

COMPARATIVE ANALYSIS OF SELECTED COORDINATION INDICATORS OF CROSS-COUNTRY SKIING WITH CLASSICAL TECHNIQUE AND SKATING

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Abstract

Cross-country skiing is recommended as a part of post-rehabilitation motor regime. The gliding step in classical technique and V-1 skating are the most common used techniques in the recreational form. The aim of the study was to clear out how the motor stereotype of cross-country skiing corresponds with bipedal walking. The used methods were the synchronized video record with the surface poly-electromyography in terrain (EMG). The data were interpreted on the basis of the comparative cross-correlation analysis of activation starts of the observed muscles. The female skier competing in the national team showed the similarity of phase moves of muscles stabilizing the pelvis and knee joint both during walking and cross-country skiing (both techniques). The difference between cross-country skiing and walking was found in phase muscles taking part on the propulsive strength for locomotion. It was not possible to compare the coordination relationship of the activity pairs: gliding step in classical technique – walking and V-1 skating – walking.

Keywords: cross-country skiing, walking, electromyography.

1 Background

Cross-country skiing belongs among cyclic strength-endurance sports with the regular work of lower and upper limbs and trunk muscles (Massaad et al, 2007). There are higher demands on agility of shoulder and hip joints during cross-country skiing (Ilavský, 2005).

According to Gregory et al. and Viitasela et al. (Gregory et al., 1994, Viitasalo et al., 1997) differences in kinematics of cross-country skiing between more and less successful competitors are rarely published. The cause is observed in the high number of factors influencing it.

Punctum fixum is also created by upper limbs during cross-country skiing, as the skier was going back to quadrupedal movement. In the shoulder girdle we suppose muscle coordination, which has its equivalent in ontogenetic forms of human locomotion (Vojta, Peters 1995, Kračmar, 2007). Thanks to vertical body position the quadrupedal character of locomotion is understood specifically. That is given by the vertical body position, which initiates the function of body stabilizing system, which was not started yet in the horizontal body position in the early course of human movement ontogenesis in the phase of quadrupedal locomotion (Véle, 2006, Kračmar, 2007). Similarly, this phenomenon is understood from the point of view of apes' phylogeny by Vančata (Vančata, 2002).

Vystrčilová et al (Vystrčilová et al. 2007, Vystrčilová et al., 2008) consider the function of *m. latissimus dorsi* as the main muscle in the trunk area and plexus brachialis crucial for human locomotion realized through the shoulder girdle (cross-country skiing, Nordic walking, crawling, climbing, crawl stroke in swimming). The muscle groups of trunk and stomach efficiently transfer strengths and stabilize trunk (Wigger, 1998).

The cross-country skier needs the balance skill (Gnad, Psotová, 2005). It enables to realize take-off and following the longest possible slide on one leg (Chrástková, 2009).

Classical technique developed gradually by making the slide longer when walking on skis and skis are parallel during the whole movement cycle. Locomotion is realized by alternate work of upper and lower limbs, which is necessary to control by neuro-muscular coordination in a way the complex and continuous movement was created (Chrástková, 2009). Realization of all movements should then be with the same frequency, maximal laxation and fluency. Figure 1 shows the course of the gliding step movement.



Fig. 1 The movement course during the gliding step in cross-country skiing classical technique

The movement cycle of the gliding step can be divided to: take-off, weigh transfer, glide and arm work. This style is used mainly in skiing uphill, eventually on the flat terrain by less strength equipped individuals. Take-off is realized from the ski skid when the take-off ski is stopped. It is realized by a gradual extension of knee, hip and finally ankle joints. The take-off phase is finished by removing the take-off ski from the surface.

The glide phase is longer than the take-off phase. The position of body's centre of gravity is changed; the dynamic balance is realized. The glide quality depends on the efficiency of the previous activity – the take-off. It is also a preparation for the next take-off. The skier's body moves to "overhang" – it is slightly leaned forward. The skier gets to one-leg stand; only the gliding ski is touching the surface.

