

ORIGINAL

Change in the activity of trunk and lower limb muscles during 2000-m rowing

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Abstract: This study aimed to clarify the changes in the activity of the trunk and lower limb muscles during 2000-m rowing. Ten male rowers performed a 2000-m race simulation on a rowing ergometer. Electromyography results of the abdominal muscles, back muscles, gluteus maximus (GMax), biceps femoris (BF), and rectus femoris (RF) were recorded. The electromyographic activity during the three strokes after the start (initial stage), at 1000m (middle stage), and before the end (final stage) were analyzed. From the handle position, the rowing motion was divided into five phases (early-drive, middle-drive, late-drive, early-recovery, and late-recovery). The peak activities of the abdominal muscles, back muscles, GMax, and BF in each stroke of the rowing motion were delayed at the middle and final stages compared to the initial stage ($P < 0.05$). The peak activity of the RF was observed in the late-drive phase at the initial stage, whereas a high RF activity was observed in the middle-drive phase at the middle and final stages ($P < 0.05$). Considering the results of the activity of the back muscles and RF, RF muscular endurance enhancement may lead to a decrease in the load on the back muscles and help prevent muscular low back pain in rowers. *J. Med. Invest.* 69: 45-50, February, 2022

Keywords: muscle activation change, electromyography, rowing motion

INTRODUCTION

The rowing motion consists of the drive and recovery phases. In the drive phase, rowers row their oars by extending the lower limbs and trunk from the catch position, where the blades of the oars are placed in the water with the lower limbs and trunk flexed. Subsequently, the rowers prepare for the next drive phase by flexing the lower limbs and trunk while placing the blades of the oars in the air in the recovery phase. Rowers often experience low back pain due to the repeated rowing motions (1-3). Therefore, there have been several studies on the activity of the trunk muscles surrounding the lumbar spine during the rowing motion (4-8).

A common method of training for rowers is a 2000-m race simulation using a rowing ergometer; the changes in the activation patterns of the trunk and lower limb muscles during training have been investigated using this method (4, 6, 8). Caldwell *et al.* (4) reported that the electromyographic (EMG) magnitude of the lumbar erector spinae (LES) and lumbar multifidus (LMF) throughout the drive phase increased at the 95% time point of a 2000-m rowing compared to the 20% and 60% time points. Pollock *et al.* (6) demonstrated that the EMG burst areas of the abdominal muscles in the drive phase were larger at 1500 m of a 2000-m rowing than at 250 m, whereas the back muscles activity showed no change. Sekine *et al.* (8) analyzed the trunk and lower limb muscles activity by dividing them into the early-drive phase, late-drive phase, and the recovery phase. As a result, the back muscles activity in the early-drive phase was higher at the

80% time point of a 2000-m rowing than at a 20% time point, whereas the rectus abdominis (RA) in the recovery phase and the long head of the biceps femoris (BF) in the late-drive phase at the 80% time point showed lower activity than at the 20% time point. However, the back muscles activity starts within the one-third of the drive phase and contributes to the peak force production of the stroke from the one-third to the two-thirds of the drive phase (5). Therefore, the EMG activity was analyzed by dividing the drive phase into three in a recent study comparing the LES activity between rowers with and without a history of low back pain during rowing motion (7). In addition, the abdominal muscles activity starts within the last one-third of the drive phase and lasts until the first half of the recovery phase (5). Thus, new findings will be revealed by an analysis of the trunk muscles activity that divides the recovery phase. However, the changes in the activation patterns of the trunk and lower limb muscles during 2000-m rowing have not been examined in consideration of these phase divisions.

This study aimed to clarify the changes in the activation patterns of trunk and lower limb muscles during a 2000-m race simulation on a rowing ergometer by dividing the drive phase into three and the recovery phase into two.

