The Kinesiology Comparison of Cross Country Skiing – Classical Technique and Pedalling

Author's Detai;s

(1), **Martina ChrastkovaRadka** (2)**Bacakova,** (3)**Daniel Spulak**,(4) **Roman Cmejla, Bronislav Kracmar**(5) [1]Charles University, Faculty of Physical Education and Sport Jose Martiho 31, 162 52, Prague 6 – Veleslavin [2]Charles University Faculty of Physical Education and Sport Jose Martiho 31, 162 52, Prague 6 - Veleslavin[3]Czech Technica University, faculty of Electricalengineering Technicka 6, 166 27, Prague 6[4]Czech Technical University, faculty of Electrical engineering Technicka 6, 166 27, Prague6[5]Charles University, Faculty of Physical Education and Sport Jose Martiho 31, 162 52, Prague 6 - Veleslavin

Abstract:

The purpose of this study was to observe, analyze and compare electromyographic (EMG) signal of the leg muscles during the cross country (XC) classic ski technique skiing by classical technique (represented by diagonal stride) and pedalling on stationary bike.The data were collected by surface electromyography method (SEMG), and by synchronized video recording. Acquired data were processed by software MatLab and MegaWin, the video recording was processed with Dartfish SW.Established values of correlation and covariance show higher level of exactingness for holding of dynamic balance during cross country skiing in comparison with cycling on the stationary bike. We found high levels of co-contraction of all analyzed muscles during the cross country skiing. During Pedalling were the muscles activated and deactivated continually.This study confirmed high level of demands for m. tibialis anterior by in cross country skiing. It is necessary as for the ending of kick as for stabilization knee join and all leg and so all body during glide phase.

Keywords: *Cross country skiing training, classic technique, cycling, Pedalling, electromyography, muscle~~s~~ activation.*

Introduction

In cross-country skiing the classical technique is one of the basic locomotion on the snow. It is also historically original style of competitive skiing. To describe classical ski race techniques a skier besides downhill technique switches between diagonal stride, double poling with or without leg kick, herringbone (Bergh & Forsberg, 1992; Bilodeau, Roy, & Boulay, 1991; Nilson, Tveit, & Eikrehagen, 2004), and step-turns. Classical technique's characteristic is alternating arm and legs in a rhythmic way with diagonal fashion, and involves movements of the skis in a parallel direction (Fuente, 2011). The plantar flexion of human foot is necessary for kicking by walking, running as by cross country skiing - the diagonal stride as well. Many muscles (m. gastrocnemius, m. soleus, m. plantaris, m. tibialis posterior, long flexors of toe, m. peroneus longus and m. peroneus brevis) participate on the plantar flexion of human foot (Sale, Quinlan, Marsh, McComas, & Belanger, 1982). However m. triceps surae has the biggest participation on this movement (60 - 80 %) (Sanderson, Martin, Honeyman, & Keef, 2006).

The arms push-off is performed the same way while push-off of the leg on the contra lateral side of the athlete´s body (Nilson, Tveit, & Eikrehagen, 2004). Cross country skier spends the most of racing time in ascending (Gerald & Brian, 1994) so diagonal striding technique is the most used technique.

The cycling is very popular across the world in many varieties and forms (transporting, sport, or medical/rehabilitation equipment). Focusing specifically on racing format of cycling, biomechanically the cyclist aims to apply power into pedals by applying constant pressure in a circle not only in a vertical direction (Burke, 1996). The cycling performance as an over-distance activity is based on aerobic recourses and is beneficial in a fat burning as well as increasing of muscle power (Balasubramanian & Jayaraman, 2009).

Muscle contractions produce electrical potential and the amplitudes are increased with the size of the muscle activation. Electromyography is method based on spreading, recording and analyzing of myo-electrical signals (Chen, Hsueh, & He, 2008).

Importantly, Bieuzen, et al. (2007) watched leg´s muscles activation (m. biceps femoris, m. vastus lateralis and m. rectus femoris) during Pedalling on bike in different levels of cadences: low level (50 prm), high level (110prm) and FCC (free choose cadence). Tested persons were separated into two groups based on their MCV (maximal volunteer contraction) and the results were compared across these groups. For presented study the results of FCC group with higher MCV (F_{max}) became to be the critical recourse.

Figure 1

1. Methods

SEMG is one of the most suitable methods for observing of human locomotion through muscle´s activation in outdoor environment. The method in non-invasive and minimized the locomotion interference. For present study we used the SEMG method with synchronized video recording (De Luca, C. J., 1993).

The study participant was highly trained senior female athlete (anthropometric measurements taken before testing), a member of Czech Cross-country Ski Team.

The research was held in Pec pod Snezkou (CZE), the nationally recognized ski resort, at the end of ski season in a good snow and weather conditions. Track for cross country skiing was set by grooming machine on the long steady climb to the Cerna hora hill with the adequate ascent (15°). For pre-test muscle warm-up and activation was used a stationary bike. For measurement was used a mobile device for EMG recording – ME 6000 providing 16 channels, 16 bit resolution in sampling frequency 2000 Hz. This device was carried on athlete´s body.