The arm work is coordinated with lower limbs. They correspond with each other in the step start phase and take-off phase (Ilavský, 2005).

Free technique – skating. Skating is more progressive in comparison with classical technique. The take-off ski is placed on the snow in the V position and then turned on the inner edge. The take-off is realized during the glide. Skiing is more fluent and demands on take-off timing are not as high as in classical technique. The take-off from the inner ski edge is supported by both poles push-off, which is more efficient than the alternate push-off used in the gliding step (Gnad, Psotová, 2005). Figure 2 shows the movement course of V-1 skating.

The take-off starts with a slightly bended knee and finishes with the gradually extended lower limb. For the right direction of the take-off and its efficient use the trunk is slightly bended forward. In the take-off phase the unloaded leg is actively transferred past the ankle of the take-off leg crossways forward so it had in the moment of placing on snow its initial speed in a glide; acceleration is reached by that. The trunk is permanently kept in a slight lean forward (Ilavský, 2005).

V-1 skating with the asymmetrical movement of arms is the slowest skating. There is only one push-off for both right and left steps of legs. V-1 skating with the asymmetrical movement is the most used type of skating among wide population. The skier does only one push-off and two steps with lower legs. Better skiers are able to do the push-off on the right or left side according to terrain conditions. This skating is used when the skier is less balanced during the glide on one ski.

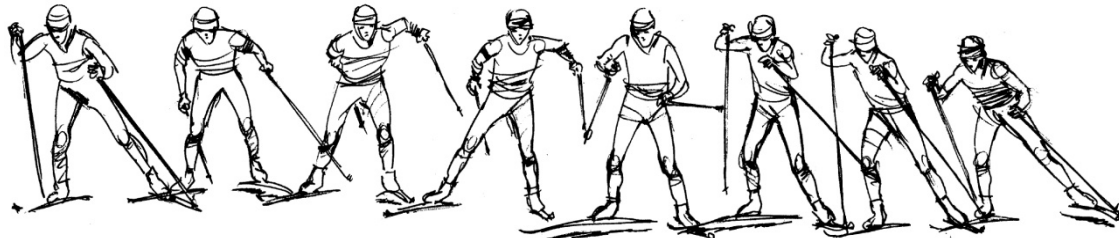


Fig. 2 The movement course of V-1 skating with asymmetrical movement of arms

Our study looked into the level of coordination similarity of both types of cross-country skiing with the motor stereotype of free bipedal walking. Comparison was realized in the competition skier, a member of Czech national team. It was the most perfect available motor stereotype considered by an expert.

2 Methods

Intra-individual comparative analysis was realized at the member of junior Czech national team in cross-country skiing. 60 working (step) cycles during walking were evaluated, then 60 cycles during the gliding step of the classical technique and 60 cycles during V-1 skating. Measuring was realized on snow of a high quality, in -8°C , on cross-country tracks in Nové Město na Moravě.

We have used the surface poly-electromyography (De Luca, 1993) with the synchronized video record measured by the portable device on the basis of EMG, carried on the sportsman body: patterning 200 s^{-1} , filtration $29\text{ Hz} - 1200\text{ Hz}$ with the time invariable $\tau = 0,04\text{ s}$ (Merletti, Parker, 2004). It had seven pairs of flat electrodes with the diameter 7 mm , distances of centres were 25 mm , earth connection and saving data into own memory. See Vystrčilová et al. (Vystrčilová et al., 2008).

3 Research design

The case intra-individual comparative analysis studied three different forms of locomotion. The variable that was not observed was locomotion speed; the manipulated variable was a working (step) cycle during cross-country skiing with the classical technique, skating on skis and free bipedal walking.

