©Journal of Sports Science and Medicine (2023) **22,** 338-344
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2023.338

Research article

Trunk Muscle Activities during Ergometer Rowing in Rowers with and without Low Back Pain

Momoko Yamashita [1], Tomoya Ishida [2], Satoshi Osuka [2,3]✉, Kentaro Watanabe [2,3], Mina Samukawa [2], Satoshi Kasahara [2], Eiji Kondo [1] and Harukazu Tohyama [2]
[1] Department of Sports Medicine, Graduate School of Medicine, Hokkaido University, Sapporo, Hokkaido, Japan; [2] Faculty of Health Sciences, Hokkaido University, Sapporo, Hokkaido, Japan; [3] Department of Rehabilitation, Hokkaido University Hospital, Sapporo, Hokkaido, Japan

Abstract

This study aimed to determine the differences in trunk muscle activity during rowing at maximal effort between rowers with and without low back pain (LBP). Ten rowers with LBP and 12 rowers without LBP were enrolled in this study. All rowers performed a 500-m trial using a rowing ergometer at maximal effort. The amplitudes of the activities of the thoracic erector spinae (TES), lumbar erector spinae (LES), latissimus dorsi (LD), rectus abdominis (RA), and external oblique (EO) muscles were analyzed using a wireless surface electromyography (EMG) system. EMG data at each stroke were converted into 10-time series data by recording averages at every 10% in the 100% stroke cycle and normalized by maximum voluntary isometric contraction in each muscle. Two-way repeated measures analysis of variance was performed. Significant interactions were found in the activities of the TES and LES ($P < 0.001$ and $P = 0.047$, respectively). In the post hoc test, the TES activity in the LBP group was significantly higher than that in the control group at the 10% to 20% and 20% to 30% stroke cycles ($P = 0.013$ and $P = 0.007$, respectively). The LES activity in the LBP group was significantly higher than that in the control group at the 0% to 10% stroke cycle ($P < 0.001$). There was a main group effect on the LD activity, with significantly higher activity in the LBP group than in the control group ($P = 0.023$). There were no significant interactions or main effects in the EO and RA activities between the groups. The present study showed that rowers with LBP compared with those without LBP exhibited significantly higher TES, LES, and LD muscle activities. This indicates that rowers with LBP exhibit excessive back muscle activity during rowing under maximal effort.

Key words: Surface electromyography, stroke cycles, water sports

Introduction

Low back pain (LBP) is the most common injury among rowers (Thornton et al., 2017; Trease et al., 2020). It accounts for 32–52% of all reported rowing injuries (Bahr et al., 2004; Wilson et al., 2010). According to a study, 18% of rowers who reported LBP missed training in excess of 1 month (O'kane et al., 2003), and in other studies, 53–79% reported LBP recurrence (Teitz et al., 2003; Newlands et al., 2015). Despite the high incidence of LBP in rowers, there is no clear consensus on prevention strategies, and the development of effective interventions remains challenging.

Dysfunction of the trunk muscles that control the spine is a factor in the development of LBP (Panjabi, 1992; Richardson et al., 1999). Bergmark (1989) proposed grouping muscles by functional characteristics into global (e.g., the erector spinae, rectus abdominis, internal oblique, external oblique, quadratus lumborum, psoas major, and vastus lateralis muscles) and local (transverse abdominis and multifidus muscles) muscles. Global muscles contribute to the regulation of spinal orientation, the balancing of extrinsic burdens, and the production of a substantial amount of torque for spinal movement. People with LBP are preferentially biased toward posture-specific activation of global muscles, which are larger and more superficial, than local muscles, which fine-tune intersegmental movement (van Dieën et al., 2003a; Ferguson et al., 2004; Marras et al., 2004; Claus et al., 2018). Although excessive activity of these muscles contributes to spinal stability, it also increases the load on the spine and is considered a risk factor for LBP (van Dieën et al., 2003b; Hodges et al., 2013).

Despite the importance of examining muscle activity during rowing when considering prevention strategies and interventions for LBP in rowers, the differences between rowers with and without LBP regarding trunk muscle activity during rowing at maximal effort (such as a 2,000-m race) are unclear. A previous study reported that the lumbar erector spinae activity was significantly higher during incremental rowing tests in rowers with a recent history of LBP than in those without LBP (Martinez-Valdes et al., 2019). Therefore, even when rowing under maximal effort, trunk muscle activity may differ between rowers with and without LBP. The purpose of this study was to investigate the differences in trunk muscle activities during rowing at maximal effort between rowers with and without LBP, assuming a 2,000-m race.

Methods

Participants

Twenty-two competitive rowers in our university's rowing team participated in this study, of whom 10 rowers were in the LBP group. The LBP group was defined by asking each rower if they experienced LBP during daily rowing trainings. The inclusion criteria for the LBP group were reports of provoked pain at an intensity greater than 30 mm on a visual analog scale (VAS) located between the first and

Received: 27 April 2023 / Accepted: 21 May 2023 / Published (online): 01 June 2023

fifth lumbar vertebrae within 30 min of daily rowing training (Ng et al., 2015). Participants were excluded if they reported the presence of specific causes of LBP, such as inflammatory diseases, radicular pain, neurological signs in the lower limbs, or any lower limb musculoskeletal injury in the 6 weeks that preceded data collection (Ng et al., 2015). In addition, participants who had missed training sessions due to LBP in the past one month prior to the study were excluded, but none of the participants were excluded based on this criterion. We explained the content of the study to the participants before the measurements, and all the rowers who agreed to participate in the study provided written informed consent. The institutional review boards of the authors' associated institutions approved this study.