This preliminary intraindividual study deals with two movement patterns: classical style of cross country skiing – diagonal stride (Cl) and Pedalling during cycling (C) on the stationary bike. Both movement patterns were measured five times in 30 second intervals, from each movement pattern were selected 60 movement cycles.

Chosen muscles were measured: m. gluteus maximus dx (m. glut. max. dx), m. gluteus medius dx (m. glut. med. dx), m. peroneus longus dx (m. peron. long. dx), m. tibialis anterior dx (m. tibial. ant. dx), m. gastrocnemius dx – caput medialis (m. gastrocn. dx - c. m.), m. rectus femoris dx (m. rect. fem. dx), m. biceps femoris dx (m. biceps fem. dx), m. adductor magnus dx (m. adduc. mag. dx), m. vastus lateralis dx (m. vast. lat. dx), m. vastus medialis dx (m. vast. med. dx).

Acquired data were transferred to PC and processed with Mega Win and Matlab software. We created an algorithm for evaluation of measuring data. The algorithm obtained data from segmented signal transmitted by accelerometer through its transducer. The signals from each EMG channels were converted into absolute values and low-pass filtered while using a FIR-filter (cut-off frequency 4,14 Hz, stop-band rejection – 55 dB) to obtain EMG envelopes. In each period according to the mentioned segmentation we detected

Figure 2
Figure 3

Local maximum of the curve of EMG signal during one movement step is marked by red colour and other secondary peak with green colour in the next pictures of the envelopes of EMG signals in the next Figures 4 – 6.

Figure 4
Figure 5
Figure 6

Discussion

Momentary holding of posture in mono-supporting balance is typical for cross-country skiing and it is not natural for human locomotion (Nestera, et al., 2007). The cyclist sitting on the seat applied power through the handle bar grasp and bike shoes clipped into pedals as a one unit. In a real situation the bicycle is unsteady and the rider has to control the balance on it. The gyroscopic phenomenon makes support for the holding of balance.

onset and cessation of the muscle contraction. Preferably, we measured the muscle contraction onset and cessation with each movement cycle rather than obtain data from the mean EMG envelope. There might be a high probability of missing data while using second method. The border of definition of the muscle activation and deactivation was set as ± 10 samples all in 1000 Hz frequency (De Luca, C. J., 1993). In 2000 Hz, the border of definition was ± 20 samples.

The results show the phase movement of each measured muscle and its activation and deactivation during one movement cycle.

The participant was fully acquainted with the nature of the study. The research was approved by Ethic Committee of Faculty of Physical Education & Sport in Prague.

2. Results

Measured muscles were divided into the functional groups in according to the shape of the curve of the EMG signals. Based on an anatomical muscle group correspondence we defined such groups: (1) Group of M. Quadriceps Femoris (m. vast. med. dx, m. vast. lat. dx, m. rect. fem. dx), (2) Group of Gluteal Muscles (m. glut. max. dx, m. glut. med. dx), and (3) Group of Lower Leg Muscles (m. tibial. ant. dx, m. peron. long. dx, m. gastrocn. dx - c. m.). Outside of this groups were m. biceps fem. dx and m. adduc. mag. dx.

In according to De Luca´s methods (1993) the boundary of differentiability was determined by using the length of movement cycle, for cross-country skiing ± 1,38 % (length of cycle: 1,375 sec ± 0,088 sec), and ± 0,72 % for Pedalling (length of cycle: 0,72268 sec ± 0,020 sec).

Table 1

In the presented research, the bike was fixed into bike stand by the back wheel; this man-made punctum fixum affects the results. During the Pedalling the covariance values of EMG signals were not less than 0.85 for all muscles. To the contrary, in diagonal stride the values of covariance fluctuated from 0.67 to 0.91.

4.1 z

z fzorth head of m. quadriceps femoris is called vastus intermedius and is located under m. rectus femoris. For this reason it is not accessible for EMG electrodes however, the muscle functions as synergist among the other mm. vastii (Čihák, 2001) and is expected to be active as the others.

The shapes of EMG signals of mm. vastii show their co-contraction during both movement patterns. M. vastus lat. dx showed longer activity (1.5 %) in both movement patterns. Deactivation of m. vastus lat. dx stopped also latter or at the same time as m. vast. med. dx.

There were two peaks of activation of both mm. vastii (m. vastus lat. dx and m. vastus med. dx) in one classical ski diagonal stride, while just only one peak was found in one Pedalling cycle. In diagonal stride the majority activation of mm. vastii was between 38% and 62 % of the movement cycle and second peak between 95% and 122 % for the vast. lat. Dx, and m. vast. med. dx between 91% and 117 %. The second deactivations showed higher value of standard deviation than primarily peak in the interval (9.47 and 7.90 compare to 1.95 and 3.71). These results could indicate that athlete had been concentrating preferably for the kick. The second activation indicates entirely one-leg balance support which is performed in dynamic manner in the gliding phase, and subsequently kicking the leg back forward for the following glide. The standard deviations of muscles activation were very low (see Table 1).

