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KINEMATIC ANALYSIS OF THE DIAGONAL TECHNIQUE WITH ELITE CROSS-COUNTRY SKIERS

KINEMATIČNA ANALIZA TEHNIKE DIAGONALNEGA KORAKA PRI VRHUNSKIH SMUČARSKIH TEKAČIH

ABSTRACT

The article deals with kinematical analysis of the most important variables of cross country skiing classical style (diagonal stride). Eighteen elite male competitors from various European countries taking part the World Cup were include in the analysis. Five variables were evaluated, the angle changes of the head and trunk position to the surface and the angle changes in the hip, knee and elbow. The variables were taken in tree phase points of half diagonal stride cycle. The analysis was made with the help of the simple PC programmes (Windows, Corel, AutoSketch). The competitors were divided into two groups. The first group included competitors of the red group of the World Cup and in the second one the competitors were placed from 35 to 125 place of the WC. Specific posture difference and concordance of their diagonal stride technique were found out at the top XC skiers according to their performance. Significant differences were observable primarily for the first and second phase points, in time of propulsive force creating.

Keywords: classical technique, cross country skiing, diagonal stride, kinematic analysis, top competitors

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IZVLEČEK

Članek obravnava kinematično analizo najpomembnejših spremenljivk pri klasičnem slogu teka na smučeh (diagonalni korak). Analiza je vključevala osemnajst vrhunskih tekmovalcev, ki nastopajo na Svetovnem pokalu teka na smučeh. Obrvnavali smo pet spremenljivk, spremembe v kotih med glavo, trupom in podlago ter spremembe v kotih v kolkih, kolenu in komolcu. Spremenljivke so bile opazovane v treh faznih točkah cikla polovice diagonalnega koraka. Analiza je bila izvedena s preprostimi računalniškimi programi (Windows, Corel, AutoSketch). Tekmovalci so bili razdeljeni v dve skupini. Prva je vključevala tekmovalce rdeče skupine Svetovnega pokala, druga pa tekmovalce, ki so bili v Svetovnem pokalu uvrščeni med 35. in 125. mestom. Glede na njihovo učinkovitost so bile med najboljšimi tekači ugotovljene specifične razlike v drži in skladnosti njihove tehnike diagonalnega koraka. Značilne razlike so bile opazne predvsem v točkah prve in druge faze, v času ustvarjanja propulzivne sile.

Ključne besede: klasična tehnika, smučarski tek, diagonalni korak, kinematična analiza, vrhunski tekmovalci

INTRODUCTION

The movement of a cross-country skier has its own biomechanical patterns; for competitors' speed, a high quality technique that can bring about progress and improvement of performance is very important. There has always been an effort to reach the most rational movement structures, thus enabling to ski faster and more effectively.

As with any other physical activity, in cross-country skiing there are various techniques because of individual characteristics – the level of coordination skills, movement abilities, balance, feeling for gliding and dispositions to power abilities (Bilodeau, 1996; Ramenskaja, 2001; Rusko, 2003). It is obvious that various terrain affects the technique, speed, length of movement cycle phases or proportion of positive or negative work (Norman & Komi, 1987; Jurdík, 1992; Bilodeau, 1996) and, consequently, the posture of body and its extremities. The important component is always the economy of the run (Norman & Komi, 1987; Cacek, 2007). Individual technique can also be connected with the methodology of training, which the racers learned in their youth.

The classic style, specifically the diagonal stride, is characterized by phases and basic movement elements. Descriptions of the movement cycle and its division into individual phases can be found, for example, in Russian literature (Donskoj & Gross, 1971; Ramenskaja, 2001), Italian (Fucci & Trozzi, 1989) literature and elsewhere. They all agree that the most important movement elements of the diagonal stride are the kick from the stopped ski, transferring the weight, balance while gliding on one ski and coordination of extremities. In order to move forward purposefully, it is absolutely necessary to keep an optimum posture of the body during the movement and to move the extremities in an optimal direction and range. Therefore, the basic criterion for assessing the level of the skiing technique is the range motion of the centre of gravity and its movement regularity (Donskoj & Gross, 1971; Komi, Norman & Caldwell, 1982; Smith, Fewster & Braudt, 1996; 1996; Korvas, Luža & Došla, 2000; Rusko, 2003); we can also take the overall coordination and movement course of the separate body segments (Holmberg et al., 2005; Smith, Fewster & Braudt, 1996; Ramenskaja, 2001). For comparison, the range of motion could be taken of the joint angle size of various body parts that are important for creating propulsive force forwards and the position of the upper body (Komi & Norman, 1987; Gagnon, 1980; Ramenskaja, 2001). Postures of the individual skiers or groups can be compared with help of the various kinds of surveys or by a computer analysis of the recorded movement. An experienced professional is able to give a subjective definition of the posture by watching the movement directly. The analysis conducted with modern technologies can define exactly the kinematic variables and compare them in the necessary number of samples.

STUDY OBJECTIVE

We are interested in the diagonal stride posture of top cross-country skiers. The technique of the investigated competitors is certainly of very high quality and effective but from direct observations we can define some differences in the position and range of movement. We would like to describe the movement patterns and make an effort to learn the differences among top skiers, divided according to performance level. This aim has been to characterize several basic components of top competitors' present technique. The question we are trying to answer is whether we can find any difference in top cross-country skiers' classical posture style (diagonal stride) according to their performance level?

METHODOLOGY

Participants

Complete data were obtained on 18 competitors – men from various countries – taking part of World Cup races. The observed skiers were divided in two groups. The first Group 1ncludes competitors of the red group of World Cup (9th to 28th place) and the second one from 46th to 125th place.