Every observed activity was measured six times in 20 seconds intervals with 3 minutes breaks to transfer data from the recorder to PC. 60 working cycles were evaluated from every activity. We have measured muscles on right side of the body in the pelvis area and lower limb. Furthermore, we have localized electrodes also contra laterally on the muscle *m. gastrocnemius sin, caput medialis*. Table 1 shows the survey of the observed muscles.

Tab. 1 Survey of the observed muscles with set sensitivity of scanning channels [mV]

muscle	channel sensitivity [mV]		
	walking	gliding step	V-1 skating
m.gluteus maximus dx	0,05	0,1	0,05
m. gluteus medius dx	0,2	2	1
vastus medialis dx	0,05	0,2	0,1
m. gastrocnemius dx, cap. medialis	0,1	0,1	0,1
m. tibialis anterior dx	0,2	0,2	0,2
m. gastrocnemius sin, cap. medialis	0,2	0,2	0,2

EMG data were processed in the Matlab software into the form of matrices of cross-correlation values of phase shifts of decisive muscle activation starts. We have evaluated the average working cycle (n=60) for every observed locomotion type. The study did not deal with the diagonal phenomenon and laterality in crossed locomotion pattern.

4 Results

Tables 2, 3, 4 state matrices of cross-correlation values of phase shifts of decisive muscle activation starts of an average working cycle (n=60). The referential muscle was chosen *m. tibialis anterior dx*.

Tab. 2 Matrix of cross-correlation values of phase shifts of decisive muscle activation starts of an average working cycle (n=60) during free bipedal walking

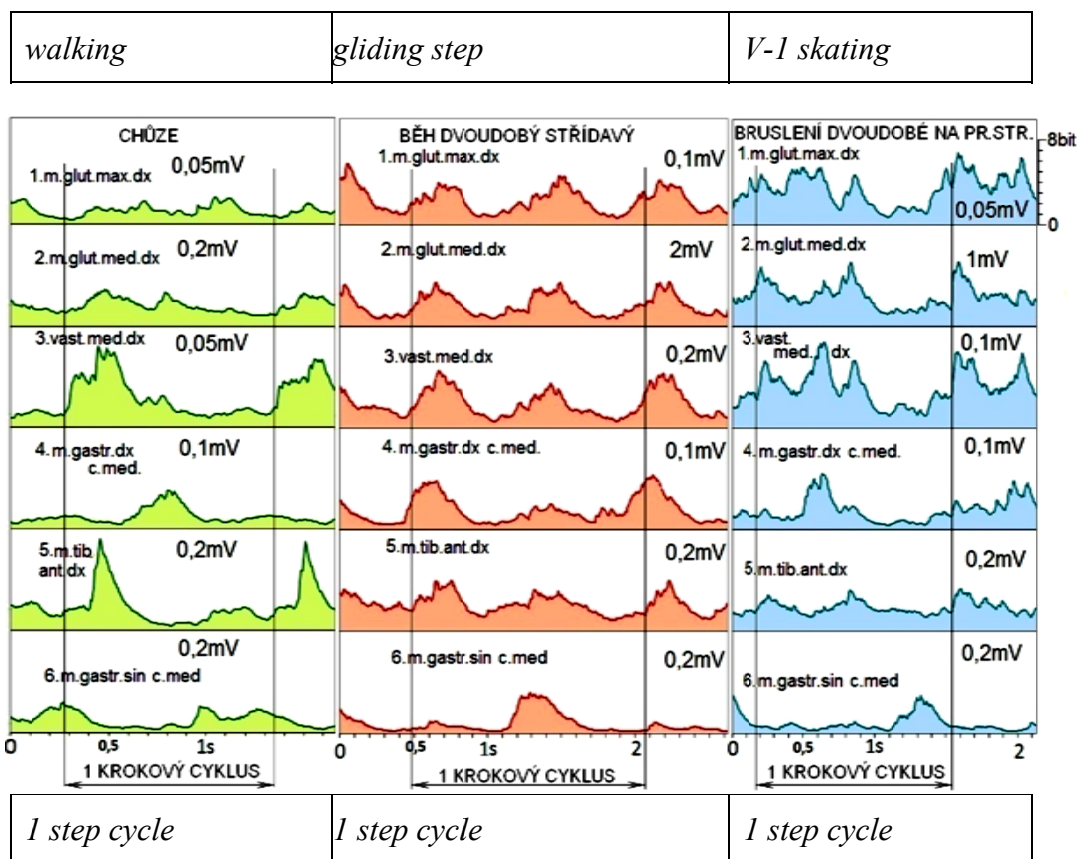
Phase shift of walking	m.glut. max.dx	m.glut. med.dx	vast. med.dx	m.gastr. dx cap.med.	m.tib.ant.dx	m.gastr. sin c.med
m.glut.max.dx	0	38%	47%	-34%	42%	17%
m.glut.med.dx	0	0	4%	-29%	5%	-21%
vast.med.dx	0	0	0	27%	-11%	-30%
m.gastr.dx c.med.	0	0	0	0	-38%	47%
m.tib.ant.dx	0	0	0	0	0	-26%
m.gastr.sin c.med	0	0	0	0	0	0

