FOOT POSITION AFFECTS KNEE JOINT TORQUE IN ERGOMETER ROWING

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Recreational and competitive athletes use rowing ergometers for aerobic exercise. Little is known about the impact of foot position on knee joint loads during this exercise. The aim of this study was to investigate the effect of foot position on hip joint kinematics as well as knee adduction and knee rotation torques. It was hypothesized that altering the foot position to a more lateral placement on a rowing ergometer would mediate knee joint torques. Data supported the hypothesis that a significant change of knee adduction torque as well as reduced external rotation torques in the knee joint would accompany more lateral foot positioning. These results support the development of adjustable foot rests for rowing ergometers to better modulate knee forces.

KEY WORDS: rowing, inverse dynamics, biomechanical modelling, motion analysis

INTRODUCTION: Rowing ergometers are widely used for aerobic exercise in health and fitness centers as well as for off water training in rowing. Previous studies have shown that parameters like ergometer design, skill level, and fatigue have significant effects on movement kinematics and kinetics (Hase, Kaya, Zavatsky, & Halliday, 2004; Hislop, Cummins, Bull, & McGregor, 2010; Mackenzie, Bull, & McGregor, 2008). In a previous study, Roemer et al. (2013) analyzed knee joint torques in normal weight and obese subjects with results suggesting that knee alignment with ankle and hip joints in ergometer rowing can be compromised by foot position. Standard ergometers fix the feet in a position hip width apart. Any hip abduction will cause elevated knee adduction torques increasing medial load in the knee joint. This is believed to be a pathogenetic factor in diseases such as knee osteoarthritis (Sharma et al, 1998, Andriacchi,1994). Therefore, the goal of this study was to investigate the effect of foot positioning on knee joint torques. It was hypothesized that a more lateral foot position would specifically a) affect hip abduction and external rotation angles; b) affect lateral reaction forces on the foot rest; and therefore c) reduce knee adduction and rotation torques.

METHODS: 10 normal weight subjects, consisting of five females and males, participated in this study.

Table 1: Anthropometric data

n	AGE	HEIGHT	MASS	BMI
10	22.80 ± 3.3 y	170.6 ± 9.3 cm	63.10 ± 10.7 kg	21.53 ± 1.8 kg/m^2

A six-camera Vicon system was used to collect kinematic data. Measuring frequency was 200 Hz. A set of 48 markers was used to quantify the 3D coordinates of the subject and the ergometer respectively. A Concept II Model D ergometer was used for this study and equipped with two 3D force transducers underneath each foot rest and one 1D force transducer between the handle bar and the chain. The kinetic data was captured using a frequency of 1000 Hz. Individual anthropometrics were taken and used as input data for the Man-Model Dynamicus (Alaska 6.01, Institute of Mechatronics, Chemnitz, Germany). Inverse kinematics and inverse dynamics were performed to calculate joint angles and joint torques. Hip and knee joints were represented as spherical joints with a degree of freedom of 3. The ankle joint was modeled as a Hooke joint with a degree of freedom of 2 (flexion/extension and abduction/adduction).
Prior to the measurement, subjects were introduced to the rowing technique and performed a short warm-up as practice. The protocol required the subjects to row at a stroke rate of 23-25

strokes per minute at a moderate resistance level. The foot rest is laterally adjustable and two positions were chosen for the analysis: FI - normal position as defined by the manufacturer, FO - lateral shift by 6 cm for each foot. Subjects rowed for two minutes at each condition with a break of two minutes between the trials. The order was randomized and the second minute of the rowing interval was captured.

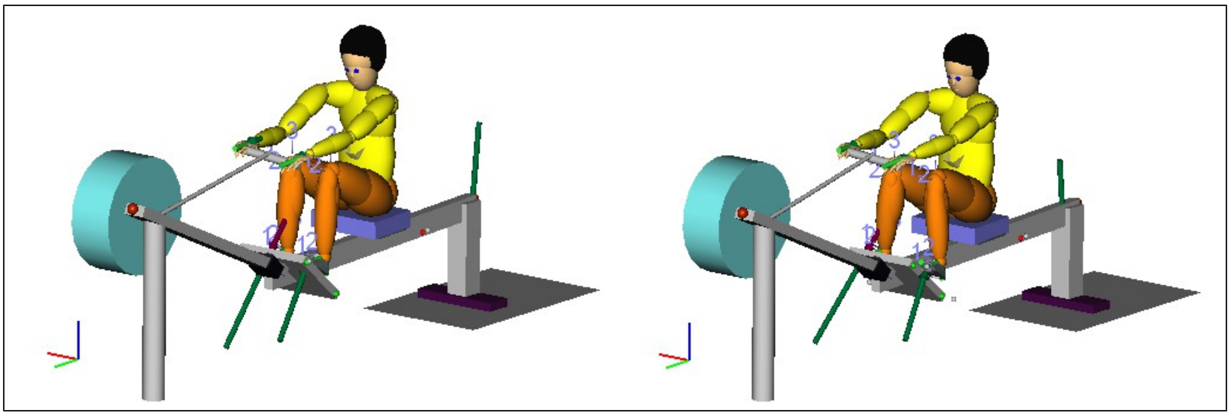

Figure 1: Simulation of the rowing strokes, showing foot position A (left) and foot position B (right)

