Asymmetrical fatiguing of the gluteus maximus muscles in the elite short-track female skaters.

CURRENT STATUS: UNDER REVIEW

Mariusz Konieczny
Opole University of Technology
ORCiD: https://orcid.org/0000-0001-7995-0882

Paweł Pakosz
p.pakosz@po.edu.pl
ORCiD: https://orcid.org/0000-0002-5754-3298

Mateusz Witkowski
School of Physical Education and Sport, Adam Mickiewicz in Poland

DOI: 10.21203/rs.3.rs-16905/v2

SUBJECT AREAS
Sports Medicine and Kinesiology

KEYWORDS
electromyography, motor laterality, short-track, muscle fatigue
Abstract

Background According to research, fast skating on short distances increases functional asymmetry of leg muscles. As has been proven in many sporting disciplines, this asymmetry can increase the risk of injury. The aim of the study was to analyze the level of right and left fatigue asymmetry of gluteus maximus muscle in elite skaters on a short track and to compare this phenomenon to a control group. The muscles were chosen deliberately, due to their influence in maintaining the right position during training on ice.

Methods The experiment compared a group of eight members of the Polish Women’s National Team in short track with a group of eight non-training people. The subjects did the Biering-Sorensen test, in which sEMG (surface electromyography) signal frequency was measured in the gluteus maximus muscles during an isometric contraction. Fatigue slopes were analyzed with a ANOVA with repeated measures. In the skaters, the fatigue differed between the right and the left gluteus maximus muscles. All the skaters had higher fatigue in the right leg. This phenomenon was not observed in the non-training subjects, who on average had similar fatigue in both legs.

Results Results showed that the right and the left muscles of the skaters in the experimental group differed in fatigue, but this difference was non-significant in the control group. The subjects from the two groups did not differ in the fatigue of the left muscle, they did in the fatigue of the right muscle. The elite speed-track skaters had higher fatigue in the right muscle than the non-training subjects.

Conclusions Training should thus be planned in a way that minimizes the risk of causing muscle fatigue asymmetry in skaters despite the typically asymmetrical muscle work during training on ice and competition, thus new training protocols should be developed or considered to decrease that asymmetry.

Trial registration The tests were previously approved by the Bioethical Commission of the Chamber of Physicians in Opole. (Resolution No. 235 of 13 December 2016).

Background
Muscular asymmetry, especially in professional athletes, increases the risk of injury, as pointed out by
various authors examining asymmetry of muscles in football players, basketball players, and people with spinal pains [1–4]. Surface electromyography is considered a reliable and credible tool for assessing the post-effort fatigue of muscles. In fatigue analysis, the most often used parameters of the sEMG signal are changes in amplitude scope and in the mean or median frequency of total capacity spectrum. In some studies however physical effort did not decrease the median frequency sEMG signal [5–8].

In muscle fatigue studies often use the Biering-Sorensen test, in which the gluteal muscles are simultaneously isolated to ensure the maximum symmetry of muscular work. Many authors have used this test to examine a fatigue level and determine differences in the muscular work of symmetrical muscles [9, 10]. To meet the needs of analysing muscular fatigue in different body positions, various elements of the Biering-Sorensen test have been modified, such as body position and the time of conducting the test. [11, 12].

The asymmetry of gluteus maximus muscles has been described in the literature most often in the contexts of walk and isolated positions [13, 14]. In short track, previous research has dealt with the muscular work of only one limb or with asymmetry in the fatigue of muscles during skating. Felser et al. studied athletes skating in a straight line and in curves [15]. Neuromuscular activation was higher in the right leg, while with the reduction in skating speed decreased neuromuscular activity, but only when skating in a straight line. This indicates that the right leg has higher activity during skating in curves. Studying athletes skating in a straight line and in curves during the subsequent laps, Hesford et al. found considerable asymmetry in oxygen supply to the two legs. The authors did not report effects of this asymmetry, but offered suggestions for training [16]. Stoter et al. showed that the bio-electric tension of muscles of speed skaters was correlated with speed at different sections of the track, but they did not analyse whether muscular asymmetry affected this phenomenon [17]. At present, the literature of the examined phenomenon contains analyses of muscle fatigue in many variants [18]. Non-invasive methods of determination of fatigue parameters also include surface electromyography (sEMG). Analysis of the sEMG signal frequency of the power spectrum provides useful information concerning local muscle fatigue [19, 20].
The idea behind the study was initiated by the coaches of the Polish National Team, worried about the asymmetry in the skaters and the related increased injury risk. Even though the coaches try to focus as much of the training as possible on symmetrical work, they stress that training on ice accounts for about 60% of the training volume and skating to the left is a typical asymmetrical work. Since the level of asymmetry varies from athlete to athlete, the coaches stress the importance of customised training, which would help them improve muscular symmetry in each athlete in an optimal way. The main research hypothesis is that intensive short-track training leads to asymmetry of the gluteus maximus muscles. Thus, the paper aims to study the size of asymmetry in muscle activity and assess the difference in fatigability between the right and the left gluteus maximus muscles of the Polish Women’s National Team in short track, and to compare this fatigability with that in non-training women.