Tab. 3 Matrix of cross-correlation values of phase shifts of decisive muscle activation starts of an average working cycle (n=60) during the gliding step of the classical technique in cross-country skiing

Phase shift of the gliding step	m.glut. max.dx	m.glut. med.dx	vast. med.dx	m.gastr. dx cap.med.	m.tib.ant.dx	m.gastr. sin c.med
m.glut.max.dx	0	-1%	0%	-4%	2%	46%
m.glut.med.dx	0	0	2%	-3%	2%	-2%
vast.med.dx	0	0	0	-5%	-1%	44%
m.gastr.dx c.med.	0	0	0	0	5%	49%
m.tib.ant.dx	0	0	0	0	0	45%
m.gastr.sin c.med	0	0	0	0	0	0

Tab. 4 Matrix of cross-correlation values of phase shifts of decisive muscle activation starts of an average working cycle (n=60) during V-1 skating with asymmetrical movement of arms

Phase shift of V-1 skating	m.glut.max.dx	m.glut.med.dx	vast.med.dx	m.gastr.dx cap.med.	m.tib.ant.dx	m.gastr.sin c.med
m.glut.max.dx	0	4%	1%	4%	0%	-44%
m.glut.med.dx	0	0	1%	-13%	1%	-19%
vast.med.dx	0	0	0	0%	0%	-49%
m.gastr.dx c,med.	0	0	0	0	14%	-48%
m.tib.ant.dx	0	0	0	0	0	-22%
m.gastr.sin c.med	0	0	0	0	0	0



Graph 1 EMG record of the selected working cycle of free bipedal walking, the gliding step and V-1 skating with asymmetrical movement of arms

5 Discussion

The following discussion is mainly based on:

- Cross-correlation values of decisive muscle activation starts (Tables 2, 3, 4). The referential muscle was chosen *m. tibialis anterior dx.* for its specific function in walking as the dorsal flexor of a leg. We describe timing of the other observed muscles of the average working cycle (n=60) in the interval -50% to +50%. The

positions of the activation start of *m. tibialis anterior dx.* has the value 0%. The low percentage values mean the time similar start of decisive muscle activation of two considered muscles.

- timing of local maximums of muscles (graph 1), and
- the area size under the EMG curve of the average working (step) cycle, which is a probability quantity and points to dynamics of muscle work quantity.