MATERIALS AND METHODS

Participants

Ten men collegiate rowers (mean \pm SD, age, 19 \pm 1 years; height, 175.1 \pm 4.2 cm; mass, 69.2 \pm 5.0 kg; rowing experience, 5 \pm 2 years) participated in this study. We excluded participants if they self-reported a history of low back pain or lower-limb injuries in the past six months. The rowing training was performed for three hours per day, six days per week, on an elite collegiate rowing team. Written informed consent was obtained from all the participants. The experimental protocol followed the

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Declaration of Helsinki and was approved by the ethical committee of our institution (Ethics number : 2012-223).

Electromyography

EMGs of the RA, external oblique (EO), internal oblique (IO), LES, LMF, gluteus maximus (GMax), BF, and rectus femoris (RF) were recorded using surface electrodes. All muscles were measured on the side of the dominant hand of the participants. Prior to the attachment of the surface electrodes, the skin was abraded with a skin abrasive and alcohol was applied to reduce the skin impedance to <2 k Ω . Surface electrodes (BlueSensor N-00-S, METS Co., Japan) of a diameter of 8-mm, were attached to each muscle belly, which was parallel to the muscle fiber, for the RA, 3 cm lateral to the umbilicus (9); for the EO, 15 cm lateral to the umbilicus (9); for the IO, 1 cm medial and downward to the anterior superior iliac spine (10); for the LES, 3 cm lateral to the L3 spinous process (9); for the LMF, 2 cm lateral to the L5 spinous process (11); for the GMax, the midpoint of the sacral vertebra and greater trochanter (12); for the BF, the midpoint of the ischial tuberosity and the lateral condyle of the femur on the posterior side of the thigh (13); for the RF, the midpoint of the anterior inferior iliac spine and the patella on the anterior side of the thigh (13). The inter-electrode distance was 20 mm. A wireless EMG telemeter system (BioLog DL-5000, S&ME Co., Japan) with a sampling rate of 1000 Hz was used to measure the surface EMG.

Experimental procedure

Following the optional 10 min warm-up with some rowing motions by each participant, all the surface electrodes were attached. Subsequently, the maximal voluntary isometric contraction (MVIC) tests of each muscle were recorded to normalize the EMG data. For the RA, the participants performed trunk flexion in a crook lying position, with hands in front of the chest, with manual resistance applied to the anterior shoulder in the trunk extension direction. For the EO, the participants performed trunk flexion and rotation toward the contralateral side in the same position as the RA. Manual resistance was applied to the shoulder with trunk extension and rotation towards the ipsilateral side. For the IO, the participants performed similar maneuvers as the EO; however, the trunk rotation was performed to the opposing side. The participants performed trunk extension in the prone position with manual resistance applied to the posterior shoulder aspect in the trunk flexion direction for the LES and LMF. For the GMax, the participants performed hip extension in the prone position with 90° knee flexion, and manual resistance was applied to the distal thigh in the hip flexion direction. For the BF, the participants performed knee flexion in the prone position with 45° knee flexion, and manual resistance was applied to the lower leg in the direction of knee extension. For the RF, the participants performed knee extension in the seated position with manual resistance applied to the lower leg in the knee flexion direction. The MVIC tests of each muscle were performed for 5 s, and the resting time between each test was at least 1 min to allow the participants to fully recover.

After the MVIC tests, the participants performed a 2000-m race simulation on a Concept 2 model D rowing ergometer (Concept Inc, Vermont, USA). The 2000-m race simulation on a rowing ergometer was performed according to previous studies (4, 6, 8). The participants were asked to row at a racing pace during the race simulation (4, 8). A 2000-m race simulation was recorded using a high-speed camera (EXLIM EX-100, CASIO Co., Ltd., Japan) at 120 Hz in the sagittal plane. The high-speed camera was synchronized with a wireless EMG telemeter system by recording the light emission timing in the EMG data with a trigger signal and recording the light emission with the camera.

