Muscular coordination of the lower extremities of oarsmen during ergometer rowing

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**ABSTRACT**

In sweep-oar rowers asymmetrical force production of the legs is a known phenomenon. The purpose of this study was to investigate the muscular activity of the legs that may cause these asymmetry even when oarsmen perform a symmetrical endurance task.

Seven male young elite oarsmen performed an all-out 2000 m test on a rowing ergometer. During stroke kinematics, myoelectric activity of six muscles of each leg and pressure distribution under both feet were measured. Data were collected over two 30 s time windows starting one and five minutes after the test started.

No significant differences were observed between legs and time windows for the range of motion of the hip, knee and ankle joint as well as for the onset/offset timing of muscles. However, in the drive phase the knee and hip muscles of the leg on the oar side (inside leg) showed 20% to 45% (both p<0.05) higher activation intensities compared to the leg opposite to the oar (outside leg). Corresponding to this, 56% to 91% (both p<0.05) higher mean pressure values under the ball of the inside foot compared to the outside foot indicated an asymmetrical force production of the legs even under kinematically symmetrical working conditions.

Keywords: EMG, pressure distribution, force, leg, symmetry
INTRODUCTION

A rowing stroke can be divided into two phases: drive and recovery. In the drive phase from the frontal to the rear movement reversal the rower slides backward on the rolling seat by extending knee and ankle joint. With the blades in the water, the rower is pulling the oar. In the recovery phase beginning at the rear reversal the rower slides forward by flexing the knee and ankle joint until the next frontal reversal. The oars are lifted out of the water during this phase.

Depending on the boat construction, rowing can be divided into sculling and sweep-oar rowing. In sculling, the rower uses two bilateral, symmetrically positioned oars simultaneously to propel the boat. The resulting body movement assumes a bilateral symmetry in muscular activation patterns (Clarys & Cabri, 1993; Wilson et al., 1988). In sweep rowing, each oarsman uses only one oar and produces boat propulsion on only one side. To achieve a long stroke length, the shoulders of the oarsman follow the pattern of the inboard lever of the oar to the catch position, where the trunk rotates to the oar side (Figure 1). With such a configuration of the arms, the leg opposite to the oar is rotated to the outward. Thus, in the drive phase the left and right sides of the body are positioned differently in relation to the inboard lever. Therefore asymmetrical muscle activation in the legs, shoulders and arms was suggested (Wilson et al., 1988). However, biomechanical analyses of laterality of the lower extremities in sweep-oar rowers reveal inconsistencies. Fukanaga et al. (1986) measured the reaction forces on the foot stretcher and reported higher forces on the inside leg located on the oar side compared to the outside leg which is opposite to the oar. In contrast Smith & Loschner (2000) measured significantly higher forces of the outside leg in comparison to the inside leg during rowing in a coxless pair (two persons, each oaring on one side). By analyzing joint moments in isometric and isokinetic strength training tasks Kramer &
Leger (1991) found significantly greater knee extension moments for the inside leg compared to the outside leg of lightweight sweep-oar rowers, whereas for heavyweight sweep-oar rowers moments were not significantly different in both knees. Parkin et al. (2001) investigated the hamstring / quadriceps ratios under isometric and isokinetic conditions and found no left and right asymmetries in either the knee extensor or flexor strength parameters. However, asymmetry of muscle activity was observed between left and right erector spinae muscles during extension, which was significantly related to the stroke side. The muscle activity was higher for the extensors located opposite to the oar side.

In training, as well as in testing protocols concerning strength and endurance parameters of rowing athletes, the use of rowing ergometers is common. Worldwide the Concept2 ergometer is mostly utilized. The rowing movement is simulated by pulling backward the ergometer handle. The force applied to the handle depends on the velocity of the flywheel (aerodynamics drag), on the brake acceleration (time derivative of the angular momentum) and on the position of the handle (self-winding tension). The Concept2 only allows a symmetrical movement that resembles sculling. However, sweep-oar rowers are tested under such symmetrical conditions. These tests and additional studies that examined muscle activation in sculling (Fortin et al. 1994, Hume et al. 2000, Ishiko 1971, Kabsch & Dworak 1969, Rodriguez et al. 1990, Peltonen et al. 1997) did not consider the apparent asymmetries in trunk and leg movement patterns and dynamics as it occurs in sweep-oar rowing. Because ergometer rowing is symmetrical, investigators mainly focused on sculling had restricted recording of muscle activity to one side of the body. Under such experimental conditions the detection of possible asymmetries in muscle activation between the two sides were not enabled. In addition, muscular coordination within the functional groups of leg
extensor and leg flexor muscles during sweep-oar rowing has not yet been characterized.