Experimental procedures

All participants completed the Oswestry Disability Index (ODI), Roland Morris Disability Questionnaire (RDQ), and VAS before rowing measurements. The ODI and RDQ were used to investigate the effects of LBP on activities of daily living. The VAS was used to evaluate pain intensity after 30 min of rowing training using scoring points ranging from 0 to 100.

The participants performed a 500-m trial at maximal effort with a rowing ergometer (Concept II Inc., Morrisville, VT, USA), as if they were in a 2,000-m race. Because a 2,000-m trial will be extremely burdensome for the participants, a 500-m trial was set as a safe distance for the measurements. The warm-up consisted of a self-selected ergometer speed for approximately 20 min before the measurement. The data collection session replaced a typical workout in the participants' training week. The examiner always paid attention to the presence or absence of pain, and if a participant was to complain of pain, the measurement was to be terminated immediately.

Trajectory data analysis to determine the rowing cycle

For kinematic data, a motion analysis system (Cortex 5.5.0, Motion Analysis Corporation, Santa Rosa, CA, USA) with seven digital cameras (Hawk cameras, Motion Analysis Corporation, Santa Rosa, CA, USA) was used to determine the rowing cycle, sampling at 200 Hz. Nineteen reflective markers were attached to the spinous process of C7, T4, T7, T10, L1, L3, and S1 and bilaterally at the lateral midline of the iliac crest, greater trochanter, lateral femoral epicondyle, lateral malleoli, mid-joint line of the dorsal aspect of the wrist, and acromion process of each participant. MATLAB (MathWorks, Natick, MA, USA) was used to filter the kinematic data and perform calculations. The raw trajectory data were filtered using a fourth-order Butterworth low-pass filter at a frequency of 12 Hz. The trajectory data of the right wrist were used to determine the analysis intervals for subsequent analyses. Each stroke was based on the trajectory data of the wrist in the sagittal plane and represented a period from one "catch position" through the "finish position" to the next "catch position" (Figure 1). The position was defined as a "catch position" when the wrist marker reached the most forward position (Pollock et al., 2009), which was equivalent to when the oars were down in the water. The position was defined as a "finish position" when the wrist marker reached the most backward position (Pollock et al., 2009), which was equivalent to when the oars were out of water. The trajectory data were analyzed for five strokes of rowing at 30 s from the 250-m distance because this period represented the steady state after the initial "push" and is considered as the period before significant fatigue sets in (Pollock et al., 2009).

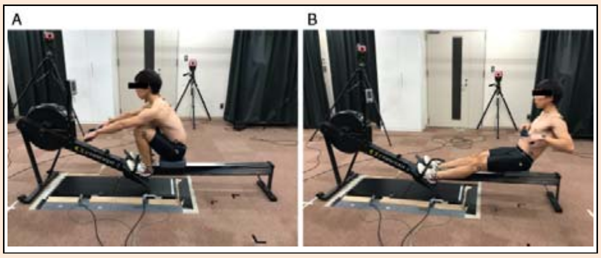

Figure 1. (A) catch and (B) finish position. All participants performed a rowing ergometer test with repetitions of catch and finish under maximal effort.

Electromyography evaluation

Electromyography (EMG) recordings of the thoracic erector spinae (TES), lumbar erector spinae (LES), latissimus dorsi (LD), rectus abdominis (RA), and external oblique (EO) muscles on the right side were recorded using a wireless surface EMG system (WEB-1000, Nihon Kohden Corporation, Tokyo, Japan). The sampling rate was set to 1,000 Hz. The placement of the electrodes was based on a previous study (Pollock et al., 2009): TES, 5 cm lateral to the midline of the T9 spinous process; LES,3 cm lateral to the midline of the L3 spinous process; LD, lateral to T9 over the muscle belly; RA,3 cm lateral to the midline at the level of the umbilicus; and EO,15 cm lateral to the umbilicus.

The EMG data were analyzed using MATLAB (MathWorks, Natick, MA, USA). The raw EMG data were bandpass-filtered at 20 - 500 Hz, full-wave rectified, and filtered using a fourth-order low-pass Butterworth filter at 10 Hz. The EMG data were synchronized with the trajectory data. The EMG data were extracted at the start of five consecutive rowings, which was consistent with the synchronized trajectory data of the right wrist. One stroke cycle, from the catch position to the next catch position calculated using trajectory data was normalized to 100% (Figure 2A). The EMG data for each stroke cycle were transformed into 10-time series data by recording the average value at every 10% in the 100% stroke cycle (Caldwell et al., 2003; Figure 2B). The 10-time series data per stroke were averaged over five strokes and used in subsequent analyses. The EMG data for each muscle were normalized as a percentage of the participant's highest maximal voluntary isometric contraction (MVIC) trial. The value used for normalization was the average of the data obtained during the 1 s period before and after the maximum during the MVIC trial. MVIC data were obtained in a manner consistent with that reported in a previous study (Escamilla et al., 2006). MVICs were measured after warm-up and before the rowing measurements, and the contraction duration was kept as short as possible (3 - 5 s) to minimize the demotivation and pain caused by prolonged contractions (Komantakis et al., 2021).