Data analysis

The EMG activity of the trunk and lower limb muscles during 11th, 12th, and 13th strokes after the start (initial stage), three strokes at 1000m (middle stage), and the 13th, 12th, and 11th strokes before the end (final stage) were analyzed. A few strokes immediately after the start have a large air resistance to increase the rotational speed of the ergometer flywheel. Therefore, the first 10 strokes were excluded from the analysis in order to analyze the strokes in which the rotational speed of the flywheel of all participants was approximately constant. The last 10 strokes were excluded because they may show different strokes from the typical strokes of the final stage due to the full power stroke as the last spurt of the 2000-m race simulation. From the handle position in the sagittal plane, the rowing motion was divided into two phases (drive and recovery) and five subphases (early-drive, middle-drive, late-drive, early-recovery, and late-recovery). The drive phase was defined as the period from the point when the handle was closest to the flywheel of the rowing ergometer to the moment it was farthest from the flywheel of the rowing ergometer. The recovery phase was defined as the period from the end of the drive phase to the moment the handle was closest to the flywheel of the rowing ergometer. Each phase was divided into three (early-, middle-, and late-drive) (7) or two (early- and late-recovery) subphases by dividing the duration equally.

The recorded EMG data were analyzed using biomedical information software (BIMUTAS-Video, Kissei Comtec Co., Ltd., Japan). The raw EMG data were band-pass filtered between 20 and 450 Hz and were represented as the root mean square (RMS) amplitude in each subphase. The RMS amplitude was normalized as a percentage (%MVIC) of the highest RMS amplitude obtained over 1 s during MVIC tests. The %MVIC data for each muscle are represented as the mean values of the three strokes in each stage, and these mean values were used in the statistical analyses.

Statistical analysis

After confirming all the data with normal distribution using the Kolmogorov-Smirnov test and homoscedasticity by using the Levene test, a two-way analysis of variances (ANOVAs) (3 stages \times 5 subphases) repeated for the stages and subphases were used to examine the changes in the EMG activity of the trunk and lower limb muscles. Additionally, repeated measures ANOVAs (three stages) were used to compare the duration of the drive and recovery phases between the stages. Bonferroni correction was used as a post-hoc test. A partial η^2 was calculated for the effect size of two-way ANOVAs and repeated measures ANOVAs, with values of ≥ 0.01 , < 0.06 , ≥ 0.06 , and < 0.14 , and ≥ 0.14 , indicating small, medium, and large effects, respectively (14). The alpha level was set to 0.05. All statistical analyses were performed using SPSS Statistics 26.0 (IBM Japan Corp, Japan).

RESULTS

The exercise time of the 2000-m race simulation was 417 ± 9 (mean \pm SD) seconds. The duration of the drive and recovery phases at each stage during the 2000-m race simulation are shown in Table 1. The duration of the drive phase in the initial and final stages was significantly shorter than that in the middle stage ($F_{(2,18)} = 7.205$, $P = 0.005$, partial $\eta^2 = 0.445$). The duration of the recovery phase in the final stage was significantly shorter than that in the middle stage ($F_{(2,18)} = 9.985$, $P = 0.001$, partial $\eta^2 = 0.526$).

The EMG activity of the trunk and lower limb muscles during

Table 1. Duration of the drive and recovery phases at each stage during a 2000-m race simulation

	Initial	Middle	Final	F _(2,18)	P-value	Effect size (partial η ²)
Duration of phase						
Drive (second)	0.859 ± 0.045 ^a	0.904 ± 0.042	0.849 ± 0.061 ^a	7.205	0.005*	0.445
Recovery (second)	1.037 ± 0.084	1.116 ± 0.085	0.924 ± 0.133 ^a	9.985	0.001*	0.526

^a Significantly shorter than that the middle stage.
* P < 0.05, Comparison by a one-way analysis of variance.

the 2000-m race simulation are shown in Figures 1-3. Significant interactions were found with respect to all the trunk and lower limb muscles ; RA (F_(8,72) = 9.003, P < 0.001, partial η² = 0.500), EO (F_(8,72) = 10.656, P < 0.001, partial η² = 0.542), IO (F_(8,72) = 4.882, P = 0.011, partial η² = 0.352), LES (F_(8,72) = 8.360, P < 0.001, partial η² = 0.482), LMF (F_(8,72) = 6.859, P = 0.001, partial η² = 0.433), GMax (F_(8,72) = 6.647, P < 0.001, partial η² = 0.425), BF (F_(8,72) = 26.348, P < 0.001, partial η² = 0.745), and RF (F_(8,72) = 22.580, P < 0.001, partial η² = 0.715).