**Methods**

**Participants**

Two research groups took part in the tests. The experimental group included eight female members of the Polish National Team in short track, with a mean age of 18.7 ± 2.9 standard deviation, mean height of 162.4 ± 2.4 cm, and mean body weight of 57.2 ± 5.9 kg. The control group included eight female students active in sports (but not in speed skating), with a mean age of 20 ± 0.9, mean height of 169.1 ± 4.1 cm, and mean body weight of 68 ± 4.2 kg. These students were randomly selected from among female students of physical education at Opole University of Technology. The research was conducted during the training cycle, after a weekend break in training, to avoid the short-term effect of fatigue accumulation due to the training. The participants were informed about the purpose and course of tests and signed a consent to participate in the tests. The tests were approved by the Bioethical Commission of the Chamber of Physicians in Opole, Poland. In interviews conducted before the tests, all the respondents declared they were right-handed and right-legged in daily and sports activities (e.g., tossing a ball, kicking a ball, supporting with a foot during swinging). Furthermore, a kick-a-ball test (with three attempts) confirmed all the participants were right-legged, while the modified Edinburgh questionnaire confirmed they were right-handed [21].
Procedures

The sEMG signal frequency in the gluteus maximus muscles was examined in an isometric contraction using the position from the Biering-Sorensen test [11, 14]. To avoid too high loads for the skaters, the tests were stopped after 60 seconds of the contraction, and they were not continued until the subject was unable to hold the position because of muscle fatigue. The effectiveness of the fatigue test during a 60-second contraction was confirmed by Mutchler et al. [22]. During the test, the subjects were lying on a horizontal table on the abdomen, with the iliac crests aligned to the edge of the table and the lower limbs attached to the straps around the ankle joints. They were instructed to hold the body (head, shoulders, and torso), without support, horizontally to the ground as long as they could, with the arms crossed at the chest (Figure 1).

The EMG measurement

In the test, a 16-channel EMG system (produced by NORAXON DTS) was used, which recorded signals with an accuracy of 16 bits at a sampling rate of 1500 Hz. The bio-electric test of activity of the right and the left gluteus maximus muscles was carried out by the SENIAM methodology [14, 23]. To improve the adherence of the electrodes, before the test, the hair was shaved and the skin was cleaned in the place where the electrodes were to be stuck. Surface electrodes (Ag/AgCl) were placed on the muscle between the movement point and the tendon attachment, along the longitudinal middle line of the muscle. Signal processing and EMG analysis were performed using NORAXON MR-XP 1.07 Master Editionx software.

Fatigue-related changes (frequency shift) in the frequency content were calculated for the raw EMG signal (Figure 2) obtained during a static contraction. Unfiltered raw sEMG was analysed step-wise in 1000 ms increments over the selected portion of the measurement (60 seconds in the Biering-Sorensen test). The mean frequency was calculated for each step using values based on the frequency power spectrum (calculated by a Prime Factor Fourier Transformation). A fatigue slope (being a regression coefficient from a linear regression line between the mean frequency and time) was estimated for each participant. The mean value of the slopes of these lines were analyzed with ANOVA with repeated measures taking into account the side factor (left/right muscle) and the studied
group (experimental, control). sEMG frequency power spectrum is expected to shift to lower frequencies during fatiguing contractions, and the mean frequency analysis can be used to estimate the magnitude of that shift. This phenomenon is well established for static contractions at constant load levels and believed to reflect local fatigue (Figure 3.).

Technical specification of NORAXON DTS is as follows:
- basic noise of the device, below 1 uV RMS,
- input impedance above 100 MΩ/Hz,
- CMR (common signal rejection factor) greater than 100 dB,
- sampling frequency 1500 Hz,
- gain 500.