Phase shifts of *M. gluteus maximus dx.*, on contrary to *m. gluteus medius dx.* (walking 38%, gliding step -1% and V-1 skating 4%) indicate a significant affinity of cross-country skiing compared to walking. The same can be found in the relationship of this muscle to our motor marker *m. tibialis anterior dx.* (42%, 2%, and 0%). We could discretely conclude that during cross-country skiing *m. tibialis anterior dx.* gets more into the postural role, together with *m. gluteus medius dx.* The character of EMG curve proves that as well. In all three types of locomotion the muscles *m. gluteus medius dx.* and *m. tibialis anterior dx.* are similar in muscle activation starts, moreover, the activation start is same in skating. Muscles *m. tibialis anterior dx.* and *m. gluteus medius dx.* have very similar start of decisive muscle activation (5%, 2%, and 1%) in all three forms of locomotion. Here we can talk about very similar coordination relationships. These two very important muscles for walking show the mutual close relationship among walking, the gliding step and V-1 skating. It results from bipedal form of locomotion, when the step start phase and the pelvis stability is kept in transversal level.

When comparing muscle activation starts of *m. tibialis anterior dx.* and *m. gastrocnemius dx., caput medialis* we find the biggest difference in walking, when the first named muscle precedes the other by 38% of the working cycle, in the gliding step it follows by 5% and in V-1 skating even by 14%. Thanks to these big differences (between walking and the gliding step 43% and walking and V-1 skating 52%) we rather consider the specifics of cross-country skiing in general. This phenomenon is probably influenced by the more difficult keeping the front-back balance in a glide on one ski (dorsal plantar sense of keeping the position and movement) on contrary to dynamic balance in one-leg stand when walking. In walking it is rather a movement (a gradual course of the highest stress on the foot forward with the following dorsal flexion); meanwhile in cross-country skiing the postural function of the muscle ensuring rather the position is more obvious here. In cross-country skiing in general the EMG curve is again shakier; it indicates the reciprocal balancing the front-back position of the foot. The greater portion of postural function is also proved by the greater portion of “postural background” of the EMG intake. Curves stay on contrary to walking in places of their local minimums on relatively higher amplitude. From the point of view of the area under the EMG curve, there are the highest demands on *m. tibialis anterior dx.* during the gliding step, the lowest during V-1 skating. The muscle *m. gastrocnemius dx., caput medialis* are stressed in this sense in the order: the gliding step, V-1 skating, walking. This muscle also have the highest values of phase shift differences between cross-country skiing in general and walking. The order is again walking - gliding step - V-1 skating.

- *M. gastrocnemius dx, caput medialis* vs. *m. gluteus maximus dx*: -34%, -4%, 4%,
- *m. gastrocnemius dx, caput medialis* vs. *m. gluteus medius dx*: -29%, -3%, -13%,
- *m. gastrocnemius dx, caput medialis* vs. *vastus medialis dx*: 27%, -5%, 0%,
- *m. gastrocnemius dx, caput medialis* vs. *m. tibialis anterior dx*: -38%, 5%, 14%.

This phase muscle, which decisive function in human locomotion is realizing and finishing foot take-off the surface, shows the general difference of cross-country skiing as one group (the gliding step and V-1 skating) on contrary to walking on the other side.

The other general difference of walking and cross-country skiing shows the mutual coordination relationship of muscle activation starts of *m. gluteus maximus* and *vastus*

medialis. In walking we find the phase correlation of 47% delay of *vastus medialis*, in cross-country running 0% and 1%. However, the knee stabilizer *vastus medialis* on contrary to walking has significantly greater area under the curve in the gliding step, approximately 200% and in V-1 skating even approximately 470%. This fact denotes cross-country skiing in general as an activity which significantly stresses the knee stabilizer *vastus medialis*. Recommendation for post-rehabilitation regime then accents specifically skating on skis. The timing of decisive muscle activation starts in the muscles *vastus medialis dx.* and *m. gluteus medius dx.* is very interesting. These two muscles start activation very similarly in walking and both types of cross-country skiing (values 4%, 2%, 1%). Both these muscles stabilizing their corresponding structure (knee, pelvis) cooperate so in their stabilizing function in all three types of locomotion. It is possible to say that from the point of stabilization cross-country skiing (both the gliding step and V-1 skating) and walking very similar. And that is despite the fact that the standing leg in walking goes through the support phase and stand on one place of the solid support and in cross-country skiing this leg finds itself in a glide. We may touch the essence of creating dynamic balance in one-leg support stand in cross-country skiing. The perfectly learned technique of cross-country skiing has in itself such a quality of dynamic balance, which approaches the balance of the standing leg in walking, when the created point of support (*punctum fixum*) does not move.