The post hoc test results demonstrated that the RA activity in the late-drive phase was significantly higher at the initial stage (42.3 ± 15.3 %MVIC) than at the middle (19.2 ± 13.7 %MVIC) and final stages (22.9 ± 13.9 %MVIC) (P < 0.016). On the other hand, the RA activity in the early-recovery phase was significantly higher at the middle (37.5 ± 12.3 %MVIC) and final stages (44.4 ± 16.4 %MVIC) than at the initial stage (23.6 ± 9.6 %MVIC) (P < 0.002). Additionally, the RA at the initial stage showed significantly higher activity in the late-drive phase than the other phases (P < 0.007), whereas the RA at the middle and final stages showed the highest activity in the early-recovery phase (Figure 1a). The other significant differences in RA activity are shown in Figure 1a.

The EO activity in the late-drive phase was significantly higher in the initial stage (50.6 ± 15.8 %MVIC) than in the middle (25.7 ± 16.7 %MVIC) and final stages (31.2 ± 19.9 %MVIC) (P < 0.010). On the other hand, the EO activity in the early-recovery phase was significantly higher at the middle (44.6 ± 11.4 %MVIC) and final stages (55.2 ± 19.7 %MVIC) than at the initial stage (27.9 ± 7.6 %MVIC) (P < 0.004). Additionally, the EO at the initial stage showed significantly higher activity in the late-drive phase than the other phases (P < 0.011), whereas the EO at the middle and final stages showed the highest activity in the early-recovery phase (Figure 1b). The other significant differences in EO activity are shown in Figure 1b.

The IO activity in the early-recovery phase was significantly higher at the final stage (36.0 ± 20.1 %MVIC) than at the initial (16.0 ± 7.5 %MVIC) and middle stages (26.1 ± 14.7 %MVIC) (P < 0.033). In addition, the IO activity in the late-recovery phase was significantly higher in the final stage (20.4 ± 11.2 %MVIC) than in the initial (7.7 ± 5.1 %MVIC) and middle stages (8.9 ± 6.4 %MVIC) (P < 0.010). Additionally, the peak IO activity at the initial stage was observed in the late-drive phase, while it was observed that the middle and final stages were shown in the early-recovery phase (Figure 1c). The other significant differences in IO activity are shown in Figure 1c.

The LES activity in the late-drive phase was significantly higher in the middle (33.1 ± 11.9 %MVIC) and final stages (34.2 ± 15.3 %MVIC) than at the initial stage (11.9 ± 7.3 %MVIC) (P < 0.010). In addition, the LES activity in the early-recovery phase was significantly higher at the final stage (30.1 ± 15.5 %MVIC) than at the initial (9.4 ± 7.8 %MVIC) and middle stages (12.0 ± 6.9 %MVIC) (P < 0.006). Additionally, the peak LES activity at the initial stage was observed in the middle-drive phase, while the peak LES activity at the middle and