The main idea behind this study was to determine, if the asymmetrical movement pattern typically shown by oarsmen in the boat would still be present and stable during symmetrical working conditions on the ergometer. We hypothesize that under apparently symmetrical working conditions during ergometer rowing sweep-oar rowers may show symmetrical kinematics but asymmetrical muscle activation patterns in the inside vs. the outside leg and that this may result in asymmetrical pressure under the foot of the inside vs. outside leg. The purpose of the current investigation was to analyse the kinematics and neuromuscular activation patterns of both legs combined with the pressure under the feet shown by sweep-oarsmen during symmetrical ergometer rowing. In addition the stability of this movement pattern was investigated.

METHODS

In the present study, symmetry was determined in two ways. One approach was to quantify the visual movement of rowing by measuring the kinematics. The other was to evaluate symmetry from EMG and pressure distribution data.

Seven male rowers (age 20±1 years, height 1.97±0.03 m, mass 95±7 kg) participated in this cross sectional study. Subjects were recruited from the national rowing young talent team of Germany. All subjects had experience of national championships. Their frequency of training sessions ranged from 8 to 11 per week. In this study all subjects performed an all-out 2000 m rowing test (6:32±0:12 min:s = 392±12 s) on a rowing ergometer (Concept2).

After the subject gave his informed written consent, the protocol began with the application of the EMG electrodes, the pressure distribution soles and the reflective
markers. The applied measurement systems did not interfere with the movement. After all measurement devices were applied, bilateral side view video of the upright standing subject with full stretched knees and hips was recorded to calibrate the individual marker position. Next, subjects warmed up for five minutes on a rowing ergometer using a self selected rowing frequency. Between the warm up period and the simulated 2000-m race the subjects rested for two minutes on the ergometer. The simulated race started from the catch position. During the simulated race data were recorded over two 30 s time windows to quantify the movement stability throughout the test. The time windows began at one minute (W1) and five minutes (W5) after the start of the test.

**Instrumentation**

The distance covered by the ergometer handle between front and rear reversal during the rowing stroke was recorded at a sampling rate of 100 Hz. Kinematic data were collected using side view video from both sides (Panasonic AG-DP800, Osaka, Japan) with a dynamic accuracy of 2 mm. Both cameras operated at 50 Hz. Reflective markers (r = 10 mm) were fixed on body landmarks to improve the video analysis (Figure 2). The video was analyzed using WINanalyze (mikromak GmbH, Berlin, Germany).

Myoelectric activity of vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF), biceps femoris (BF), tibialis anterior (TA) and gastrocnemius lateralis (GL) of both lower extremities were recorded using surface electrodes in a bipolar configuration (N-00-S, Blue-Sensor, Ambu A/S, Ballerup, Denmark). After skin preparation according to SEMIAN standards the electrodes were fixed with tape in the middle of each muscle belly. A ground electrode for differential signal recording was fixed on the fibula head of each leg. EMG signals were amplified using miniature
amplifiers (BioVision, Wehrheim, Germany), converted by a 12-bit PCMCIA AD-
board (DaQ 700, National Instruments Corp, Austin TA, USA) and stored continuously
on a Notebook (Aspire 1400LC, Acer Inc., Hsichi, Taiwan) using a commercially
available software package (Dasylab, National Instruments Corp, Austin TA, USA).
The sampling rate was 1000 Hz.

Pressure distribution under both feet was recorded at 80 Hz using pairs of
capacitive insoles of the foot size of each subject (Pedar mobile, novel GmbH, Munich,
Germany). The system measures forces perpendicular to the plane of the soles on the
foot stretcher at the area of the loaded sensors. From this the pressure of defined areas
are calculated. The insoles were placed in the shoes and fixed with special tape. For the
benefit of higher time resolution the mid foot area has not been recorded. As observed
in a preliminary pilot test, the loss of information was negligible for the purpose of this
study.