The muscle *m. tibialis anterior dx.* finds itself in cooperation with both above mentioned stabilizing muscles - *vastus medialis dx.* (value of the phase shift in the gliding step – 1%, in V-1 skating 0%) in cross-country skiing in general, meanwhile it precedes (-11%) in walking. This situation relates to step dynamics. In walking the *m. tibialis anterior dx.* activation precedes foot tread, so after the tread the observed stabilizing muscles were activated (*vastus medialis dx.* and *m. gluteus medius dx.*). *M. tibialis anterior dx.* in comparison with the other stabilizing muscle *m. gluteus medius dx.* brings values of the phase shift 2% and 1% in cross-country skiing, in walking the value is 5%. This change of the phase shift in walking on the contrary to the pair *m. tibialis anterior d.* and *vastus medialis dx.* (5% on contrary to -11%) relates logically to keeping front-back position on the gliding ski.

Our chosen “walking marker”, *m. tibialis anterior dx.*, in relation to the side pelvis stabilizer, *m. gluteus medius dx.* has similar phase shifts with little essential differences in timing. Walking 5%, the gliding step 2%, V-1 skating 1%. This phenomenon again shows the kinesiology relationship of all three observed types of locomotion. In the course of EMG curve of *m. tibialis anterior dx.* in the graph 1 we can show significant local maximums in walking, phase characterized. The curve character is more explosive in both types of cross-country skiing, the amplitude does not decline to zero (tonic background), the muscle responds to the requirement of keeping posture in the regime of dynamic balance in a glide.

Tables 2, 3, 4 also state phase shifts of the contra-lateral muscle *m. gastrocnemius sin, caput medialis*. The muscle inclusion in V-1 skating is not supported by the work of shoulder girdle and is not discussed later. Comparison with a similar research about the kinesiology content of sport movement in cross-country skiing is not possible as there is no similar topic in Czech and foreign sources.

Conclusion

Cross-country skiing differs from walking in general in timing of decisive muscle activation start mainly in phase muscles *m. gluteus maximus dx.*, *m. gastrocnemius dx.*, *caput medialis* vs. *vastus medialis dx.*, *m. tibialis anterior dx.* The muscles working for stabilization, such as *m. gluteus medius dx.* and *vastus medialis dx.*, work in a very similar timing in walking and in cross-country skiing in general. In *m. tibialis anterior dx.*, our chosen walking marker (explained above), we have found the muscle persistence in a certain tonic tension in the areas

of local minimums in cross-country skiing, in walking the EMG record shows a more phase course.

We find significantly greater areas under the EMG curve in *vastus medialis dx.* in cross-country skiing.

For the post-rehabilitation motor regime we find the use more in insufficiency of pelvis stabilization and after knee joint operations. The muscle characteristics of activation of the observed stabilizing muscles approach the characteristics of free bipedal walking as the basic and also the natural form of human locomotion. On the basis of measurements of our selected muscles it is not possible to state, which of the observed types of cross-country skiing is more related to free bipedal walking.

The stated conclusions are valid with regard to the research form – the case study of the woman skier on a very high performance level (Czech national team) with high expertly judged level of coordination.