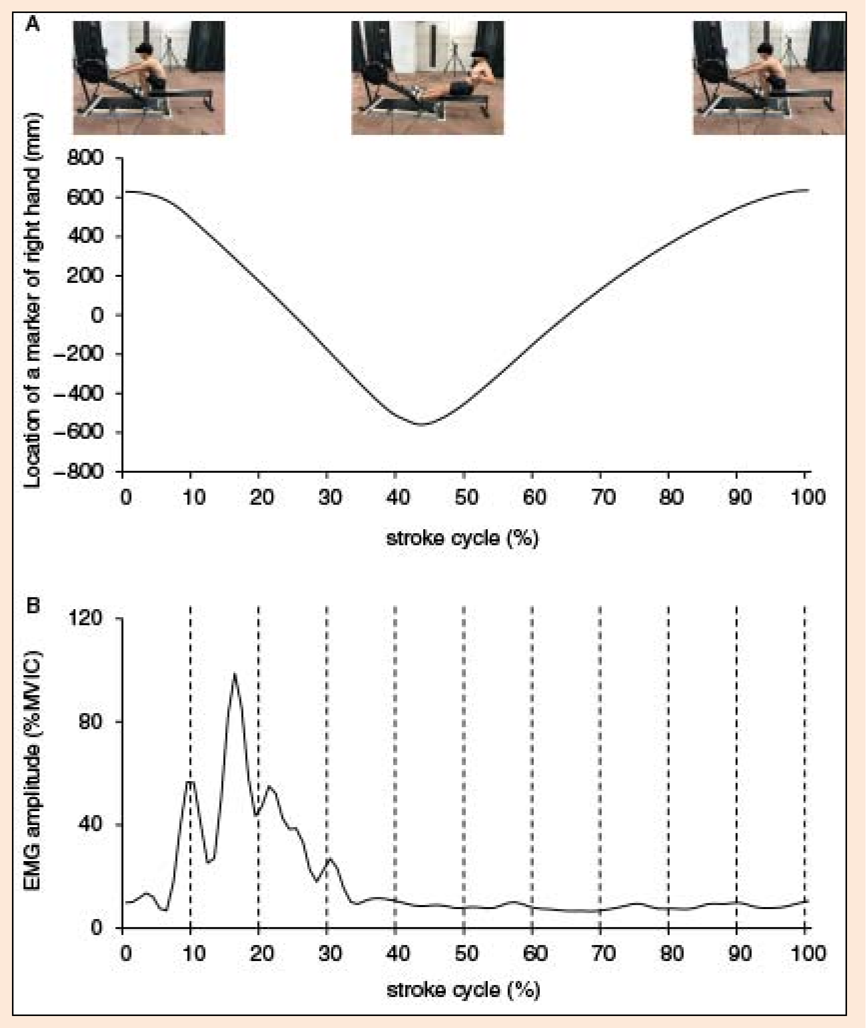

Figure 2. (A) **Trajectory data measured using the motion analysis system with an infrared reflective marker attached to the right wrist. Positive values indicate that the infrared reflective marker is positioned infront of its resting position, while negative values indicate that it is positioned behind its resting position. Each stroke cycle was defined by the sagittal position of the infrared reflective marker and consisted of one stroke from the "catch position," where the infrared reflective marker was positioned furthest forward, through the "finish position," where it was positioned backward, to the next catch position. (B) The EMG amplitude is normalized by the maximum voluntary isometric contraction value. The mean value is calculated at every 10% of the stroke cycle in accordance with the stroke cycle specified in the trajectory data and used for statistical analysis.**

Kinematics evaluation

The range of motion of the spinal segments, pelvis, hip, and knee were calculated in the sagittal plane (Pollock et al., 2009). The spinal segment angles are representative of the motion of the upper vertebral segment marker relative to the lower vertebral segment marker (Pollock et al., 2009). The pelvic angle represents the inclination angle relative to the horizontal line that runs through the sacral marker (Pollock et al., 2009). Each angle data was extracted from five strokes contemporaneous with the right wrist trajectory data and EMG data. The range of motion at each stroke was obtained from the difference between the maximum and minimum values (Pollock et al., 2009), and the mean of five strokes was used for statistical analysis.

Statistical analyses

IBM SPSS Statistics 28 (IBM, Chicago, IL, USA) was used for the statistical analyses. Two-way repeated measures analysis of variance was used for two factors, group, and stroke cycle comparisons for EMG data. If an interaction effect was observed, a post hoc analysis was performed using the Bonferroni correction test for comparison between groups at each time interval. In addition, demographic data, trial time, stroke rate, and range of motion during the 500-m trial were compared between the groups using an independent t-test or Mann–Whitney U test based on the distribution of the data by the Shapiro-Wiik test. Statistical significance was set at $\alpha = 0.05$.