M. rect. fem. dx perform just one significant interval of activation during one cycle. Its timing of connection of m. rect. fem. dx is in Pedalling differs significantly compare to diagonal stride. This conclusion is applicable to any complete interval of activation as well as to any phase of muscle activation and deactivation. The Figure 2 shows the phases of muscle activation as they supported each other, and significantly overlap in result to perform in high efficiency. In Pedalling the significant activation of m. rect. fem. dx was found between 72% and 128 %. The standard deviation of the onset was calculated 2.28; the standard deviation of the cessation was 18.17. In diagonal stride the interval of muscles activation was between 39% and 66 % (SD = 1.85 and 4.73).

Presented paper was compared with study of Bieuzen, et al. (2007). Based on their maximal volunteer contraction (MVC; F_{max} – higher MVC; F_{min} - lower MVC) he set two different groups of tested athletes. He found intervals of 63% to 108% (F_{max}) and 66% to 109% (F_{min}) of m. vast. lat. activation and the interval of 41% to 99 % (F_{max}) and 55% to 104 % (F_{min}) of m. rect. fem. activation.

In our research contrary to Bieuzen we calculated the length of activation of m. vast. lat. as 58% while he presented 45% (F_{max}) and 43 % (F_{min}). M. rect. fem. showed in both studies similar results: 58% and 49% respectively 56 %. One of possible explanations of this disproportion is that our tested athlete was highly trained.

Average covariance and correlation values emphasize a high level of movement pattern of athlete. Lower values of covariance and correlation were found in cross-country skiing than in Pedalling. The reasons are: (1) Very limited possibility to find a fixed point, punctum fixum, on snow surface; and (2) The limited stability in one-leg gliding phase in diagonal stride. The values of correlation and covariance are in order Pedalling – diagonal stride:

- m. rect. fem. dx: cor. 0.99 / cov. 0.95 – cor. 0.95 / cov. 0.92.
- m. vast. lat. dx: cor. 0.98 / cov. 0.95 – cor. 0.93 / cov. 0.86
- m. vast. med. dx: cor. 0.99 / cov. 0 98 – cor. 0.92 / cov. 0.82

Figure 7

4.2 The group of mm. glutei (m. glut. max. dx, m. glut. med, dx)

The records of EMG signals of mm. glutei show tendency of co-contraction during both movement patterns. In one interval the majority of peaks did no match, however, they overlapped. In Pedalling cycle m. glut. max. dx performed as the one peak while m. glut. med. dx in two peaks. In diagonal stride both muscles reached two significant peaks.

In diagonal stride, the intervals of m. glut. max. dx activity were between 33% and 64 % (primarily), and 90% and 114% (secondary), and m. glut. med. dx showed the activation between 36% and 59 % (majority) and 3% to 30 %. Majority of deactivations showed surprisingly high values of standard deviation (10.99) of m. glut. max. dx; standard deviation of m. glut. med dx in the second peak deactivation was 5. All other standard deviations fluctuated around 2 -3.

In Pedalling,_significant activation of m. glut. max. was found between 96% and 144 % per one movement cycle. Majority of peaks of m. glut. med. dx were located between 99% and 139 % while the secondary peak was between 50% and 88 %. The low values of standard deviation (2 -3) proved the evidence of high level of movement economy for the Pedalling. It also indicated that the ongoing Pedalling in a steady manner costs the participant less effort than using diagonal stride technique on unstable snow surface. This idea is supported by the high value of covariance and correlations: in order Pedalling – cross country skiing:

- m. glut. max. dx: cor. 0.99 / cov. 0.98 – cor. 0.94 / cov. 0.81
- m. glut. med. dx: cor. 0.99 / cov. 0.98 – cor. 0.95 / cov. 0.80

Figure 8

4.3 The group of triceps surae (m.tibial.ant.dx, m.peron.*long.dx, m.gastrocn.dx – c. m.)*

The muscles of this group are called “walking markers” because they are synergists in propulsive phase (Véle, 2006). M. tibial. ant. and m. gastrocnemius are main dorsal extensors. In diagonal stride both muscles are irreplaceable in the push-off phase. In Pedalling there is no such equivalent of the toe-off phase, however, both muscles support the foot work while participate in the pedal propulsion.

M. tibial. ant. stabilizes all lower extremity so in diagonal stride affects one-leg stability in the gliding phase. In Pedalling, only m. tibial. ant. dx was activated two times in one cycle. In diagonal stride the activation was performed even three times per one cycle without phase of full relaxation (eccentric x contracting phase). Majority peaks of the muscle activation were between 78% and 97 % while in Pedalling between 71% and 109 %. For diagonal stride the secondary peak of activation was between 33% and 56 %, for Pedalling between 20% and 59 % for Pedalling. In diagonal stride the tertiary peak was between 1% and 22 %. Intervals of activation of m. tibial. ant. dx lasted shorter during diagonal stride than Pedalling, the timing of the peaks in both movement patterns was very similar. For majority of intervals the standard deviations of the onsets and cessations were calculated very low (1.18 – 2.40). Only secondary interval of the muscle activation in both movement patterns shows higher value of standard deviation (6.93/6.52 for diagonal stride and 3.55/4.47 for Pedalling). The ambivalence of the secondary activation points out a stabilization role of m. tibial. ant. in the gliding phase of diagonal stride.