For the data analysis the first 10 rowing strokes were time normalized and averaged for each subject. The beginning point for the normalized rowing stroke was the catch position. The data analysis included the drive phase only. Kinematic and kinetic data for each foot position were compared using paired-samples t-tests. Significance was established at $p<0.01$ based on a Bonferroni adjustment for the use of multiple t-tests.

RESULTS: In support of our first hypothesis hip abduction angles and external rotation angles both increased ($p<0.001$, $z>1.9$, $P=0.99$,Fig. 2) for the FO position.

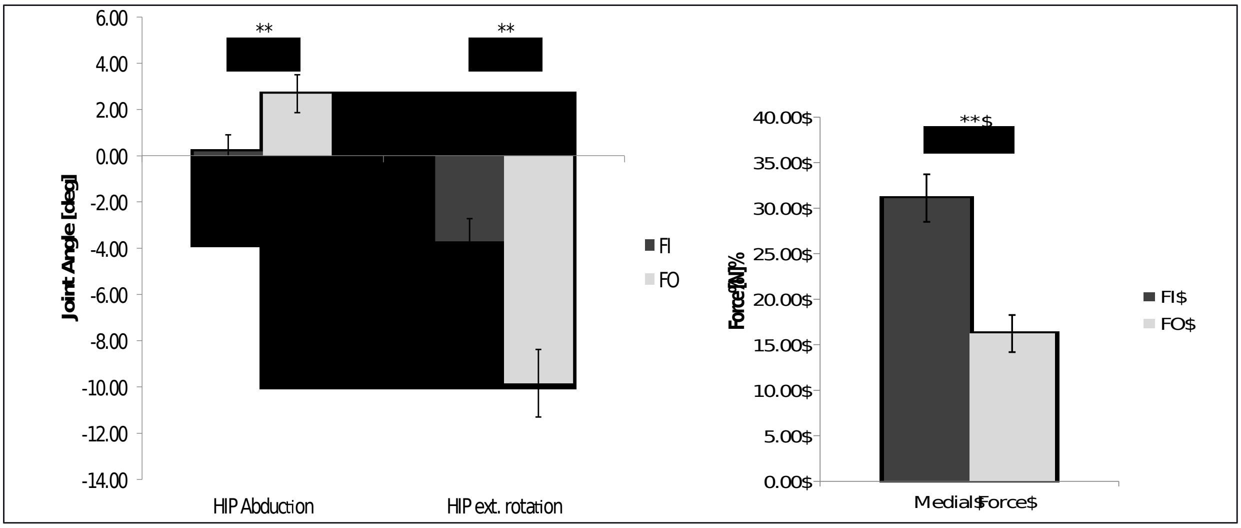

Figure 2: Average values ± SE for hip abduction and external rotation angles and medial forces on the foot rest for normal foot position (FI) and lateral adjusted foot position (FO). ** indicates significant differences with p<0.05

The medio-lateral foot contact force on the foot rest was directed medially for both conditions and decreased significantly ($p<0.001$, $z=3.1$, $P=0.99$, Fig. 2) for the FO position which supports our second hypothesis. Furthermore, in support of our third hypothesis, the knee adduction torque was significantly reduced and switched to a knee abductor torque ($p=0.001$, $z=1.57$, $P=0.96$, Fig. 3) with wider foot placement (FO). Internal rotation torque was also reduced in FO and switched to an external rotation torque in the knee joint ($p=0.001$, $z=1.459$, $P=0.95$, Fig. 3).