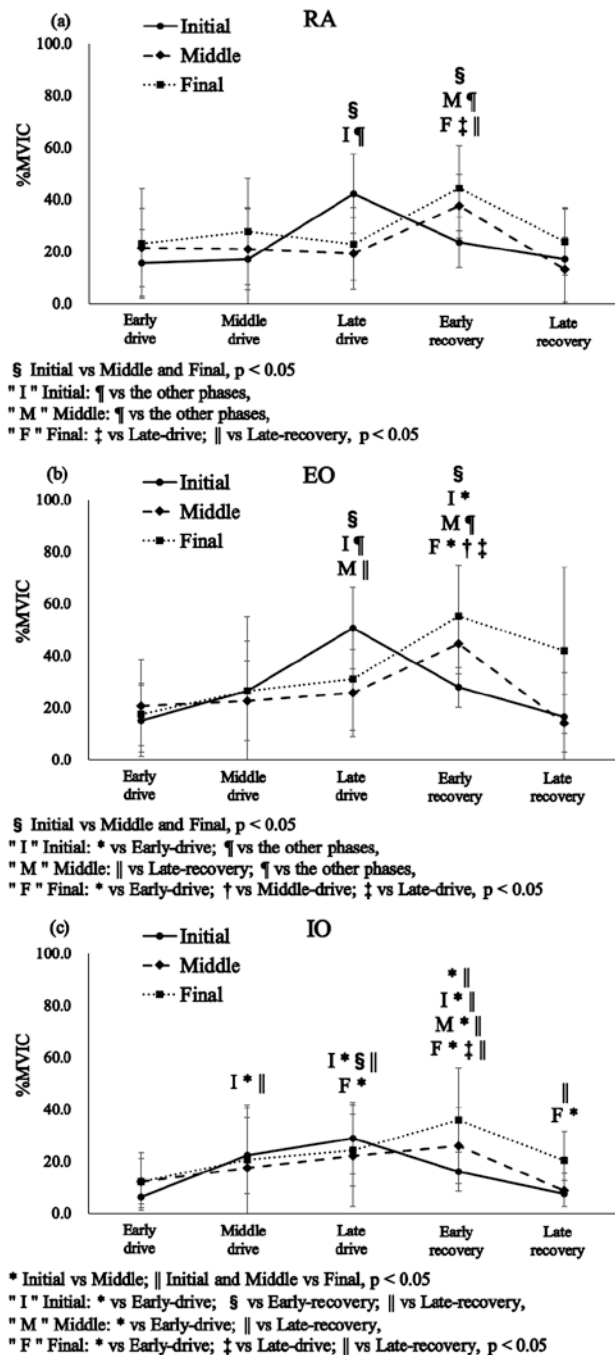


Figure 1. Mean and standard deviation for the electromyographic activity of the abdominal muscles regarding (a) the rectus abdominis (RA), (b) external oblique (EO), and (c) internal oblique (IO). MVIC, maximal voluntary isometric contraction.

final stages was observed in the late-drive phase (Figure 2a). The other significant differences in the LES activity are shown in Figure 2a.

The LMF activity in the late-drive phase was significantly higher in the middle (31.2 ± 15.3 %MVIC) and final stages (30.9 ± 9.0 %MVIC) than at the initial stage (13.1 ± 10.6 %MVIC) ($P < 0.036$). In addition, the LMF activity in the early-recovery phase was significantly higher at the final stage (24.4 ± 12.7 %MVIC) than at the initial (6.8 ± 5.5 %MVIC) and middle stages (14.6 ± 8.0 %MVIC) ($P < 0.045$). Additionally, the peak LMF activity at the initial stage was observed in the middle-drive phase, while the peak LMF activity in the middle and final stages was observed in the late-drive phase (Figure 2b). The other significant differences in the LMF activity are shown in Figure 2b.

The GMax activity in the early-recovery phase was significantly higher in the final stages (28.5 ± 19.2 %MVIC) than in the initial (10.4 ± 8.4 %MVIC) and middle stages (17.3 ± 12.6 %MVIC) ($P < 0.024$). Additionally, the peak GMax activity at the initial and middle stages was observed in the middle-drive phase, while the peak GMax activity at the final stage was observed in the late-drive phase (Figure 3a). The other significant differences in the GMax activity are shown in Figure 3a.