Results

There were no differences in age, height, weight, or BMI between the LBP and control groups ($P = 0.346$, $P = 0.456$, $P = 0.323$, and $P = 0.356$, respectively; Table 1). The ODI, RDQ, and VAS scores were significantly higher in the LBP group than in the control group ($P < 0.001$, $P = 0.004$, and $P < 0.001$, respectively; Table 1). There were no significant differences in the 500-m measurement time or stroke rate between the two groups ($P = 0.112$ and $P = 0.909$, respectively; Table 2). All participants completed the 500-m rowing measurement without LBP.

Table 1. Participants characteristics and questionnaire scores in the low back pain and control groups.

	Low back pain group	Control group	P value
Age, yrs	20.6 (2.5)	21.7 (2.5)	0.346
Height, cm	166.7 (10.2)	170.1 (8.8)	0.456
Weight, kg	61.0 (10.4)	65.6 (10.6)	0.323
BMI, kg/m^2	21.8 (1.7)	22.5 (1.9)	0.356
ODI, /100	12.0 (7.8)	1.50 (3.1)	< 0.001
RDQ, /24	2.7 (2.5)	0.0 (0.0)	0.004
VAS, /100	46.3 (17.2)	3.8 (7.8)	< 0.001

The values are given as the mean (standard deviation). Abbreviations: VAS, visual analogue scale. ODI, Oswestry Disability Index. RDQ, Roland Morris Disability questionnaire.

Table 2. Trial time and stroke rate during the 500-m trial in the low back pain and control groups

	Low back pain group	Control group
Trial time, s	102.9 (5.5)	108.6 (9.6)
Stroke rate, strokes/min	30.6 (3.7)	31.0 (2.3)

The values are presented as mean (standard deviation).

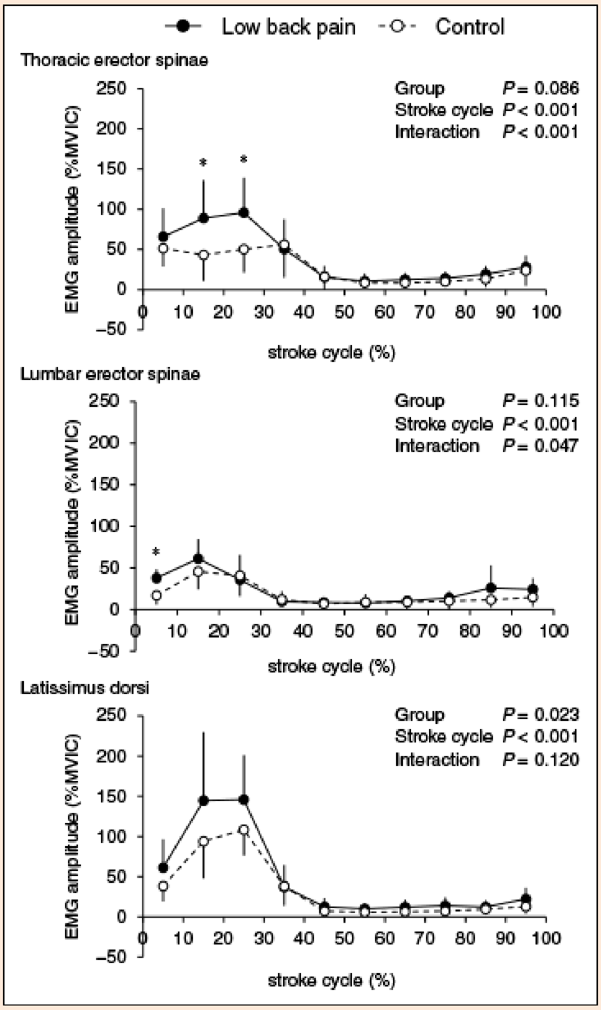

Figure 3. The EMG amplitude of the thoracic erector spinae, lumbar erector spinae, and latissimus dorsi muscle activities during rowing in the low back pain and control groups. * $P < 0.05$ (low back pain vs. control group).

Significant interactions were found in the TES and LES muscle activities ($P < 0.001$ and $P = 0.047$, respectively; Figure 3). In the post hoc test, the TES activity in the LBP group was significantly higher than that in the control group at the 10% to 20% and 20% to 30% stroke cycles ($P = 0.013$ and $P = 0.007$, respectively). The LES activity in the LBP group was significantly higher than that in the control group at the 0% to 10% stroke cycles ($P < 0.001$). There was a main group effect in the LD activity, with significantly higher activity in the LBP group than in the control group ($P = 0.023$). There were no significant interactions or main effects in the activities of the RA and EO muscles (Figure 4). There were significant main effects of stroke cycle on the TES, LES, LD, EO, and RA muscles ($P < 0.001$, $P < 0.001$, $P < 0.001$, $P < 0.001$, and $P < 0.001$, respectively). For kinematics data, there was a significant difference of the range of motion at L3 ($P = 0.027$; Table 3).