Data analysis

The movement of the ergometer handle was used to identify the drive and
recovery phases within a rowing cycle. The beginning of the drive phase was defined as
the frontal reversal (FR) in movement direction of the rower (forward to backward). It
was indicated by the minimum distance between the handle and the flywheel of the
ergometer. The end of the drive phase was indicated by the rear reversal (RR) where the
distance between handle and flywheel reached its maximum. One rowing cycle was
defined from one to the next front reversal. To compare subjects with individual cycle
length all time parameters were related in percentage of the rowing cycle (%-cycle). In
the kinematic analysis a two-dimensional model of each lower extremity was used to
analyze angular amplitude of the hip, knee and ankle joints in the sagittal plane.
Reference angles were taken in an upright standing position of each subject. The maximum angular amplitude describes the range of motion (ROM) of the particular joint from maximum joint extension to maximum joint flexion in the rowing movement.

EMG signals were triggered by the beginning and finish of the drive phase. The raw EMG signals were rectified and a linear envelope was calculated using the moving average method (window length 20 ms, step 1 ms). The onset of EMG was defined as the instant of the first value, when the rectified EMG exceeded threshold of three times the standard deviation of the respective rectified resting EMG for more than 20 ms. The analyzed EMG parameters included time, mean amplitude (RMS = root mean square) and integrals (iEMG) of recovery activation (during the forward sliding of the seat) and drive activation. For each muscle, RMS and iEMG were described relative to the maximum values (%-max) of the respective subjects, measured over the whole test period.

The analysis of the pressure measurements was performed using the novelwin software (novel GmbH, Munich, Germany). In the analysis the area under each foot was divided in four anatomical sections including the medial and lateral ball (BM, BL) and the medial and lateral heel (HM, HL). Maximum pressure, instant of maximum pressure, mean pressure and pressure-time-integral were analyzed for all four sections, named above. To eliminate differences in body weight and individual stroke force, the pressure parameters were related to the maximum values for the respective subjects.

To identify bilateral differences for the parameters named above, the legs were categorized as inside leg (ISL) and outside leg (OSL) according to the rowing side of the respective subjects. The inside leg is on the oar side, the outside leg is opposite to the oar side.
Statistics were computed using the SPSS software package (SPSS 12.0, SPSS Inc., Chicago IL, USA). To account for the small number of homogeneous subjects, two separate Wilcoxon tests were performed to evaluate the differences between the inside leg vs. the outside leg and between the two different time windows, respectively. The analyzed variables were defined by the measured parameters of the kinematics, EMG and pressure distribution. The level of significance was set to p<0.05. Error bars in graphs represent one standard deviation (SD).

RESULTS

The rowers demonstrated stroke rates of 31.9±1.0 vs. 32.2±1.7 strokes per minute (p=0.12) at the one-minute (W1) and five-minute (W5) time window respectively. Within the strokes a similar length of the drive and recovery phase in both time windows were observed. The respective values were 51±4%-cycle and 49±3%-cycle at W1 vs. 46±3%-cycle and 54±4%-cycle at W5 (all p>0.05). As expected, minimum angles of the ankle, knee and hip joint were observed in the catch position at the front reversal of the rower (Table 1). At this position, the distance between the ergometer handle and the flywheel had its minimum. As described in the methods, this point in time was set to be the beginning of the rowing cycle. Consequently all joints had their minimum angles at 0±1%-cycle. Between legs and time windows no significant differences were found in minimum angles. During all strokes the largest range of motion (ROM) occurred at the knee joint. No significant differences in ROM of the hip, knee and ankle joint were observed between the time windows at one minute (W1) and five minutes (W5) after the test has started (Table 1). In addition, there were no significant differences between the ISL and OSL.
The EMG analysis did not reveal significant differences between legs and time windows for the beginning and duration of muscle activation (Figure 3 and 4). At the rear reversal of the rower, the TA showed muscle activation beginning at 44±12%-cycle until 65±14%-cycle (Figure 4). The activation of the BF began at 53±10%-cycle and continued until 23±7%-cycle into the next drive phase. The activity of GL muscle beginning at 76±6%-cycle lasted until 26±7%-cycle into the next drive phase. At the end of the recovery phase the knee extensors VM, VL and RF showed an activation prior to the next drive phase starting at 82±8, 82±7 and 87±9%-cycle respectively. These activations continued until 24±8%-cycle (VM), 24±10%-cycle (VL) and 17±7%-cycle (RF) into the following drive phase.