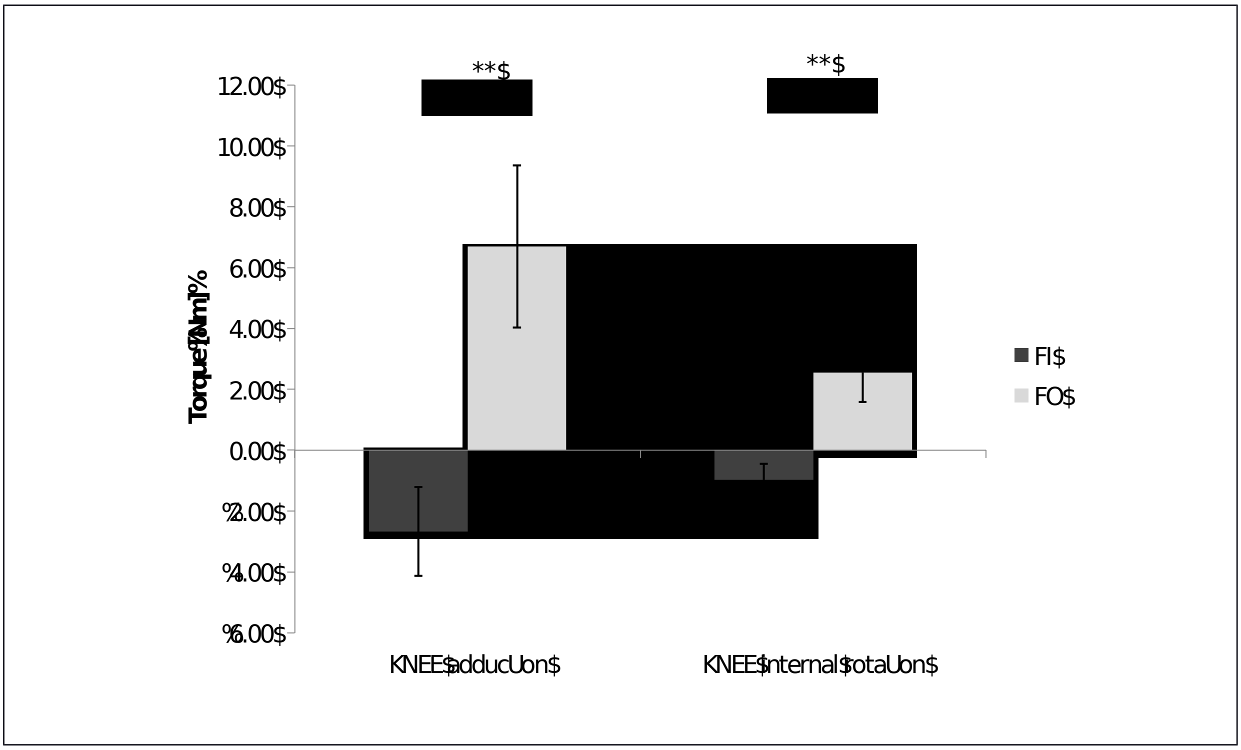

Figure 3: Average values ± SE for knee joint torques for normal foot position (FI) and lateral adjusted foot position (FO). ** indicates significant differences with p<0.05

DISCUSSION: The purpose of this study was to investigate the effect of foot positioning on knee joint torques in ergometer rowing. Since ergometer rowing is widely used in fitness and health facilities a better understanding of movement kinematics and kinetics especially related to the force producing lower extremity segments is important to avoid overuse injuries. The results of this study show that foot positioning has a significant impact on the kinetic forces at the knee joint.

The amount of knee adductor torque and internal rotation torque for FI are moderate and replicated results of our previous study (Roemer et al. 2013). The results for the FO position indicate that a lateral shift of the feet changed the knee alignment significantly. The kinematic results for the hip joint showed small but meaningful changes in hip abduction and external rotation. These changes were expected and reflect the lateral shift of the feet. However, a portion of the change in angle is also attributed to a change in knee alignment relative to the ankle joint.

Applying the FO position not only reduced the knee adductor torque, but also generated a substantial switch to a knee abductor torque. Concomitantly, the internal rotation torque switched to an external rotation torque. If the knee alignment relative to the ankle joint had remained similar to FI, no change in knee adduction or rotation torque would have occurred. Hence, the hip abduction angle does not reflect the full amount of lateral shift. Even though the subjects increased their hip abduction, they aligned the knee joint medially of the hip and the ankle. This altered alignment caused a reduction in medial foot contact force, however, despite this significant reduction, the force did not switch to a dominant lateral location. Therefore, the force vector passed the knee joint medially in the FI position and laterally in the FO position resulting in a change from knee adduction to knee abduction torque and from an internal rotation to an external rotation torque

The widespread use of rowing ergometers in fitness and health facilities, combined with the results of the current and the previous study, support lateral adjustment of the foot position to address potential overloading of the medial compartment of the knee joint. A more lateral placement significantly alters knee joint torques and can provide a more comfortable alignment for individuals compared to the fixed foot position. Considering the high number of repetitions during a rowing workout, an adjustable foot rest on the rowing ergometer may reduce the risk of overuse injuries on the knee joint.

CONCLUSION: The aim of this study was to investigate the effect of altering foot position to a more lateral placement on knee joint torques. Data indicate that a more lateral foot position significantly alters external forces and knee joint torques and supports the concept of adjustable foot rest positions to avoid potential overuse injuries in the knee joint.

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