M. peroneus long. dx is plantar flexor too. In diagonal stride we found in one cycle two peaks of the activation: majority peak was between 36 % and 56 % and the secondary peak between 78 % and 93 %. In Pedalling the muscle was activated only once but the activation interval lasted longer than in diagonal stride (4% to 47 %). The standard deviations of the activation were higher in diagonal stride than Pedalling. M. peroneus long. dx stabilizes the knee as well as all lower extremity in gliding phase.

M. gastrocn. dx is the last muscles of this group which we measured. In both diagonal stride and Pedalling the muscle activation performed only one peak. The shift of the peaks is 1/5 of one movement cycle in confrontation between the watched locomotion. The onset of significant activation occurred 33 % and the cessation 63 % of the movement cycle timeline in diagonal stride. The interval of activity of m. gastrocn. dx was found between 31% and 57 % in Pedalling. The values of standard deviation in both movement patterns were calculated low (2), except in diagonal stride were the muscle deactivation was 5.86.

Activation without relaxation phases and stabilization function of this group are proved by the average covariance and correlation value.

The values of correlation and covariance are in order Pedalling – cross country skiing:

- m. tibial. ant. dx: cor. 0.99 / cov. 0.87 – cor. 0.94 / cov. 0.67
- m. peron.long.dx: cor. 0.99 / cov. 0.96 – cor. 0.94 / cov. 0.67
- m. gastr.dx–c.m.: cor. 0.99 / cov. 0.98 – cor. 0.95 / cov. 0.90

Figure 9

4.4 M. adductor mag.dx &m. biceps fem.dx

M. biceps fem. dx and m. adduct. mag. dx showed the maximal activation while reaching 50 % of the interval in both movement patterns. In the diagonal stride the curve of EMG signal performed two peaks. The majority interval of connection was between 34% and 64 % and the second peak was found between 95% and 118 %.

M. adduct. mag. dx showed differences in the activation during the diagonal stride and Pedalling. The intervals of activation in diagonal stride were calculated between 40 % and 73 %, in Pedalling between 26 % and 75 %. In Pedalling a high value of standard deviation (12.48) proved significantly slow deactivation of the muscle. This disproportion could be explained as an application of an extra power to control the knee's direction in sagittal plan during complex Pedalling cycle. In diagonal stride the calculated value of standard deviation was 7.99 which can support an idea that the muscle is still active during the follow-through phase after the leg push-off action

The values of correlation and covariance are in order Pedalling – cross country skiing:

- m. bic. fem. dx: cor. 0.98 / cov. 0.95 – cor. 0.95 / cov. 0.84
- m. add. mag. dx: cor. 0.99 / cov. 0.89 – cor. 0.94 / cov. 0.82

Figure 10

Bieuzen, at al. (2007) calculated m. biceps fem. activation in the range of 53 % (F_{max}) and 61 % (F_{min}). In present study the range of activation was calculated 53 % in Pedalling. The values of the length of intervals connection in both studies show similarity.

3. Conclusions

The high level of movement economy was proved by calculated values of covariance and correlation of movement patterns, the diagonal stride in cross-country skiing and the Pedalling in cycling. However, in diagonal stride the some low calculated values indicated higher demands of stability in one-leg support as well as higher effect of the push-off compare to Pedalling on the stationary bike. This is also proved by higher values of all standard deviations of the onsets and cessions of muscle activity in a diagonal stride.

The graphic records of EMG signals showed the high co-contraction of all measured muscles during push-off in a diagonal stride while on the contrary all measured muscles in Pedalling are activated and deactivated gradually.

The EMG data indicate also confirms high demands of classical technique generally on functional stress on m. tibial. ant. which is a key muscle finalizing the push-off from the ski. Further, this muscle is also not indispensable only for the stabilization of the knee, but for all lower extremity and after all for whole body during the one-leg supporting phase. It was also found that m. glut. max. refers to Pedalling is in sitting position less activated then in standing position.

These findings should be useful in training program; primarily during technique training but during strength & power concepts as well. These findings should be useful during physiotherapy for correction of body muscular disbalances.

4. References

[1] V. Balasubramanian, S. Jayaraman, “Surface EMG based muscle activity analysis for aerobic cyclist,” Journal of Body work and Movement Therapies (13), pp. 34–42, 2009.

[2] U. Bergh, A. Forsberg, “Influence of body mass on cross-country ski racing performance,” Medicine and Science in Sport and Exercice, 24(9), pp. 1033-1039, 1992.