Statistical Analysis
The slopes representing the subjects’ fatigue were analyzed with ANOVA with repeated measures. The two groups (short track and control) constituted the between-subject factor, and the two sides (left leg and right leg) constituted the within-subject factor. Since the interaction was significant, Tukey’s post hoc tests were applied for pair-wise comparisons of the four factor combinations. For the analyses, a 0.05 significance level was used. All analyses were made in Statistica v. 13.1.

Results
In the ANOVA, the main effect of the group was non-significant ($F(1, 14) = 2.964, p = 0.107$). The main effect of the side (right-left) of the muscle, however, was significant ($F(1, 14) = 20.323, p < 0.001$), and so was the group-by-side interaction ($F = (1, 14) = 6.111, p = 0.0268$) (Figure 4). Tukey’s tests (Table 1) showed that the right and the left muscles of the skaters (i.e., the subjects in the experimental group) differed in fatigue ($p=0.001$); this difference was non-significant in the control group. The subjects from the two groups did not differ in the fatigue of the left muscle, they did in the fatigue of the right muscle. The elite speed-track skaters had higher fatigue in the right muscle than the non-training subjects. Size differences are shown in Figure 4.

Figure 5 shows significant interactions that indicate that the average slope differences between the
right and left muscles differ between the two groups. The more to the left a point lies, the greater the difference between the subject’s muscles was. All elite skaters, the asymmetry is visible in the graph (so the points lie far to the left from the zero line). In a non-trained group only a several people had this asymmetry (so only a few points lie far to the left of the zero line). We see thus that the interaction was significant because the groups differed in these differences (representing asymmetry) in the fatigue of the right and the left muscles.

Figure 6 pairs the left and right maximus gluteus muscles for each subject. This graph clarifies that the non-training subjects who had a small difference in the fatigue of the muscles had in general low fatigue of both muscles. While the subjects from the two groups did not differ in the fatigue of the left muscle, they did in the fatigue of the right muscle: the elite speed-track skaters had higher fatigue in the right muscle than the non-training subjects \((p = 0.001; \text{ Table 1 and Figures 4 and 5})\).

Table 1. Post-hoc Tukey’s tests for the combinations of the groups (skaters and control) and side (left and right muscle).

|                      | Skaters, right muscle | Skaters, left muscle | Control, right muscle |
|----------------------|-----------------------|----------------------|-----------------------|
| Skaters, left muscle | 0.001                 |                      |                       |
| Control, right muscle| 0.029                 | 0.234                |                       |
| Control, left muscle | <0.001                | 0.955                | 0.497                 |

Discussion
The research aimed to determine differences in muscle fatigue in the left and the right maximum gluteus muscles in female short-track skaters and compare these differences with those in healthy non-training women.

What was surprising, however, was so high asymmetry of muscle fatigue observed in the members of the Polish Women’s National Team in short-track speed skating. In general, short-track training focuses on symmetrical movements, so it should not generate so high asymmetry between the right and the left gluteus maximus muscles. Too high asymmetry in these muscles can increase the risk of injury, so is unfavourable in high-performance athletes \([1–3]\). thus its importance should not be
underestimated in professional sports that involve alternating limb movements. Such high asymmetry, as in the tested athletes, however, has not been observed in the non-training subjects. Asymmetry in an experimental group can be caused by specific training in short-track. Small asymmetry in non-training people is likely a normal phenomenon, and it should not increase the possibility of injury.

Even though experiments without the control group are difficult to interpret, most studies on muscle fatigue did not include non-training subjects [15, 16]. The control group was included in the experiment to analyze muscle asymmetry in skaters against the background of non-training people, which did help us draw richer conclusions about the studied phenomenon.

The studied skaters train at a skating rink in about 60% of the annual training volume, remaining 40% being focused on symmetrical training of both limbs. Various elements of their individual skating techniques—especially the technique of skating on curves—can cause asymmetry in the gluteus maximus muscles, an unfavourable phenomenon in speed skating because of the increased injury risk it poses. Unfortunately, the phenomenon of muscle asymmetry in professional short-track skaters is still poorly studied, which makes it difficult to design a training process that would not generate asymmetry. Asymmetry in muscle fatigability is certainly not limited to short track, however.

Mastalerz et al. reported differences in fatigue between the muscles of the right and the left legs in runners, reaching from 12,5 % to 26,5 %, depending on the muscle [24]. Hartz et al. showed higher fatigue of the right arm in a 30-second tension in throwing athletes [25].

