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KINETICS OF THE LOWER EXTEREMITIES IN ERGOMETER ROWING DEPEND ON BODY MASS INDEX

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The aim of this study was to investigate the influence of body mass index (BMI) on the kinetics of the lower extremities in ergometer rowing. Our results indicate that BMI has a major impact on lower extremity kinetics in ergometer rowing. Significantly increased knee joint torques with respect to external adduction and internal rotation were found. Furthermore, differences in hip and knee extension torques were found. The results indicate that obese individuals are at higher risk of overloading the knee joint during ergometer rowing.

KEYWORDS: rowing, body mass index, inverse dynamics, biomechanical modelling, motion analysis

INTRODUCTION: Rowing ergometers are widely used for aerobic exercise in health and fitness centers. Previous studies have shown that parameters like ergometer design, skill level, and exhaustion have significant effects on movement kinematics and kinetics (Hase, Kaya, Zavatsky, & Halliday, 2004; Hislop, Cummins, Bull, & McGregor, 2010; Mackenzie, Bull, & McGregor, 2008). Anthropometrics in athletes such as height, segment length, and weight have also been known and to influence rowing technique and therefore success rate in rowing (Soper & Hume, 2004). The impact of anthropometrics with respect to different levels of body weight and BMI are not well understood for ergometer rowing. However, ergometers are used as non-weight-bearing aerobic exercise for overweight and obese individuals. Kinematic and kinetic analysis in gait implies that BMI has a significant influence on gait kinematics and joint reactions (Stephen P. Messier, 2010; S. P. Messier, Gutekunst, Davis, & DeVita, 2005). Therefore, the goal of this study was to determine if an increase in BMI will alter movement kinematics and joint kinetics for the lower extremities in ergometer rowing.

METHODS: Forty subjects participated in this study: 10 overweight (OW, BMI 25-30 kg/m^2), 10 obese (OB, BMI> 25 kg/m^2), 10 normal weight (NW, BMI 18-25 km/m^2), and 10 normal weight skilled rowers (SK). Each group consisted of five female and five male subjects. For the data analysis 39 subjects (one drop out in the skilled rower group) could be used.

Table 1
Means and standard deviations of age, height, weight and BMI of overweight and normal weight subjects

	Normal weight	Overweight	Obese	NW skilled
Weight	66.5 ± 9.2	78.1 ± 9.3*	103.3 ± 22.6*	70.1 ± 8.1
BMI	21.8 ± 1.6	26.7 ± 1.3*	35.5 ± 4.7*	21.9 ± 1.2
Height	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1	1.8 ± 0.1
Age	27.4 7 ±.2	24.1 ± 6.0	26.0 ± 3.1	23.9 ± 4.3

* significant difference at p<0.05

A six camera Vicon system was used to collect kinematic data. Measuring frequency was 200Hz. Body composition was measured of all subjects by a segmental body composition analyzer (Tanita, BC-418 Pro, Arlington Heights, USA). A marker set of 48 markers was used to quantify the 3D coordinates of the subject and the ergometer respectively. Subjects rowed on a Concept II Model D ergometer in this study 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 1000Hz. Individual anthropometrics were

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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 three different resistance levels (3, 5 and 7). They were asked to row for two minutes at each level with a break of two minutes between the trials. The second minute of the rowing interval was captured.

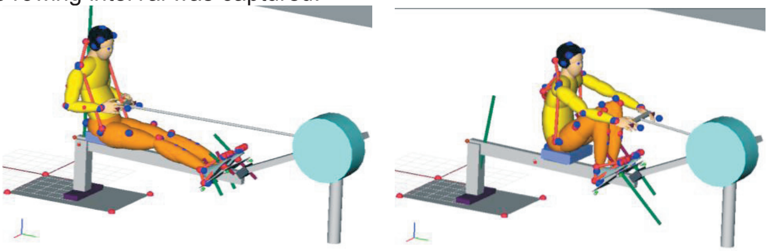

Figure 1: Simulation of the rowing strokes, showing the beginning and midpoint of the normalized rowing stroke.