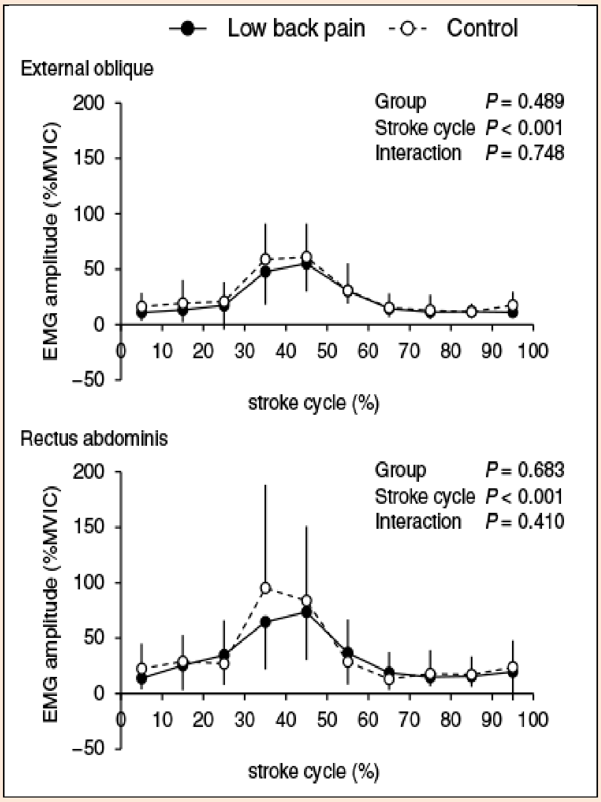

Figure 4. The EMG amplitude of the external oblique and rectus abdominis muscle activities during rowing in the low back pain and control groups.

Table 3. Range of motion of the spinal segments, pelvis, hip, and knee joints in the low back pain and control groups.

	Low back pain group	Control group	P value
T4, degree	25.8 (8.8)	29.0 (8.4)	0.180
T7, degree	16.7 (6.8)	18.8 (13.3)	0.947
T10, degree	58.3 (27.0)	74.3 (9.7)	0.093
L1, degree	6.3 (2.4)	9.1 (4.6)	0.059
L3, degree	14.6 (4.6)	19.9 (5.6)	0.027
Pelvis, degree	44.3 (19.4)	44.0 (9.6)	0.971
Hip, degree	78.8 (22.1)	82.0 (8.6)	0.649
Knee, degree	109.7 (10.3)	111.6 (10.0)	0.679

The values are presented as mean (standard deviation).

Discussion

In this study, we investigated the differences in the amplitude of trunk muscle activity during rowing at maximal effort in a 2,000-m race between rowers with and without LBP. This study revealed that the amplitudes of the LES and TES muscle activities were significantly higher in the LBP group than in the control group, especially in the 0–30% of one stroke cycle. A main group effect was observed in LD muscle activity, with higher muscle activity observed in the LBP group than in the control group. However, no significant interaction or main effects were found in the abdominal muscle groups, such as the EO and RA.

This is the first study to show that LES, TES, and LD muscle activities during rowing under maximal effort, simulating a 2,000-m race, were significantly higher in the LBP group than in the control group. Martinez-Valdes et al. (2019) reported that the amplitude of LES activity was higher in rowers with a history of LBP than in asymptomatic rowers during an incremental rowing test. A previous study reported that the cross-sectional area of the back muscles of rowers with LBP was significantly larger than that of rowers without LBP (McGregor et al., 2002), suggesting that rowers with LBP may exhibit excessive activity of the back muscles than of the lower or upper limbs to generate force during strokes. The results of this study support those of the above-mentioned previous studies.

The TES, LES, and LD muscles that showed significant differences in this study are classified as global muscles (Bergmark, 1989). Previous studies have reported that individuals with LBP overactivate their global muscle groups. Increased global muscle activity increases spine stress (van Dieën et al., 2003a; Ferguson et al., 2004; Marras et al., 2004), and this may contribute to LBP (van Dieën et al., 2003b; Hodges et al., 2013). In addition, repeated excessive muscle activity is believed to cause muscle pain (Johansson and Sojka, 1991; Visser and van Dieën, 2006). The finding of this study that rowers with LBP exhibit excessive activity in the back muscles suggests that pain may occur in the muscles. Tsao et al. (2011) reported that experimentally induced LBP increased the excitability of superficial trunk muscles, including the OE and LES, to cortical stimulation by transcranial magnetic stimulation, indicating that LBP may rapidly induce plasticity of cortical motor pathways. Experimental LBP may elicit long-term plasticity of the cortical motor pathways related to global muscle overactivity, even after pain extinction (Rohel et al., 2022). Therefore, the differences in muscle activity observed in this study may be related to central nervous system plasticity. Furthermore, in this study, significant differences were found in LES and TES muscle activity from 0–30% of the stroke cycle. The first half of the stroke cycle is called the "drive phase" and is the phase that generates the driving force for rowing. In a previous study, peak forces estimated at L4/L5 during rowing using ergometer under maximal effort were 2694 N of compressive force (4.6 times the rower's body weight) and 660 N of shear force (Fl et al., 2000). The "drive phase" requires the back muscle group activties to generate propulsive force, and muscle activity during this phase may be important in examining its relationship with LBP. To prevent and improve LBP, attention should be paid to the activity of global back muscles during rowing, especially during the "drive phase."