Comparing the two time windows (W1 vs. W5) neither for the ISL nor for the OSL significant differences in EMG amplitudes were observed. In contrast, by comparing the two legs (ISL vs. OSL) in the drive phase, the knee extensors VL and RF of the ISL demonstrated significantly higher values than the respective muscles of the OSL. The respective mean amplitudes of the ISL vs. the OSL of the VL were 40.7±9.2 vs. 32.1±8.9%-max (W1) and 42.8±7.6 vs. 35.0± 7.1%-max (W5) (both p<0.05). The corresponding values of the RF were 38.7±11.6 vs. 28.7±11.1%-max at W1 and 40.0±9.1 vs. 30.7± 7.1%-max at W5 (both p<0.05). Furthermore, during the drive phase, the BF of the ISL demonstrated mean amplitudes of 42.6±9.6%-max (W1) and 44.3±7.4%-max (W5) which were significantly higher (p<0.05) than the values observed for the OLS (35.0±8.7%-max (W1), 35.6±8.2%-max (W5)).

No significant differences between time windows could be observed for the integrated EMG. As described for the RMS values, for both time windows similar significant differences (p<0.05) between legs were observed for the iEMG (Figure 5).
At the ISL the VL, RF, BF and GL showed increased iEMG values of 25%, 45%, 32% and 20% (all p<0.05) respectively compared to the OSL.

In the analysis of the pressure distribution the medial ball (BM) demonstrated 51% higher mean pressure values (p<0.05) than the lateral ball (BL) (Table 2 and Figure 6). The maximum pressure of BM was more than twice as high when compared to BL. Compared to the BM the medial and lateral heel (HM, HL) showed significantly smaller mean and maximum pressure (p<0.01). This was observed for all subjects, independent of leg side and time windows. In both time windows the pressure time started about 46%-cycle (p<0.05) earlier under the ball compared to the heel. In addition, BM and BL demonstrated significantly (p<0.01) longer duration of pressure time and significantly (p<0.01) earlier occurring maximum pressure compared to HM and HL. Consequently BM and BL demonstrated significantly (p<0.01) higher pressure-time-integrals compared to HM and HL (Table 2).

Corresponding to the findings of the EMG, the analysis of pressure distribution parameters showed significant differences between legs. Independent of time windows mean pressure under the medial and lateral ball of the ISL foot was 56% and 98% (both p<0.05) higher and pressure-time-integrals was 74% and 91% (both p<0.05) higher compared to the respective areas of the OSL foot. At W1 the recorded mean pressure values for the ISL vs. OSL under the BM were 66.4±24.7%-max vs. 38.1±26.9%-max and for the BL 35.8±12.0%-max vs. 18.7±9.2%-max (all p<0.05). At the HM mean pressure values of 1.2±0.9%-max vs. 0.4±0.2%-max and at the HL 2.3±2.0 vs. 2.5±2.1%-max (all p<0.05) were observed for the ISL vs. OSL respectively. Again no significant differences between time windows could be observed (Figure 6).
DISCUSSION

In rowing the leg muscles play an important role in the force generation during the drive phase, by stretching the legs against the foot stretcher. As considered by several authors the hip and knee extensors are identified as the most important muscles for propulsion (Fortin et al., 1994; Rogriguez et al., 1990; Wilson et al., 1988). The main objective of this study was to analyze the neuromuscular activation patterns in both legs in sweep-oarsmen during ergometer rowing. The idea behind this study was to determine, if the asymmetrical movement pattern that is present during on-water rowing in a boat would still be present and stable during symmetrical ergometer rowing conditions. We determined symmetry in two ways. One approach was to quantify the visual movement of rowing by measuring the kinematics. The other was to evaluate symmetry from EMG and pressure distribution data. We hypothesized that sweep-oarsmen would demonstrate symmetrical kinematics but asymmetrical muscle activation patterns in the leg on the oar side (inside leg) vs. the leg opposite to the oar (outside leg) and the this may result in asymmetrical pressure under the respective foot when rowing under apparently symmetrical working conditions on an ergometer.