For the data analysis the first 15 rowing strokes were time normalized and averaged for each subject. The beginning point for the normalized rowing stroke was the beginning of the recovery phase (Fig. 1). The joint torque was normalized with respect to BMI and will be shown as Nm/kg/m^2. Start of one rowing stroke was defined as the start of the recovery phase; therefore, the drive phase covers the second half of the total rowing stroke. An independent sample t-test with a significance level of $p \leq 0.05$ was used for the statistics.

RESULTS: The resistance level did not have any effect on joint kinematics or kinetics. No significant differences between resistance levels were found for any parameter. Therefore, only the results for resistance level 7 will be discussed in detail. The analysis of joint kinematics revealed significantly less hip and knee flexion in OB compared to all other groups. No differences were found between NW, OW, or SK rowers for those angles. Ankle flexion was only significantly different between OB, NW and OW subjects. Hip abduction, ankle abduction, and knee internal rotation were significantly different between the SK and NW groups compared with the OW and OB groups indicating a relationship between body shape and hip abduction. No difference with respect to skill level was found. External rotation in the hip joint was different between the OB and the NW and SK groups. No difference was found between any group for knee abduction or adduction with respect to maximum values. However, time histories of the knee adduction show different patterns for the OB group compared to the other three groups (Fig. 2).

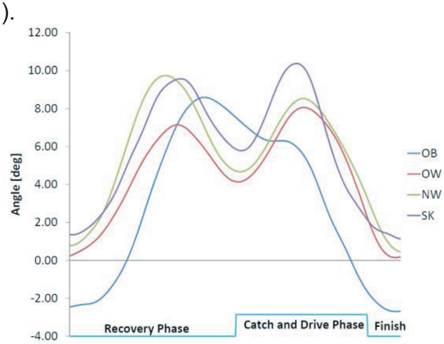

Figure 2: Simulation of the rowing strokes, showing the beginning and midpoint of the normalized rowing stroke

The kinetic results give more insight into the different patterns. The OB group produced an external adductor torque at the beginning of the catch phase while the SK rowers showed an external abductor torque during the drive phase.

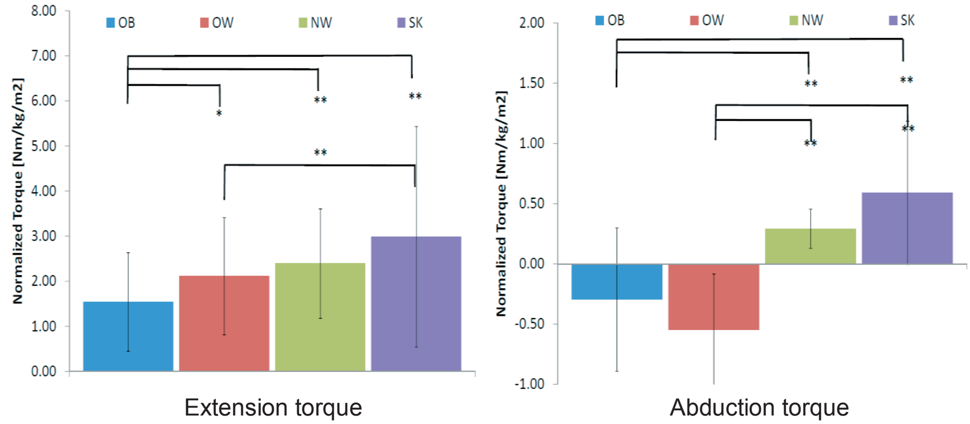

Figure 3: Statistics for knee extension torques and knee abduction torques normalized to BMI.

OB subjects produced significantly less knee extension torque compared to all other groups. OW subjects showed less knee extension torques compared to the SK rowers. Most interestingly, NW and SK rowers created internal abductor torques during the drive phase, while the OW and OB groups showed internal adductor torques. Similar results were found for knee rotation. SK and NW rowers generated external rotation torques while the OW and OB groups generated internal rotation torques.