The symptoms of the rowers in the LBP group in this study were relatively mild. The rowers in this group were capable of rowing at maximum performance, and the impact of LBP on their daily lives as assessed by ODI and RDQ was mild. Therefore, the results of this study can be generalized to rowers with mild LBP and may be related to rowers with worsening LBP.

In this study, there were no statistically significant differences in 500-m trial time or stroke rate between the LBP and control groups. Therefore, the differences in muscle activity of the LES, TES, and LD muscles observed between the LBP and control groups in this study were not likely to be caused by differences in rowing performance. The force applied to the oar handle depends on the musculoskeletal forces or joint torques generated by knee and hip extension and upper limb pull movements, in addition to that generated by the back muscles (Baudouin and Hawkins, 2002). The pelvic muscles, in particular, are so important to posture and technique during rowing. The control group exhibited comparable performance with significantly lower muscle activity in the back muscle group compared to that observed in the LBP group, which may have generated more upper and/or lower extremity muscle activity.

Concurrent with the electromyography analysis in this study, we have analyzed the range of motion in sagittal plane angles of the spinal segments, pelvis, hip, and knee joints. We found that the range of motion of L3 was significantly larger in the control group than the LBP group. However, it is difficult to relate the present kinematics results to the EMG results. It may be possible to explain the relationship between EMG and kinematics in the present results by measuring not only trunk muscles but also other muscle activities such as pelvic muscles.

This study has some limitations. First, it is unclear whether the abnormalities in EMG activity indicate a cause or an effect of LBP because this study was a cross-sectional study. Prospective studies are required to clarify this causal relationship. Second, EMG recordings were obtained using a surface EMG system. Although the electrode placements in this study were consistent with those in a previous study (Pollock et al., 2009), it is likely that the surface EMG detected the activity of other muscles. Third, muscle activity measurements were limited to trunk muscle measurements. Further analysis of the muscle activity of other muscles, including the pelvic muscles, would provide further evidence related to the study results. Fourth, MVIC was used to normalize the muscle activity of the rowers with LBP. Although MVIC is not accurately measured in individuals with LBP (Larivière et al., 2003), the most appropriate normalization method for individuals with LBP has not yet been established (Besomi et al., 2020). Finally, although this study used rowing ergometers to analyze muscle activity during rowing, it has been reported that sagittal lumbar motion differs between rowing ergometers and rowing on water (Wilson et al., 2013). Since changes in trunk kinematics also affect muscle activity, it should be noted that the results of this study are limited to the characterization of muscle activity on the rowing ergometer as different muscle activities may be observed when rowing on water.

Conclusion

The present study showed that rowers with LBP compared with those without LBP exhibited significantly higher TES, LES, and LD muscle activities during the drive phase of ergometer rowing. These results indicate that rowers with LBP exhibit excessive back muscle activity during rowing under maximal effort.

Acknowledgements
The authors have no conflict of interest to declare. This study's experiments comply with the current laws of the country in which they were performed. The datasets generated and analyzed during the current study are not publicly available, but are available from the corresponding author who was an organizer of the study.

References

Bahr, R., Andersen, S.O., Løken, S., Fossan, B., Hansen, T. and Holme, I. (2004) Low back pain among endurance athletes with and without specific back loading--a cross-sectional survey of cross-country skiers, rowers, orienteerers, and nonathletic controls. *Spine* **29**, 449-454. https://doi.org/10.1097/01.brs.0000096176.92881.37

Baudouin, A. and Hawkins, D. (2002) A biomechanical review of factors affecting rowing performance. *British Journal of Sports Medicine* **36**, 396-402. https://doi.org/10.1136/bjsm.36.6.396

Bergmark, A. (1989) Stability of the lumbar spine. A study in mechanical engineering. *Acta Orthopaedica Scandinavica. Supplementum* **230**, 1-54. https://doi.org/10.3109/17453678909154177

Bonato, P., Ebenbichler, G.R., Roy, S.H., Lehr, S., Posch, M., Kollmitzer, J. and Della Croce, U. (2003) Muscle fatigue and fatigue-related biomechanical changes during a cyclic lifting task. *Spine* **28**, 1810-1820. https://doi.org/10.1097/01.BRS.0000087500.70575.45

Caldwell, J.S., McNair, P.J. and Williams, M. (2003) The effects of repetitive motion on lumbar flexion and erector spinae muscle activity in rowers. *Clinical Biomechanics (Bristol, Avon)* **18**, 704-711. https://doi.org/10.1016/s0268-0033(03)00117-7