Corresponding to literature (Nelson & Widule, 1983; Torres-Moreno et al., 2000) the largest ROM was observed at the knee joint (Table 1). The minimum and maximum angular amplitude of all joints occurred at the frontal and rear reversal, respectively. The activation pattern of the leg muscles in the present study widely correspond to Wilson et al. (1988). In the recovery phase TA and BF and later GL were activated to flex the ankle and knee joints pulling the rower forward on the sliding seat into the catch position (Figure 3). In this movement phase the rowers probably pulled on the strip of the foot stretcher with the instep of their feet. As the heel demonstrated only irregular and short contacts to the foot stretcher with low pressure, we assume that the
heel did not function as a thrust bearing. Shortly prior to the front reversal the activation of the knee extensors probably reduced the velocity of the forward movement. This eccentric muscle work led to an increase of the pressure between feet and foot stretcher. The different shape of the pressure time curve (Figure 3) compared to the force time curves presented by Colloud et al. (2006b) probably resulted from the changing angle of the line of action relative to the plane of the pressure soles during the drive phase. The higher maximum and mean pressure of the medial compared to the lateral ball could probably be attributed to the position of the feet fixed on the foot stretcher (Soper, 2004). The knee extensors were active until about 40% (RF) and 50% (VM, VL) of the drive phase (20 and 25%-cycle, respectively), driving the rower backward on the rolling seat. It is suggested that the BF stabilizes the hip joint during the leg extension (Hamill & Kutzen, 2003). In the second half of the drive phase starting at about 25%-cycle the rowers demonstrated a heel contact, lasting until the rear reversal of the rowing movement at about 50%-cycle. The shorter and less intensive second activation burst of the knee extensors prior to the rear reversal probably decreased the knee extension velocity and provided a smooth transition from the drive phase into the recovery phase.

Comparing the inside leg (ISL) vs. the outside leg (OSL) there were no significant differences in ROM, amplitudes and timing of the minimum and maximum angles. As hypothesized the kinematic data indicated a symmetrical rowing movement performed by the oarsmen on the ergometer. The kinematic data corresponded with the temporal features of the bilateral muscular activation. The onset and duration of muscle activation of the ISL and OSL were similar (Figure 4).

In contrast the EMG amplitudes of the knee extensors demonstrated significant differences between ISL vs. OSL. The activation of VL and RF were about 25% and 32% higher for the ISL. This consequently led to significantly higher integrated EMG
values of about 25% for the VL and 45% of the RF muscle (Figure 5). Combined with data from the literature (Metral & Cassar, 1981; Woods & Bigland-Ritchi, 1983; Hakkinen et al., 1997; Herzog et al. 1998; Hay et al., 2006) the current observations strongly indicate that the muscle activity of the inside leg is higher than the activity of the outside leg. This in turn probably led to higher generated forces at the ISL. The assumption is supported by the significantly (56% and 91%) higher mean pressure values under the medial and lateral ball of the foot of ISL compared to the foot of the OSL. From the combined results of the EMG and pressure distribution analysis, it is suggested, that the ISL of the observed oarsmen produced higher forces compared to the OSL when rowing on an ergometer. The results support our hypothesis, that despite kinematical symmetrical joint excursion of both legs during ergometer rowing the muscular activation in the two legs and consequently the pressure distribution under the two feet of sweep-oar rowers in the present study were asymmetrical.

Comparing the time windows (W1 vs. W5) no significant differences for the kinematic parameters such as ROM, minimum and maximum angular amplitude and the respective times when these maximum excursions occurred were found. (Table 1). Also EMG and pressure distribution parameters were similar in W1 and W5. This indicates that the oarsmen obtained the asymmetrical movement pattern of the ISL vs. the OSL over 5:30 min:s (330 s) of the simulated 2000 m race, lasting about 6:30 min:s (390 s).

As reported by Colloud et al. (2006a) asymmetrical forces at the foot stretcher may not only occur in oaring but also in sculling. Unfortunately the authors did not report the measured values. Based on MRI analysis Green and Wilson (2000) showed an asymmetrical recruitment of leg muscles in rowers with different levels of experience during ergometer rowing. The differences are mainly attributed to the rowing side of the subjects in on-water conditions.
Based on the current results it could be assumed that the highly trained oarsmen in this study transferred their task specific movement pattern that is optimized for sweep rowing in the boat to the ergometer. In on-water rowing the shoulders of the oarsman follow the pattern of the inboard lever of the oar. Because of this posture of the trunk and arms, the leg opposite to the oar is rotated to the outside. Consequently in the drive phase the ISL and OSL are positioned differently in relation to the inboard lever.

One weakness of the present study is that the maximum strength of ISL and OLS of each subject was not measured. However the current findings agree with the higher forces (Fununaga et al., 1986) and greater knee joint moments (Kramer and Leger, 1991) reported in ISL compared to OSL during sweep-oar rowing. Therefore there is a higher force requirement for ISL compared with OSL while rowing in the boat. The coaching staff faces a difficult decision of prescribing preferential exercise training for ISL to prepare it for this increased force demand in the boat. On the other hand a specific exercise prescription for the OSL probably could use a possibly higher muscular adaptation capacity of this less trained leg to increase the overall force production in the drive phase.