The BF activity in the middle-drive phase was significantly higher at the initial stage (43.6 ± 23.3 %MVIC) than at the middle (27.2 ± 15.8 %MVIC) and final stages (16.3 ± 16.7 %MVIC) ($P < 0.010$). On the other hand, the BF activity in the late-drive

phase was significantly higher at the final stage (41.3 ± 17.3 %MVIC) than at the initial (6.0 ± 5.1 %MVIC) and middle stages (25.8 ± 11.6 %MVIC) ($P < 0.005$). Additionally, the BF at the initial stage showed significantly higher activity in the middle-drive phase than in the other phases ($P < 0.049$), while the BF at the final stage showed significantly higher activity in the late-drive phase than in the other phases ($P < 0.004$) (Figure 3b). The other significant differences in the BF activity are shown in Figure 3b.

The RF activity in the late-drive phase was significantly

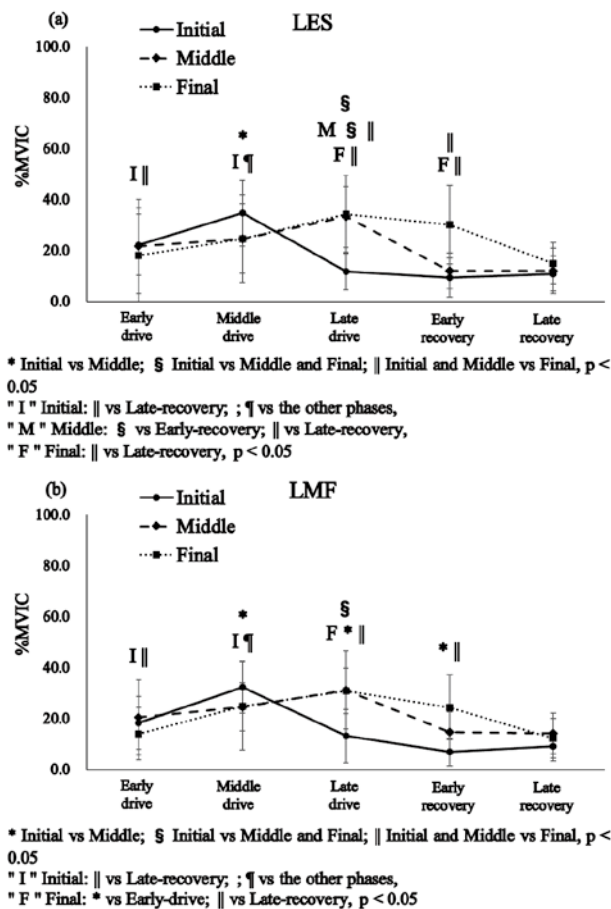


Figure 2. Mean and standard deviation for the electromyographic activity of the back muscles regarding (a) the lumbar erector spinae (LES) and (b) lumbar multifidus (LMF). MVIC, maximal voluntary isometric contraction.