Claus, A.P., Hides, J.A., Moseley, G.L. and Hodges, P.W. (2018) Different ways to balance the spine in sitting: Muscle activity in specific postures differs between individuals with and without a history of back pain in sitting. *Clinical Biomechanics (Bristol, Avon)* **52**, 25-32. https://doi.org/10.1016/j.clinbiomech.2018.01.003

van Dieën, J.H., Cholewicki, J. and Radebold, A. (2003a) Trunk muscle recruitment patterns in patients with low back pain enhance the stability of the lumbar spine. *Spine* **28**, 834-841. https://doi.org/10.1097/01.BRS.0000058939.51147.55

van Dieën, J.H., Selen, L.P. and Cholewicki, J. (2003b) Trunk muscle activation in low-back pain patients, an analysis of the literature. *Journal of Electromyography and Kinesiology* **13**, 333-351. https://doi.org/10.1016/s1050-6411(03)00041-5

Escamilla, R.F., Babb, E., DeWitt, R., Jew, P., Kelleher, P., Burnham, T., Busch, J., D'Anna, K., Mowbray, R., and Imamura, R.T. (2006) Electromyographic analysis of traditional and nontraditional abdominal exercises: implications for rehabilitation and training. *Physical Therapy & Rehabilitation Journal* **86**, 656-671. https://doi.org/10.1093/ptj/86.5.656

Ferguson, S.A., Marras, W.S., Burr, D.L., Davis, K.G. and Gupta, P. (2004) Differences in motor recruitment and resulting kinematics between low back pain patients and asymptomatic participants during lifting exertions. *Clinical Biomechanics (Bristol, Avon)* **19**, 992-999. https://doi.org/10.1016/j.clinbiomech.2004.08.007

Hodges, P.W., Coppieters, M.W., MacDonald, D. and Cholewicki, J. (2013) New insight into motor adaptation to pain revealed by a combination of modelling and empirical approaches. *European Journal of Pain (London, England)* **17**, 1138-1146. https://doi.org/10.1002/j.1532-2149.2013.00286.x

Johansson, H. and Sojka, P. (1991) Pathophysiological mechanisms involved in genesis and spread of muscular tension in occupational muscle pain and in chronic musculoskeletal pain syndromes: a hypothesis. *Medical Hypotheses* **35**, 196-203. https://doi.org/10.1016/0306-9877(91)90233-o

Koumantakis, G.A. and Oldham, J.A. (2021) Paraspinal strength and electromyographic fatigue in patients with sub-acute back pain and controls: Reliability, clinical applicability and between-group differences. *World Journal of Orthopedics* **12,** 816-832. http://doi.org 10.5312/wjo.v12.i11.816

Larivière, C., Arsenault, A. B., Gravel, D., Gagnon, D. and Loisel, P. (2003) Surface electromyography assessment of back muscle intrinsic properties. *Journal of electromyography and kinesiology* **13**, 305-318. https://doi.org/10.1016/s1050-6411(03)00039-7

Marras, W.S., Ferguson, S.A., Burr, D., Davis, K.G. and Gupta, P. (2004) Spine loading in patients with low back pain during asymmetric lifting exertions. *The Spine Journal* **4**, 64-75. https://doi.org/10.1016/s1529-9430(03)00424-8

Martinez-Valdes, E., Wilson, F., Fleming, N., McDonnell, S.J., Horgan, A. and Falla, D. (2019) Rowers with a recent history of low back pain engage different regions of the lumbar erector spinae during rowing. *Journal of Science and Medicine in Sport* **22**, 1206-1212. https://doi.org/10.1016/j.jsams.2019.07.007

McGregor, A.H., Anderton, L. and Gedroyc, W.M. (2002) The trunk muscles of elite oarsmen. *British Journal of Sports Medicine* **36**, 214-217. https://doi.org/10.1136/bjsm.36.3.214

Morris, F.L., Smith, R.M., Payne, W.R., Galloway, M.A. and Wark, J.D. (2000) Compressive and shear force generated in the lumbar spine of female rowers. *International Journal of Sports Medicine* **21**, 518-523. https://doi.org/10.1055/s-2000-7409

Newlands, C., Reid, D. and Parmar, P. (2015) The prevalence, incidence and severity of low back pain among international-level rowers. *British Journal of Sports Medicine* **49**, 951-956. https://doi.org/10.1136/bjsports-2014-093889

Ng, L., Campbell, A., Burnett, A., Smith, A. and O'Sullivan, P. (2015) Spinal kinematics of adolescent male rowers with back pain in comparison with matched controls during ergometer rowing. *Journal of Applied Biomechanics* **31**, 459-468. https://doi.org/10.1123/jab.2015-0012

O'Kane, J.W., Teitz, C.C. and Lind, B.K. (2003) Effect of preexisting back pain on the incidence and severity of back pain in intercollegiate rowers. *The American Journal of Sports Medicine* **31**, 80-82. https://doi.org/10.1177/03635465030310012501

Panjabi, M.M. (1992) The stabilizing system of the spine. Part II. Neutral zone and instability hypothesis. *Journal of Spinal Disorders* **5**, 390-397. https://doi.org/10.1097/00002517-199212000-00002

Pollock, C.L., Jenkyn, T.R., Jones, I.C., Ivanova, T.D. and Garland, S.J. (2009) Electromyography and kinematics of the trunk during rowing in elite female rowers. *Medicine and Science in Sports and Exercise* **41**, 628-636. https://doi.org/10.1249/MSS.0b013e31818c1300

Rohel, A., Desmons, M., Léonard, G., Desgagnés, A., da Silva, R., Simoneau, M., Mercier, C. and Massé-Alarie, H. (2022) The influence of experimental low back pain on neural networks involved in the control of lumbar erector spinae muscles. *Journal of Neurophysiology* **127**, 1593-1605. https://doi.org/10.1152/jn.00030.2022

Richardson, C.A., Jull, G., Hodges, P. and Hides, J. (1999) Therapeutic exercise for spinal segmental stabilization in low back pain: scientific basis and clinical approach. Sydney: Churchill Livingstone.