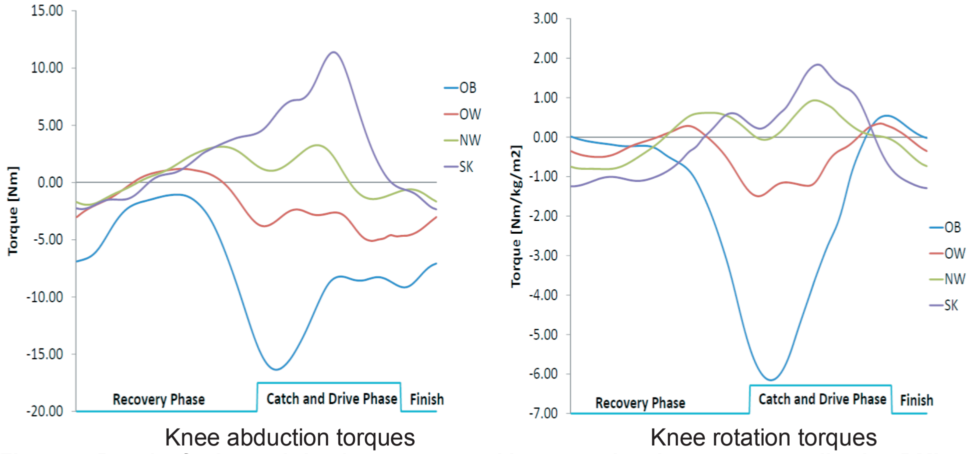

Figure 4: Results for knee abduction torques and knee rotational torques normalized to BMI.

Furthermore, the timing for generating the torques is different (Fig. 4). OB and OW subjects generated torques at the beginning of the drive phase with maximum knee flexion (124 ±14.3 deg). NW and SK rowers produced their maximum torques at the end of the drive phase were the knee flexion angle was less than 82 degrees.

DISCUSSION: Ergometer rowing allows for non-weight-bearing aerobic exercise which is widely used in fitness and health facilities. This type of aerobic exercise might be beneficial for obese individuals in particular. It is known that parameters like ergometer design, skill level, and exhaustion have significant effects on movement kinematics and kinetics (Hase, et al., 2004; Hislop, et al., 2010; Mackenzie, et al., 2008). Anthropometrics in athletes such as height, segment length, and weight have also been known to influence rowing technique and therefore success rate in rowing (Soper & Hume, 2004). The results of this study show that BMI has a significant impact on rowing kinetics for the lower extremities. Obese individuals are at higher risk for knee osteoarthritis and therefore this type of non-weight-bearing exercise might be beneficial (Messier, 2010). Results from this study show that obese individuals put increased loads on the medial compartment of their knee joint with respect to knee adduction torques combined with internal rotation torques. These increased loads have been linked to the risk of knee osteoarthritis in various gait studies (Messier, 2010; Messier, et al., 2005). Therefore, our results indicate that the high BMI might increase the risk of knee overuse in ergometer rowing for obese individuals. For this study it is not assumed to be a result of the increased body weight since the exercise is weight supported. High BMI values further indicate altered body shapes. In particular the trunk and the thighs will increase in circumference and decrease the ability for hip and knee flexion as well as increase hip abduction which was shown in the kinematic analysis. The combination of increased thigh circumference and a piece of equipment that forces the feet into a close position laterally is likely to increase external adductor torques in the knee joint. Therefore, a change of the setup of rowing ergometers needs to be considered in order to prevent knee joint overloads for obese individuals.

CONCLUSION:

The aim of this study was to investigate the influence of body mass index (BMI) on the kinetics of the lower extremities in ergometer rowing. Results show that BMI has a major impact on lower extremity kinetics in ergometer rowing. This indicates that obese individuals are at higher risk to overload their knee joints during ergometer rowing due to their body shape. A change of the current rowing ergometer design might be necessary. Future research is needed to investigate changes in design that can optimize knee joint loads for individuals with increased BMI.

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