[3] F. Bieuzen, R. Lepers, F. Vercruyssen, C. Hausswirth, J. Brisswalter, “Muscle activation during cycling at different cadences: Effect of maximal strength capacity,” Journal of Electromyography and Kinesiology (17), pp. 731–738, 2007.

[4] Bilodeau, B., Roy, B., & Boulay, M. R. (1991). A comparison of three skating techniques and the diagonal stride on heart rate responses and speed in cross-country skiing. *International Journal of Sport Medicine*, *12*(1), pp. 71-76.

[5] E. Burke, “High Tech Cycling.” Champaign, IL, 1996.

[6] R. Čihák, “Anatomie I.” Grada Publishing, Praha, 2001.

[7] C.J. De Luca, “The use of Surface Electromyography in Biomechanics,” 1993. [Online]. Available: http://www.delsys.com/. [Accessed: Sept. 17, 2009].

[8] F.C. Fuente, “An analysis of performance in elite young cross-country skiing: Classical style Vs skate skiing,” Journal of Social Sciences, 7(4), pp. 565-568, 2011.

[9] A.S. Gerald, S.H. Brian, “Kinematic Analysis of Skating Technique of Olympic Skiers in the Men's 50-km Race,” Journal of Applied Biomechanics, 10, 79-88, 1994.

[10] C.C., Chen, Y.H., Hsueh, Z.C. He, “A Novel EMG Feedback Control Method in Functional Electrical Stimulation Cycling System for Stroke Patients,” Proceedings of World Academy of Science: Engineering & Technolog, 44, p. 216, 2008.

[11] C. J. Nestera, A. M. Liua, E. Ward, D. Howarda, J. Coecheba, T. Derrick, P. “Patterson, In vitro study of foot kinematics using a dynamic walking cadaver model,” Journal of Biomechanics, 9, pp. 1927–1937, 2007.

[12] J. Nilson, P. Tveit, O. Eikrehagen, “Effects of Speed on Temporal Patterns in Classical Style and Freestyle Cross – Country Skiing,” Sports Biomechanic, 3(1), pp. 85-108, 2004.

[13] D. Sale, J. Quinlan, E. Marsh, A. J. McComas, A. Belanger, “Influence of joint position on ankle plantarflexion in humans,” Journal of Applied Physiology, 52(6), pp. 1636–1642, 1982.

[14] D. J. Sanderson, P. E. Martin, G. Honeyman, J. Keef, “Gastrocnemius and soleus muscle length, velocity, and EMG responses to changes in Pedalling cadence,” Journal of Electromyography and Kinesiology 16(6), pp. 642-649, 2006.

[15] F. Véle, “Kineziologie, Přehled kineziologie a patokinezioligie pro diagnostiku a terapii poruch pohybové soustavy,” Triton, Praha, 2006.

Author Profile

Author Photo

Martina Chrastkova

Department: Charles University in Prague, Faculty of Physical Education & Sport, Department of Outdoor Activities.

She graduated in Mgr. study program the teaching for grammar school PE & Geography at the Charles University in Prague, the Faculty of Physical Education & Sport and the Science Faculty in 2010. She graduated as coach for cross country skiing too. Afterwards she was received into PhD study at the Faculty of Physical Education & Sport which is now completing.

Her specialization is EMG analysis during cross country skiing and roller skiing, walking, running, Pedalling, etc.

She had absolves study stage at the University of Calgary (CAN) at Dr. Walter Herzog (May – August 2013) and she had participated in EMG research of roller skiing in Olympic Sport Centre.

She was member of Czech National Cross-Country Ski Team (Junior, U-23, B-team) for 8 years. She has started on the World Championships for junior and under 23 years, on the World Cups or Winter World University Games. She is holder the bronze medal from the relay race from the World Championship in Rovaniemi 2005. In this time she is inclined to ski marathons (Swix Ski Classic, Worldloppets, etc.).

She was honored as the “Athletes from Zdar nad Sazavou 2011”.

Martina is redactor of xc-skiing magazine Nordic Mag. She tries to educate in terms of nutrition, sports and healthy lifestyle.

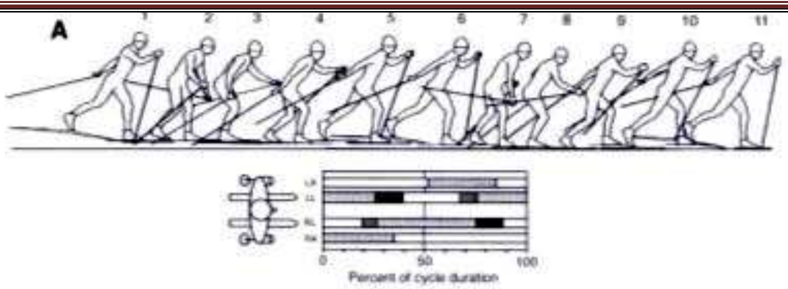


Figure 1: Cross coutry skiing – classic texhnique: diagonal stride (Nilson, Tveit, & Eikrehagen, 2004)