Teitz, C.C., O'Kane, J.W. and Lind, B.K. (2003) Back pain in former intercollegiate rowers. A long-term follow-up study. *The American Journal of Sports Medicine* **31**, 590-595. https://doi.org/10.1177/03635465030310041901

Thornton, J.S., Vinther, A., Wilson, F., Lebrun, C.M., Wilkinson, M., Di Ciacca, S.R., Orlando, K. and Smoljanovic, T. (2017) Rowing Injuries: An Updated Review. *Sports Medicine (Auckland, N.Z.)* **47**, 641-661. https://doi.org/10.1007/s40279-016-0613-y

Trease, L., Wilkie, K., Lovell, G., Drew, M. and Hooper, I. (2020) Epidemiology of injury and illness in 153 Australian international-level rowers over eight international seasons. *British Journal of Sports Medicine* **54**, 1288-1293. https://doi.org/10.1136/bjsports-2019-101402

Tsao, H., Tucker, K.J. and Hodges, P.W. (2011) Changes in excitability of corticomotor inputs to the trunk muscles during experimentally-induced acute low back pain. *Neuroscience* **5,** 127-133.

https://doi.org/10.1016/j.neuroscience.2011.02.033

Visser, B. and van Dieën, J.H. (2006) Pathophysiology of upper extremity muscle disorders. *Journal of Electromyography and Kinesiology* **16**, 1-16. https://doi.org/10.1016/j.jelekin.2005.06.005

Wilson, F., Gissane, C., Gormley, J. and Simms, C. (2010) A 12-month prospective cohort study of injury in international rowers. *British Journal of Sports Medicine* **44**, 207-214. https://doi.org/10.1136/bjsm.2008.048561

Wilson, F., Gissane, C., Gormley, J. and Simms, C. (2013) Sagittal plane motion of the lumbar spine during ergometer and single scull rowing. *Sports Biomechanics* **12**, 132-142. https://doi.org/10.1080/14763141.2012.726640

Key points

- Trunk muscle activities of rowers with and without low back pain were assessed during ergometer rowing.
- Rowers with low back pain compared with those without low back pain exhibited significantly higher thoracic erector spinae, lumbar erector spinae, and latissimus dorsi muscle activities.
- Rowers with low back pain exhibit excessive back muscle activity during rowing under maximal effort.

AUTHOR BIOGRAPHY

Momoko YAMASHITA
Employment
Department of Sports Medicine, Graduate School of Medicine, Hokkaido University
Degree
MSc
Research interests
Biomechanics of rowing
E-mail: momosukepie@gmail.com

Tomoya ISHIDA
Employment
Faculty of Health Sciences, Hokkaido University
Degree
PhD
Research interests
Rehabilitation and prevention for sports injuries
E-mail: t.ishida@hs.hokudai.ac.jp

Satoshi OSUKA
Employment
Faculty of Health Sciences, Hokkaido University
Degree
PhD
Research interests
Rehabilitation for spinal disease
E-mail: pt-osuka@huhp.hokudai.ac.jp

Kentaro WATANABE
Employment
Faculty of Health Sciences, Hokkaido University
Degree
MSc
Research interests
Rehabilitation for ankle instability
E-mail: wataken_0121_soccer@eis.hokudai.ac.jp

Mina SAMUKAWA
Employment
Faculty of Health Sciences, Hokkaido University
Degree
PhD
Research interests
Effects of therapeutic exercises and prevention for sports injuries
E-mail: mina@hs.hokudai.ac.jp

Satoshi KASAHARA
Employment
Faculty of Health Sciences, Hokkaido University
Degree
PhD
Research interests
Rehabilitation for neurological disease and motor control for aged adults
E-mail: kasahara@hs.hokudai.ac.jp

Eiji KONDO
Employment
Department of Sports Medicine, Graduate School of Medicine, Hokkaido University
Degree
PhD
Research interests
Knee surgery and sports injury
E-mail: eijik@med.hokudai.ac.jp

Harukazu TOHYAMA
Employment
Faculty of Health Sciences, Hokkaido University
Degree
PhD
Research interests
Rehabilitation for sports injuries and exercise therapy for musculoskeletal disorders
E-mail: tohyama@med.hokudai.ac.jp

✉ **Satoshi Osuka, PT, Ph.D.**
Department of Rehabilitation, Hokkaido University Hospital, West 5, North 12, Kita-Ku, Sapporo Hokkaido 060-8648, Japan.