In conclusion the results of the current study supported the hypothesis, that although sweep-oarsmen rowed with a kinematically symmetrical posture due to the constraints of the rowing ergometer, the activation of the leg muscles and the pressure under the feet were still asymmetrical, reminiscent of the force and EMG pattern while rowing in a boat. The asymmetrical muscular forces between legs may have implications for exercise prescription to additionally focus on the less trained leg to
improve the overall force production of the athletes during the drive phase and therefore the competitive performance.
REFERENCES


List of figures:

Table 1 – Means (±SD, n=7) of minimum (Min [°]), maximum angles (Max [°]), maximum range of motion (ROM [°]) and time of maximum (t-max [%-cycle]) at the hip, knee and ankle joints. The kinematics demonstrated no significant differences between the inside leg (ISL) and the outside leg (OSL).

Table 2 – Mean (±SD, n=7) of the beginning of contact (Pt-Start, [%-cycle]), pressure time duration (Ptd, [%-cycle]), maximum pressure (P-max, [%-max]), instant of maximum pressure (t-Pmax, [%-cycle]) and pressure-time-integral (Pti, [%-max]) under the foot areas of the medial and lateral ball (BM, BL) and medial and lateral heal (HM, HL) of the inside and outboard leg (ISL, OSL) at the time windows starting at one minute (W1) and five minutes (W5).

Figure 1 – Schematic drawing of the typical body position of a sweep-oar rower in the catch position. The inside leg (ISL) and outside leg (OSL) are in a different position relative to the inner lever of the oar.

Figure 2 – Kinematic model of rowing from the view of the camera positioned right from the ergometer. A second camera is positioned on the opposite side. Markers were bilaterally placed on body landmarks at the thoracal-lumbar-junction (TLJ), trochanter major (TM), joint centre of the knee (K), malleolus lateralis (ML) and on top of the hallux (HL). Hip angle is defined as TLJ – TM – K, knee angle as TM – K – ML and ankle angle as K – ML – HL. The rower’s left an right legs and arms are in a symmetrical position related to the ergometer handle.

Figure 3 – Raw EMG signals of the vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF), biceps femoris (BF) and tibialis anterior (TA) and pressure-time curve of the ball and heel of the foot of the inside leg (ISL) of one subject within the...
time window starting at one minute (W1). Data are displayed for the rowing cycle including drive phase (from rear reversal (RR) to frontal reversal (FR)) and recovery phase (FR to next RR) [%-cycle]. Leg extensor muscles were mainly active during the drive phase sliding the rower backward, while TA and BF performed knee flexion and dorsiflexion of the ankle sliding the rower forward during the recovery phase. The generating forces were applied to the foot stretcher by the ball of the foot. A short heal contact occurred at the end of the drive phase.

Figure 4 – Onset and duration (average and standard deviations, n=7) [%-cycle] of the EMG activity of vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF), biceps femoris (BF), tibialis anterior (TA) and gastrocnemius lateralis (GL) of the inside leg (ISL) and outside leg (OSL) within a rowing cycle consisting of drive phase (from rear reversal (RR) to frontal reversal (FR)) and recovery phase (FR to next RR). Data are shown for the time window starting at one minute (W1). ISL and OSL demonstrated a similar activation pattern in the time domain during ergometer rowing.

Figure 5 – Integrated EMG (average and standard deviations, n=7) [%-max] of the vastus medialis (VM), vastus lateralis (VL), rectus femoris (RF), biceps femoris (BF) and gastrocnemius lateralis (GL) of the inside and outboard leg at the time windows starting at one minute (ISL 1, OSL 1) and five minutes (ISL 5, OSL 5). Although subjects were rowing in an ergometer in a symmetrical posture, muscle activity in ISL was higher than in OSL.

Figure 6 – Mean pressure (average and standard deviations, n=7) [%-max] under the foot areas of the medial and lateral ball (BM, BL) and medial and lateral heal (HM, HL) of the inside and outboard leg at the time windows starting at one minute (ISL 1, OSL 1) and five minutes (ISL 5, OSL 5). During the drive phase the ball of the foot applied the generated force to the foot stretcher. The highest pressure was measured at
BM. Although subjects were rowing in an ergometer in a symmetrical posture, pressure was higher under the ball of ISL vs. OSL.