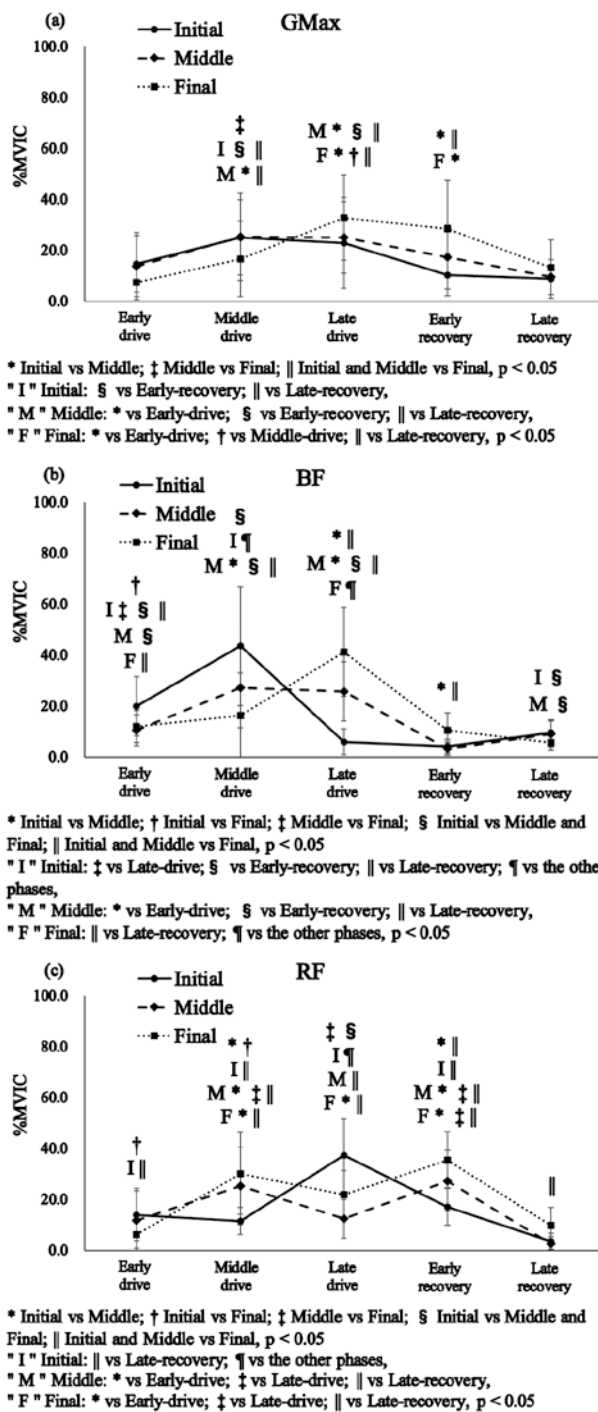


Figure 3. Mean and standard deviation for the electromyographic activity of the lower limb muscles regarding (a) the gluteus maximus (GMax), (b) biceps femoris (BF), and (c) rectus femoris (RF). MVIC, maximal voluntary isometric contraction.

higher at the initial stage (37.4 ± 14.2 %MVIC) than at the middle (12.4 ± 7.6 %MVIC) and final stages (22.0 ± 9.3 %MVIC) ($P < 0.018$). On the other hand, the RF activity in the middle drive and early-recovery phases was significantly higher at the final stage (middle drive : 30.2 ± 16.2 %MVIC, early recovery : 35.5 ± 11.1 %MVIC) than at the initial stage (middle drive : 11.5 ± 5.4 %MVIC, early recovery : 17.0 ± 7.3 %MVIC) ($P < 0.008$). Additionally, the peak RF activity at the initial stage was observed in the late-drive phase, while the RF activity in the middle and final stages showed high activity in the middle drive and early-recovery phases (Figure 3c). The other significant differences in the RF activity are shown in Figure 3c.

DISCUSSION

This study investigated the changes in the activation patterns of the trunk and lower limb muscles during a 2000-m race simulation on a rowing ergometer. The participants performed rowing motions with fatigue at the middle and final stages, since a 2000-m rowing in the racing pace is a high-intensity exercise task. The main finding was that the peak activities of the abdominal muscles, back muscles, GMax, and BF in each stroke of the rowing motion were delayed at the middle and final stages when compared to the initial stage.

The abdominal muscles showed peak activities in the late-drive phase at the initial stage, while they showed peak activities in the early-recovery phase at the middle and final stages (Figure 1). The abdominal muscles decelerate the trunk extension and shift to trunk flexion when switching from the drive phase to the recovery phase (5). The peak activities of the abdominal muscles in the late-drive phase at the initial stage were observed as preparation for switching from the drive phase to the recovery phase, while this preparation was delayed at the middle and final stages due to fatigue.