Felser et al. showed that muscle tension activity in muscles of both legs differed between the moments of skating in a straight line and in curves; greater differences occurred in the right leg muscles [15]. This result stresses the importance of the cornering technique, likely that element of the training which most strongly increases asymmetry of leg muscles. Hesford et al. also observed asymmetry in legs of though they studied the oxygenation of the quadriceps muscle [16].

**Study's limitations**

The limitation of the studies was the size of the experimental group, but due to the specificity of the group, it was not possible to study more skaters.
During the experiment, the skaters were in the middle of the training cycle. On the other hand, the tests were conducted after a weekend break in training, so the muscles were relaxed; had the tests been conducted right after training, the muscles would have been tired, which might have affected the tests.

The results offer an important lesson for the coaches of the Polish Women’s National Team in short-track skating.

Conclusions
Elite female short-track skaters have significant asymmetry in fatigability of the gluteus maximus muscles.

In healthy individuals there is no statistically significant difference in the asymmetry of fatigue the gluteus maximus muscles.

The results offer an important lesson for the coaches of the Polish Women’s National Team in short-track skating.

Abbreviations
sEMG: surface electromyography
Ag:/AgCl: silver chloride electrode
RMS: root-mean-square
CMR: common signal rejection

Declarations
Ethics approval and consent to participate
The tests were previously approved by the Bioethical Commission of the Chamber of Physicians in Opole. (Resolution No. 235 of 13 December 2016).

Availability of data and materials
The datasets generated and/or analysed during the current study are not publicly available. However, the data are available from the corresponding author on reasonable request.

Consent for publication
Research participants have agreed in writing to the publication of the data contained in the article.

Competing interests
The authors declare that they have no competing interests

**Funding**

No funding was received.

**Authors' contributions**

MK, PP; Responsible for conception and design of the project. MK, PP; Data collection. PP, MW; Performed data analysis, interpreted the data. MK; Drafted, wrote and revised the manuscript. All authors read and approved the final version of the manuscript to be published manuscript.

**Acknowledgments**

Authors whose names appear on the submission have contributed sufficiently to the scientific work and, therefore, share collective responsibility and accountability for the results.

**Corresponding author**

Correspondence to Pawel Pakosz

**References**

1. Plisky PJ, Rauh MJ, Kaminski TW, Underwood FB. Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. The Journal of orthopaedic and sports physical therapy. 2006;36:911–9.

2. Reeves NP, Cholewicki J, Silfies SP. Muscle activation imbalance and low-back injury in varsity athletes. Journal of Electromyography and Kinesiology. 2006;16:264–72.

3. Fousekis K, Tsepis E, Poulmedis P, Athanasopoulos S, Vagenas G. Intrinsic risk factors of non-contact quadriceps and hamstring strains in soccer: A prospective study of 100 professional players. British Journal of Sports Medicine. 2011;45:709–14.

4. Morel B, Rouffet DM, Bishop DJ, Rota SJ, Hautier CA. Fatigue Induced by Repeated Maximal Efforts is Specific to the Rugby Task Performed. International Journal of Sports Science & Coaching. 2015;10:11–20.

5. Gandevia SC. Spinal and supraspinal factors in human muscle fatigue. Physiological reviews. 2001;81:1725–89.
6. Tomažin K, Strojnik V, Šarabon N. Changes in surface EMG signal under the influence of peripheral fatigue. European Journal of Sport Science. 2002;2:1–9.

7. Farina D. Interpretation of the surface electromyogram in dynamic contractions. Exercise and sport sciences reviews. 2006;34:121–7.

8. Arendt-Nielsen L, Mills KR. The relationship between mean power frequency of the EMG spectrum and muscle fibre conduction velocity. Electroencephalography and Clinical Neurophysiology. 1985;60:130–4.

9. Howard J, Granacher U, Behm DG. Trunk extensor fatigue decreases jump height similarly under stable and unstable conditions with experienced jumpers. European Journal of Applied Physiology. 2015;115:285–94.

10. Pitcher MJ, Behm DG, MacKinnon SN. Neuromuscular fatigue during a modified Biering-Sørensen test in subjects with and without low back pain. Journal of Sports Science and Medicine. 2007;6:549–59.

11. Champagne A, Descarreaux M, Lafond D. Back and hip extensor muscles fatigue in healthy subjects: Task-dependency effect of two variants of the Sorensen test. European Spine Journal. 2008;17:1721–6.