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Table 2

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<td>53.0 ± 2.6 *</td>
<td>2.5 ± 0.9 +</td>
<td>22.4 ± 13.1</td>
</tr>
<tr>
<td>W5 ISL</td>
<td>55.9 ± 3.1 *</td>
<td>54.9 ± 2.7 *</td>
<td>2.4 ± 7.2 +</td>
<td>15.7 ± 13.5</td>
<td></td>
</tr>
<tr>
<td>OSL</td>
<td>54.1 ± 3.0 *</td>
<td>52.4 ± 3.1 *</td>
<td>0.2 ± 2.1 +</td>
<td>29.8 ± 7.2</td>
<td></td>
</tr>
<tr>
<td>P-max</td>
<td>W1 ISL</td>
<td>88.2 ± 9.0 #</td>
<td>38.1 ± 17.9 *</td>
<td>14.8 ± 0.0</td>
<td>10.6 ± 3.1</td>
</tr>
<tr>
<td>[%-max]</td>
<td>OSL</td>
<td>80.6 ± 14.8 #</td>
<td>29.7 ± 8.7 *</td>
<td>7.1 ± 0.9</td>
<td>5.7 ± 0.8</td>
</tr>
<tr>
<td>W5 ISL</td>
<td>82.4 ± 6.1 #</td>
<td>37.7 ± 17.4 *</td>
<td>1.6 ± 4.6</td>
<td>1.3 ± 3.4</td>
<td></td>
</tr>
<tr>
<td>OSL</td>
<td>76.9 ± 15.3 #</td>
<td>30.5 ± 8.6 *</td>
<td>0.1 ± 0.6</td>
<td>0.9 ± 2.1</td>
<td></td>
</tr>
<tr>
<td>t-Pmax</td>
<td>W1 ISL</td>
<td>0.0 ± 3.8 *</td>
<td>8.0 ± 11.7 *</td>
<td>36.1 ± 7.4</td>
<td>43.2 ± 18.5</td>
</tr>
<tr>
<td>[%-cycle]</td>
<td>OSL</td>
<td>0.0 ± 5.3 *</td>
<td>4.8 ± 9.6 *</td>
<td>39.4 ± 14.2</td>
<td>37.2 ± 6.3</td>
</tr>
<tr>
<td>W5 ISL</td>
<td>0.8 ± 4.0 *</td>
<td>9.6 ± 11.8 *</td>
<td>40.5 ± 15.8</td>
<td>41.4 ± 16.5</td>
<td></td>
</tr>
<tr>
<td>OSL</td>
<td>-1.6 ± 2.1 *</td>
<td>5.2 ± 12.6 *</td>
<td>35.5 ± 5.2</td>
<td>36.7 ± 4.1</td>
<td></td>
</tr>
<tr>
<td>P Ti</td>
<td>W1 ISL</td>
<td>64.1 ± 34.0 x*</td>
<td>36.1 ± 24.7 x*</td>
<td>2.9 ± 2.0</td>
<td>5.4 ± 3.3</td>
</tr>
<tr>
<td>[%-max]</td>
<td>OSL</td>
<td>39.4 ± 38.8 x*</td>
<td>16.6 ± 15.2 x*</td>
<td>2.4 ± 1.1</td>
<td>6.2 ± 3.8</td>
</tr>
<tr>
<td>W5 ISL</td>
<td>62.9 ± 34.1 x*</td>
<td>37.1 ± 26.6 x*</td>
<td>2.6 ± 2.0</td>
<td>5.0 ± 2.5</td>
<td></td>
</tr>
<tr>
<td>OSL</td>
<td>37.5 ± 36.5 x*</td>
<td>17.2 ± 15.3 x*</td>
<td>1.9 ± 0.5</td>
<td>5.6 ± 2.9</td>
<td></td>
</tr>
</tbody>
</table>

# = significant differences to all other foot areas (p<0.05)
* = significant differences to HM and HL (p<0.05)
+ = significant differences to HL (p<0.05)
x = significant differences between ISL and OSL (p<0.05)
Figure 1
Figure 2
Figure 3
Figure 4
* = significant differences between legs (p<0.05)

Figure 5
* = significant differences between legs (p<0.05)
+ = significant differences between foot areas (p<0.05)

Figure 6