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KOMPARATIVNÍ ANALÝZA VYBRANÝCH KOORDINAČNÍCH UKAZATELŮ BĚHU NA LYŽÍCH KLASICKOU TECHNIKOU A BRUSLENÍM

Běh na lyžích je doporučován jako součást postrehabilitačního pohybového režimu. Užívanými způsoby běhu v rekreační formě jsou střídavý běh dvoudobý a bruslení dvoudobé. Cílem studie bylo objasnit, jak koresponduje pohybový stereotyp běhu na lyžích s volnou bipedální chůzí. Metodou objektivizace byl synchronizovaný videozáznam s povrchovou polyelektromyografií (EMG) v terénu. Interpretace dat proběhla na základě komparativní kroskorelační analýzy nástupů aktivace sledovaných svalů. U běžkyně na lyžích na úrovni reprezentace ČR byla nalezena příbuznost fázových posunů svalů stabilizujících pánev a kolenní kloub při chůzi i při obou formách běhu na lyžích. Odlišnost běhu na lyžích obecně oproti chůzi byla nalezena u svalů fázických, podílejících se na propulzní síle pro lokomoci. Nebylo možno komparativně posoudit míru koordinační příbuznosti dvojic činností: střídavého běhu - chůze a bruslení - chůze.

KOMPARATIVE ANALYSE AUSGEWÄHLTER KOORDINATIONSPARAMETER IM KLASSISCHEN LANGLAUFSTIL SOWIE IM SKATING

Der Skilanglauf wird als Bestandteil der Förderung des Bewegungshaushalts nach einem Reha-Aufenthalt empfohlen. Die gebräuchlichen Formen des Laufens zur Erholung sind Langlauf und Skating mit Doppelstockschi. Ziel der Studie war es aufzuklären, wie der Bewegungsstereotyp des Skilanglaufs mit dem freien menschlichen Gang korrespondiert. Mit Hilfe der Objektivierung wurde eine synchronisierte Videoaufzeichnung mit elektromyographischen Aufnahmen der Körperoberfläche im Gelände durchgeführt. Die Auswertung der Daten erfolgte auf Grundlage der komparativen Kreuzkorrelationsanalyse der anfänglichen Aktivierung der untersuchten Muskeln. Bei einer Skilangläuferin, die auf hohem Niveau die Tschechische Republik repräsentiert, wurde ein Zusammenhang zwischen Phasenverschiebungen in den Muskeln, die das Becken und Kniegelenk stabilisieren, beim Gehen und bei beiden Formen des Skilanglaufs, festgestellt. Der allgemeine Unterschied zwischen Skilanglauf und Gehen wurde an den phasischen Muskeln festgestellt, die für die Antriebskraft zur Lokomotion verantwortlich sind. Es war nicht möglich, das Ausmaß von koordinationsrelevanten Zusammenhängen zweier Tätigkeiten: abwechselndes Laufen-Gehen und Skating-Gehen einzuschätzen.

ANALIZA PORÓWNAWCZA WYBRANYCH WSKAŹNIKÓW KOORDYNACJI BIEGU NA NARTACH TECHNIKĄ KLASYCZNĄ I DOWOLNĄ

Bieg na nartach zalecany jest jako element porehabilitacyjnych form ruchu. W rekreacyjnej formie stosuje się bieg techniką klasyczną i dowolną (łyżwową). Celem opracowania było wyjaśnienie zależności stereotypu ruchowego biegu na nartach z wolnym chodem bipedalnym. Wykorzystaną metodą badawczą był zsynchronizowany zapis wideo z powierzchniową polielektromiografią (EMG) w terenie. Interpretację danych przeprowadzono w oparciu o porównawcze analizy kroskorelacyjne rozpoczęcia aktywności badanych mięśni. U zawodniczki - reprezentantki RCz w długodystansowym biegu na nartach stwierdzono pokrewieństwo fazowych przesunięć mięśni stabilizujących miednicę oraz stawu kolanowego w czasie chodzenia i w obu stylach biegania na nartach. Aktywacja mięśni fazowych, które stabilizują i uczestniczą w sile pulsacyjnej ruchu, inaczej wygląda w przypadku biegu na nartach i chodu. Nie można było porównać i ocenić koordynacyjnej zależności par czynności: bieg klasyczny – chód i bieg łyżwowy – chód.