Apendix:

Table 1: Mean delay of activation & deactivation of muscles activity (%)

Measured muscles	1st interval of activity				2nd interval of activity				3rd interval of activity			
	Pedalling		XC skiing –CT: diagonal stride		Pedalling		XC skiing –CT: diagonal stride		Pedalling		XC skiing –CT: diagonal stride	
	Act (%) SD	Deact (%) SD	Act (%) SD	Deact (%) SD	Act (%) SD	Deact (%) SD	Act (%) SD	Deact (%) SD	Act (%) SD	Deact (%) SD	Act (%) SD	Deact (%) SD
M.glut max. dx	- 4.33 1.74	44.11 1.85	33.35 2.29	64.21 10.99	-	-	-9.66 2.68	14.23 3.92	-	-	-	-
M.glut med. dx	-1.14 1.78	39.23 1.53	35.95 2.00	59.27 2.18	50.37 1.72	87.95 2.02	2.75 5.09	30.04 2.97	-	-	-	-
M.per. long. dx	4.45 2.27	47.02 1.89	35.76 5.76	56.04 6.01	-	-	77.97 1.38	93.19 4.98	-	-	-	-
M.tib. ant.dx	71.19 2.40	109.33 1.97	78.17 1.43	96.60 1.18	20.30 3.55	59.14 4.47	32.66 6.93	56.35 6.52	-	-	1.28 1.16	21.88 2.61
M.gast dx:c.m	12.77 2.00	57.09 1.73	32.86 2.27	62.49 5.86	-	-	-	-	-	-	-	-
M.rect fem.dx	71.58 2.28	127.55 18.17	39.42 1.85	65.95 4.73	-	-	-	-	-	-	-	-
M.bic. fem.dx	20.88 4.22	73.56 3.71	33.66 6.12	61.74 2.16	-	-	-5.48 4.38	17.93 2.25	-	-	-	-
M.add mag. dx	26.41 3.60	74.91 12.48	40.11 2.83	73.29 7.99	-	-	-	-	-	-	-	-
Vastus lat. dx	-13.87 3.48	43.93 2.80	38.17 1.97	61.52 1.95	-	-	-4.61 1.01	22.12 9.47	-	-	-	-
Vastus med. dx	-15.08 2.02	40.28 2.11	36.69 1.65	61.85 3.71	-	-	-8.86 1.98	17.08 7.90	-	-	-	-

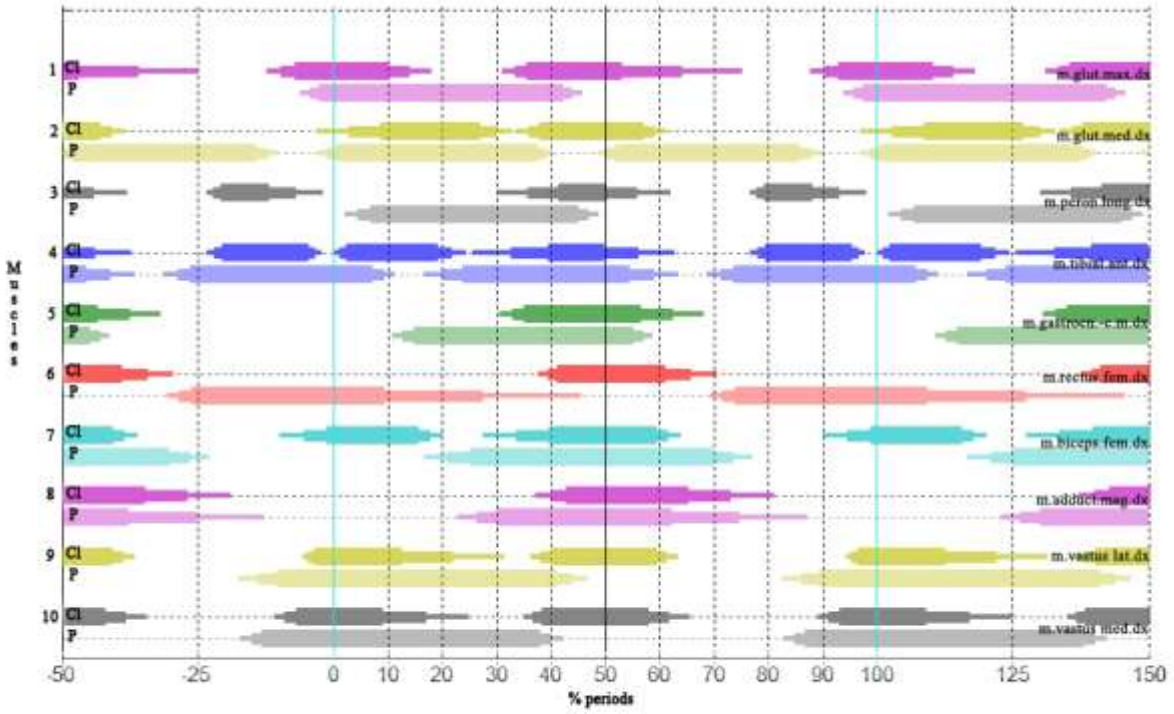


Figure 2: The Comparison of activation´s intervals of muscles during pedalling and XC-skiing

