature on the timing of peak ACL loading within the gait cycle (Shimokochi & Shultz, 2008). Future research should therefore focus on further clarifying the stance phase at which most knee injuries occur to specify pert. timing. An interesting finding of the current study is the trend of male participants to show a stronger effect of internal moment perturbations than females. Markolf et al. (1990) found internal rotations to highly increase strains at the ACL. However, those strains were decreased significantly with increasing knee flexion angles. Males may increase knee flexion compared to females resulting in higher strains at the ACL of the latter and therefore increasing the risk of injuring the ligament. This explanation remains hypothetical and further research should be conducted including the identification of knee flexion angles. There is disagreement in the literature with regard to the rotational direction of the tibia during ACL injuries. A feasible explanation for these diverse findings could be the occurrence of varying injury mechanisms. Subjects with decreased stiffness in the knee joint in external rotation may be more prone to an injury mechanism involving high strains in external rotation. Those with a decreased stiffness in the direction of internal rotation may therefore be more susceptible to a mechanism involving excessive strains in internal rotation. The quantity of directional stiffness may be tested using the method described in this study. Training programs should then focus on stiffening the joint in a specific direction in dependence of the test outcome.

CONCLUSION: The present study has shown that kinematic changes exist following rotational loading of the knee joint through the application of a functional pert. Specific training programs should be set up to stiffen the joint through muscular contraction. The outcome of testing excessive knee motion following a pert. in internal and external direction will help clarify the rotational direction in which knee joint stiffness is lacking, eventually leading to decreased incidence rates of knee injuries in athletes.

REFERENCES:

Bogey, R.A., Gitter, A.J., & Barnes, L.A. (2010). Determination of ankle muscle power in normal gait using an EMG-to-force processing approach. *Journal of Electromyography and Kinesiology,* *20*(1), 46-54.

Cappozzo, A., Catani, F., Croce, U.D., & Leardini, A. (1995). Position and orientation in space of bones during movement: anatomical frame definition and determination. *Clinical Biomechanics, 10*(4), 171-178.

Dixon, S.J., Hinman, R.S., Creaby, M.W., Kemp, G., & Crossley, K.M. (2010). Knee joint stiffness during walking in knee osteoarthritis. *Arthritis Care & Research*, *62*(1), 38-44.

Harmon, K.G., & Ireland, M.L. (2000). Gender differences in noncontact anterior cruciate ligament injuries. *Clinics in Sports Medicine*, *19*(2), 287-302.

Hewett, T.E., Myer, G.D., Ford, K.R., Heidt, R.S., Colosimo, A.J., McLean, S.G., van den Bogert, A.J., Paterno, M.V. & Succop, P. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *The American Journal of Sports Medicine*, *33*(4), 492-501.

Markolf, K.L., Gorek, J.F., Kabo, M.J., & Shapiro, M.S. (1990). Direct measurement of resultant forces in the anterior cruciate ligament. An in vitro study performed with a new experimental technique. *The Journal of Bone and Joint Surgery*, *72*(4), 557-567.

McLean, S.G., Huang, X., Su, A., & Van Den Bogert, A.J. (2004). Sagittal plane biomechanics cannot injure the ACL during sidestep cutting. *Clinical Biomechanics*, *19*(8), 828-838.

Powell, J.W., & Barber-Foss, K.D. (2000). Sex-related injury patterns among selected high school sports. *The American Journal of Sports Medicine*, *28*(3), 385-391.

Resch, J.E., May, B., Tomporowski, P.D., & Ferrara, M.S. (2011). Balance performance with a cognitive task: a continuation of the dual-task testing paradigm. *Journal of Athletic Training*, *46*(2), 170-175.

Shimokochi, Y., & Shultz, S.J. (2008). Mechanisms of noncontact anterior cruciate ligament injury. *Journal of Athletic Training*, *43*(4), 396-408.

Steinbrück, K. (1999). Epidemiologie von Sportverletzungen - 25-Jahres-Analyse einer sportorthopödisch-traumatologischen Ambulanz. *Sportverletzungen Sportschäden*, *13*, 38-52.

Stroop, J.R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*, 643-662.

Swanik, C.B., Covassin, T., Stearne, D.J., & Schatz, P. (2007). The relationship between neurocognitive function and noncontact anterior cruciate ligament injuries. *The American Journal of Sports Medicine*, *35*(6), 943-948.

Zürcher, A.W., Wolterbeek, N., Harlaar, J., & Pöll, R.G. (2008). Knee rotation during a weightbearing activity: influence of turning. *Gait & Posture*, *28*(3), 472-477.