12. Larivièreme C, Gravel D, Arsenault AB, Gagnon D, Loisel P. Muscle recovery from a short fatigue test and consequence on the reliability of EMG indices of fatigue. European Journal of Applied Physiology. 2003;89:171–6.

13. Choi SA, Cynn HS, Yi CH, Kwon OY, Yoon TL, Choi WJ, et al. Isometric hip abduction using a Thera-Band alters gluteus maximus muscle activity and the anterior pelvic tilt angle during bridging exercise. Journal of Electromyography and Kinesiology. 2015;25:310–5.

14. Coorevits P, Danneels L, Cambier D, Ramon H, Vanderstraeten G. Assessment of the validity of the Biering-Sørensen test for measuring back muscle fatigue based on
15. Felser S, Behrens M, Fischer S, Baeumler M, Salomon R, Bruhn S. Neuromuscular activation during short-track speed skating in young athletes. International Journal of Sports Physiology and Performance. 2016;11:848-54.

16. Hesford CM, Laing SJ, Cardinale M, Cooper CE. Asymmetry of quadriceps muscle oxygenation during elite short-track speed skating. Medicine and Science in Sports and Exercise. 2012;44:501-8.

17. Stoter IK, Macintosh BR, Fletcher JR, Pootz S, Zijdewind I, Hettinga FJ. Pacing strategy, muscle fatigue, and technique in 1500-m speed-skating and cycling time trials. International Journal of Sports Physiology and Performance. 2016;11:337-43.

18. Al.-Mula RM, Sepulveda F, Colley M. sEMG Techniques to Detect and Predict Localised Muscle Fatigue. In: EMG Methods for Evaluating Muscle and Nerve Function. 2012.

19. Oskoei MA, Hu H, Gan JQ. Manifestation of fatigue in myoelectric signals of dynamic contractions produced during playing PC games. In: Proceedings of the 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS’08 - “Personalized Healthcare through Technology.” 2008. p. 315-318.

20. Farina D. Interpretation of the surface electromyogram in dynamic contractions. Exercise and Sport Sciences Reviews. 2006;121-127.

21. Büsch D, Hagemann N, Bender N. The dimensionality of the edinburgh handedness inventory: An analysis with models of the item response theory. Laterality. 2010;15:610-28.

22. Mutchler JA, Weinhandl JT, Hoch MC, Van Lunen BL. Reliability and fatigue characteristics of a standing hip isometric endurance protocol. Journal of Electromyography and Kinesiology. 2015;25:667-74.
23. Mika A, Oleksy Ł, Kielnar R, Wodka-Natkaniec E, Twardowska M, Kamiński K, et al. Comparison of two different modes of active recovery on muscles performance after fatiguing exercise in mountain canoeist and football players. PLoS ONE. 2016;13.

24. Mastalerz A, Gwarek L, Sadowski J, Szczepański T. The influence of the run intensity on bioelectrical activity of selected human leg muscles. Acta of Bioengineering and Biomechanics. 2012;14:101–7.

25. Hartz CS, Pires PF, Moreno MA, Bigaton DR. EMG frequency spectral characteristics of inspiratory accessory muscles during the shoulder lifting motion in throwing athletes. Manual Therapy, Posturology & Rehabilitation Journal. 2015;13:232.

Figures

Figure 1

Body position in the Biering-Sorensen test.
Figure 2

Exemplary raw sEMG records during warm-up before testing the Biering-Sorensen test
Figure 3

Exemplary fatigue slope (raw sEMG records) being a regression coefficient from a linear regression line between the mean frequency and time.
Figure 4

Mean fatigue slopes for the right and the left gluteus maximus muscles of the skaters and non-training people (means ± standard error of the mean from the linear model).
The differences in the fatigue slopes between the right and the left gluteus maximus muscles for each subject from the two groups studied. Slight vertical jitter (random noise) was added to avoid the overlap of the points. The grey vertical line represents a no-difference reference point.
Figure 6

The fatigue slopes estimated for the right gluteus maximus muscle versus the slopes estimated for the left muscle, for the two groups. The grey diagonal reference lines represent no difference between the fatigue slopes for the two muscles. To facilitate the muscle-to-muscle comparison, the vertical and horizontal scales share the minimum and maximum values and have the isometric property. A subject with small fatigue in both muscles would be represented by a point located in the top right corner of the corresponding panel; a subject with severe fatigue in both muscles would be represented by a point located in the bottom left corner.

Supplementary Files
This is a list of supplementary files associated with this preprint. Click to download.

COREQChecklist.pdf
ConsenttoParticipate.docx