1	Gluteus maximus muscle R
2	Gluteus medius muscle R
3	Peroneus longus muscle R
4	Tibialis anterior muscle R
5	Gastrocnemius muscle - medial part R
6	Rectus femoris muscle R
7	Biceps femoris muscle R
8	Adductor magnus muscle R
9	Vastus lateralis muscle R
10	Vastus medialis muscle R

Figure 3: Legend of measured muscles

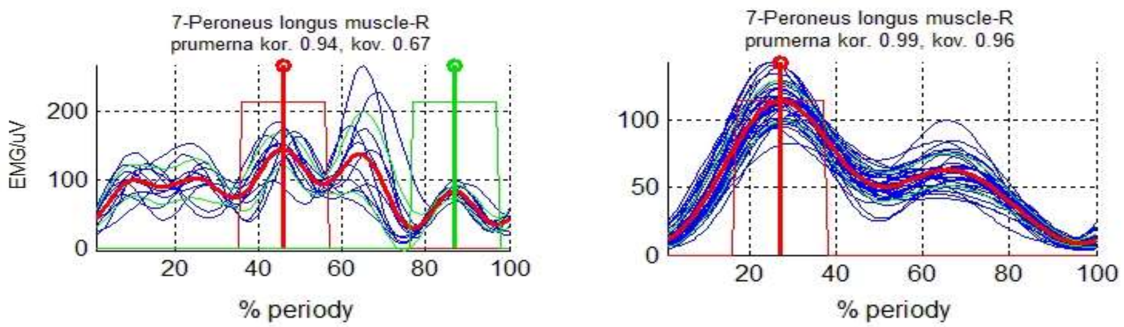
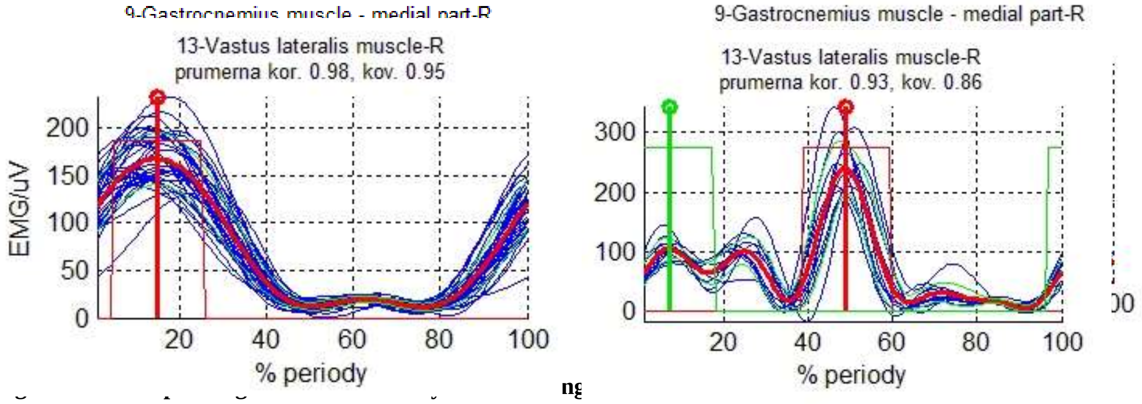


Figure 4: Envelope of signal locomotion´s cycles: xc-skiing on left side, pedalling on right side



ng

Figure 6: Envelope of signal locomotion´s cycles: xc-skiing on left side, pedalling on right side

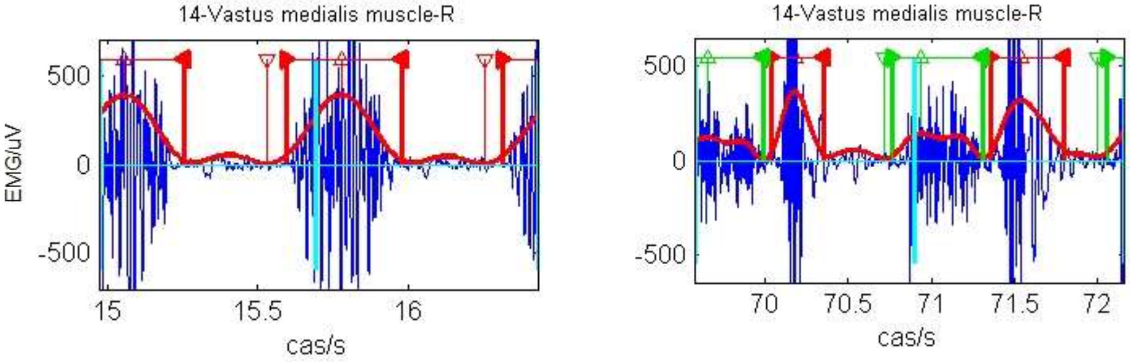


Figure 7: The run of smooth-faced EMG signal during locomotion cycle: Left EMG Envelope for xc-skiing. Right EMG Envelope for pedalling