The back muscles demonstrated peak activities in the middle-drive phase at the initial stage, while they demonstrated peak activities in the late-drive phase at the middle and final stages. Additionally, they continued high activity until the early-recovery phase at the final stage (Figure 2). Similarly, the GMax and BF showed peak activities in the middle-drive phase at the initial stage, while they showed peak activities in the late-drive phase at the final stage (Figure 3a, 3b). The back muscles, GMax, and BF contribute to the peak force production of the stroke in the middle-drive phase during the rowing motion by trunk extension and hip extension, respectively (5). However, high activity of the back muscles, which lasted until the early-recovery phase at the final stage, was not necessary for efficient rowing motions. Considering the report that the LES activity in rowers with a history of low back pain was higher than that in rowers without low back pain during the rowing motion (7), unnecessary high activity of the back muscles, which was observed to last until the early-recovery phase at the final stage, may lead to the development of muscular low back pain in the rowers.

RF demonstrated peak activity in the late-drive phase at the initial stage, while it demonstrated high activity in the middle-drive and early-recovery phases at the middle and final stages (Figure 3c). A possible explanation for the peak activity of RF in the late-drive phase at the initial stage is that the RF became active in order to prevent the posterior pelvic tilt, including the posterior trunk inclination, when switching from the drive phase to the recovery phase. On the other hand, the RF activity in the late-drive phase decreased in the middle and final stages compared to the initial stage. This result may lead to a decrease in the knee extension force. Thus, the back muscles, GMax, and BF activity (Figure 2, 3a, 3b) increased in order to compensate

for a decrease in the knee extension force by trunk and hip extension. Conversely, in the middle-drive phase at the final stage, we suggest that the RF activity increased in order to contribute to the peak force production of the stroke using the knee extension because the BF activity related to the hip extension decreased (Figure 3b). However, it is unclear why the RF showed high activity in the early-recovery phase at the middle and final stages. From the results of the RF activity, muscular endurance enhancement of the RF may prevent a decrease in the knee extension force in the late-drive phase at the middle and final stages. Moreover, it can lead to a decrease in the load on the back muscles and contribute to the prevention of the development of muscular low back pain in rowers.

There were some limitations to this study. First, the participants were healthy rowers, who were men. The results of the present study might be different in rowers who are women or rowers with low back pain. Second, the 2000-m race simulation was carried out with an ergometer, not on the water. The surface of the water is unstable and has irregular external perturbation due to waves. It has been reported that the trunk muscles activity on the unstable surface increased (15), and it is expected that rowing on the water increases overall muscle activity compared to rowing on an ergometer. In addition, it is possible that an increase in muscle activity may be observed locally in any of the muscles. On the other hand, when rowing on the water, the influence of skills such as maintaining the balance of the boat is greater. Therefore, the results vary widely among the participants, and the results may differ from those in present study. Third, we did not analyze trunk and lower limb motion during the rowing motion. The trunk and lower limb motions may change at each stage. Additionally, we did not measure the activity of the upper limb muscles related to the force produced by the stroke. Then, the data, such as fatigue and heart rate were also not measured, although we consider that the changes in the activity of the trunk and lower limb were influenced by fatigue. Finally, the duration of each phase at the initial and final stages was shorter than that in the middle stage (Table 1). This duration difference between the stages may have influenced the results of the activity of the trunk and lower limbs.

In conclusion, this study investigated the changes in the activation patterns of trunk and lower limb muscles during a 2000-m race simulation on a rowing ergometer by dividing the drive phase into three and the recovery phase into two. The peak activities of the abdominal muscles, back muscles, GMax, and BF in each stroke of the rowing motion were delayed at the middle and final stages compared to the initial stage. In particular, a high activity of the back muscles, which lasted until the early recovery phase at the final stage, may lead to the development of muscular low back pain in rowers. Considering the results of the activity of the back muscles and RF, a muscular endurance enhancement of RF may lead to a decrease in the load on the back muscles and contribute to the prevention of the development of muscular low back pain in rowers.

CONFLICT OF INTEREST DISCLOSURE

None of the authors received any funding support to complete this report. None of the authors has any conflicts of interest to declare.

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