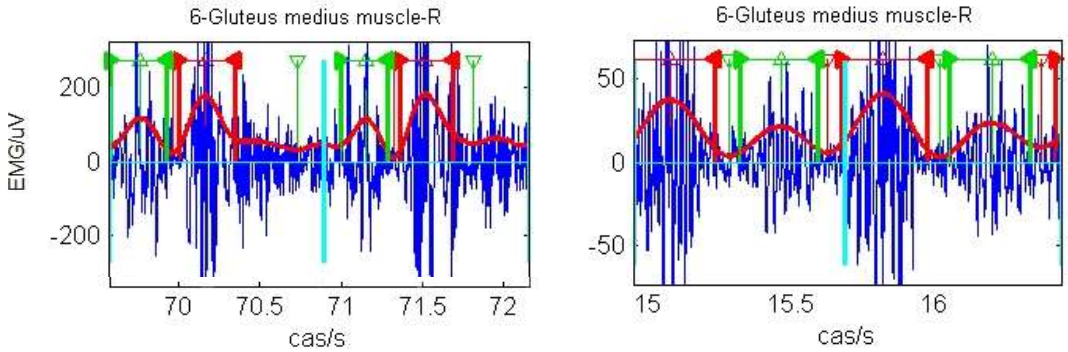


Figure 10: The run of smooth-faced EMG signal during locomotion cycle: Left EMG Envelope for xc-skiing. Right EMG Envelope for pedalling

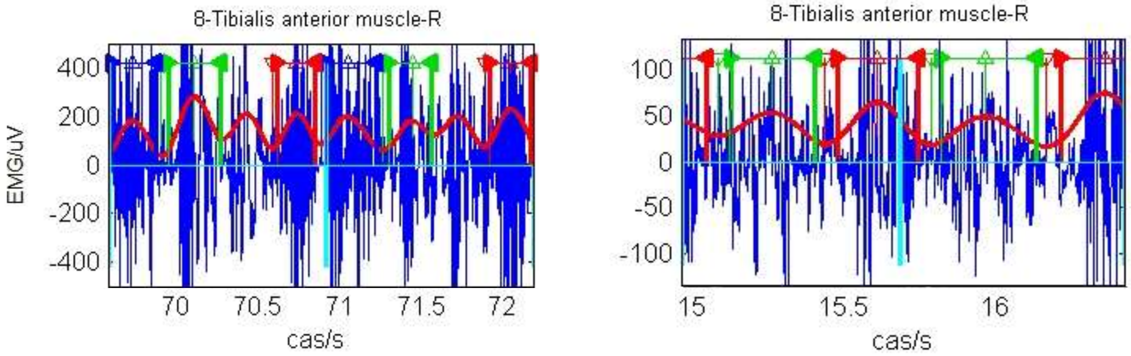


Figure 9: The run of smooth-faced EMG signal during the movement cycle: Left EMG Envelope for xc-skiing. Right EMG Envelope for pedalling

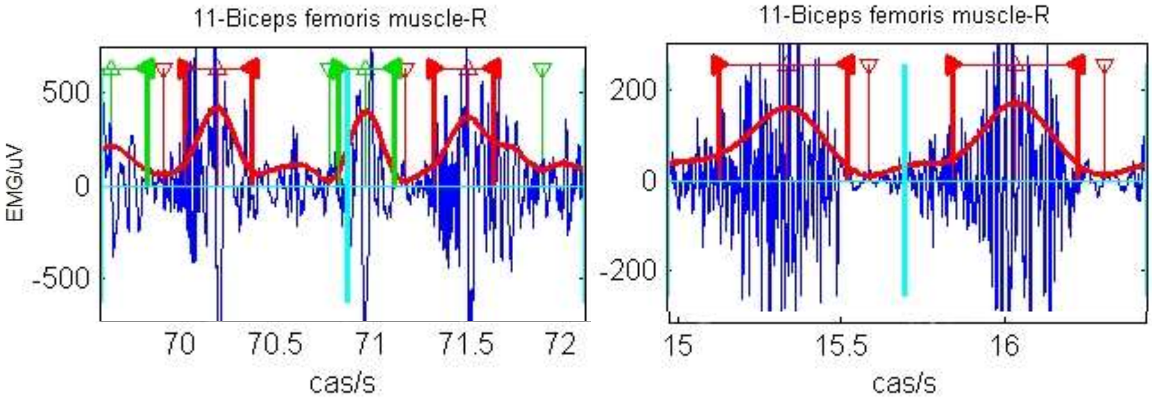


Figure 8: The run of smooth-faced EMG signal during locomotion cycle: Left EMG Envelope for xc-skiing. Right EMG Envelope for pedalling

Author Photo