Table 1: The competitor's characteristic of both groups

Group	Number	Height		Weight		Age		FIS place		FIS points	
		x	SD	x	SD	x	SD	x	SD	x	SD
I	9	183.3	4.1	76.2	4.8	28.6	3.9	16.8	10.1	7.85	1.5
II	9	178	5.2	71	6.3	27.4	2.9	78	34.3	25.9	8.8

Instruments

Simple general PC programs (Windows, Corel, AutoSketch) were used for creating the competitors' posture kinograms. The video used for the kinematic analysis of the cross- country skiers posture was recorded during the men's relay competition of the 2000 World Cup in Nové Město na Moravě, Czech Republic, held on January 13, 2000.

Procedure

The competitors were recorded with a video camera placed on a rotary tripod 1.0 m above the ground and 11.5 m from the competition track, at an angle of ±10° from the perpendicular axis to the direction of the skiers' movement. A camera with a recording speed of 25 frames per second was used. The part of the track where the racers were recorded can be described as a slightly the rising hill with a 5° inclination. On this inclination, the skiers had a high probability of using the technique of diagonal stride in the highest race pace.

The video recording was taken on the 7th km of the track. After transforming the recording video into a digital form, kinograms were created (Korvas, Luža & Došla, 2000, Harvánek 2001). Every kinogram is composed of the axis of the skiers body single parts made with the help of the PC program Corel. The angles at phase points were measured with help of the program AutoSketch.

For some researchers, this method is less satisfactory, but for us it provides information about the posture of the body or the position of extremities during half movement cycle of various performance level competitors. Five posture variables were investigated: the position of trunk and head to the surface, the angle value of hip, elbow and knee joints (Figure 2).

Significant differences were calculated by help of T-test ($P \le 0.1$).

In the resulting kinograms, three important positions (phase points) were depicted from each competitor from half of the diagonal stride movement cycle, in order to define the monitored variables (Figure 1).

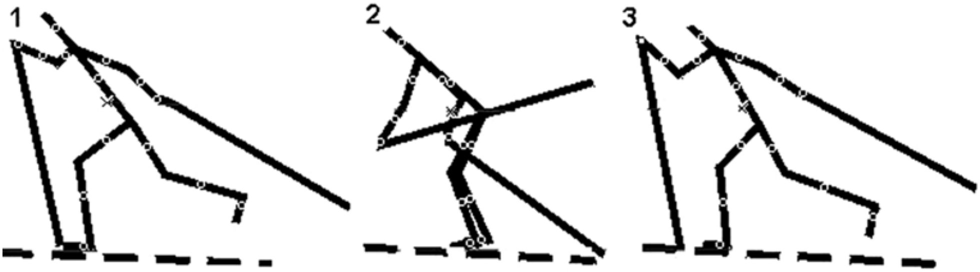

Figure 1: The kinogram example of the diagonal stride

Phase points are characterized as: phase point 1 (stopping the ski, starting the kick by the left leg, starting the right pole push-off), phase point 2 (the lowest phase of the push-off, when the legs are over passing), and phase point 3 (the finish of the leg back movement).

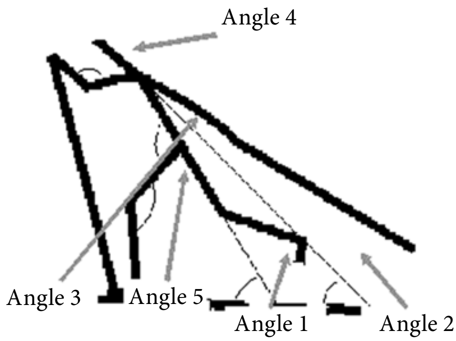

Figure 2: The measured variables

Legend: angle 1 – the angle of the trunk axis to the surface, angle 2 – the angle of the head axis to the surface, angle 3 – the angle in the hip joint, angle 4 – the angle in the elbow joint, angle 5 – the angle in the knee joint.

Results

In Tables 2 and 3, the results of research are presented. The results enabled us to determine several significant differences among the investigated variables between our groups. In all three phase points, the distinct position was found only for the head (pI = 0.056, pII = 0.057, pIII = 0.081). The competitors of Group 2 were holding their heads more upright during the whole half of motion cycle with a maximal difference of 6.2° (Point 2) to Group 1. At Point 2, angle of axis of their head (Group 2) was the same as the axis of their trunk.

At all phase points, the trunk posture was more bent in Group 1 with significant difference at the beginning of leg kick (point 1, p = 0.075) only. Both groups showed the lowest trunk position at Point 2.

Table 2: The average value of the first group posture (in degrees)

Phases	Trunk		Head		Hip		Elbow		Knee	
	x	SD	x	SD	x	SD	x	SD	x	SD
1st phase point	53.5	3.7	46.8	8.1	99.7	6.2	106.6	15.7	126.0	5.1
2nd phase point	42.5	2.4	35.4	8.2	103.4	6.9	111.8	14.7	135.1	21.4
3rd phase point	57.3	1.6	45.4	6.3	182	7.1	164.9	10.0	147.0	8.6

Table 3: The average value of the second group posture (degree)

Phases	Trunk		Head		Hip		Elbow		Knee	
	x	SD	x	SD	x	SD	x	SD	x	SD
1st phase point	56.1	2.5	53.0	3.1	109.1	4.1	123.9	15.9	134.0	5.4
2nd phase point	41.9	2.6	41.9	7.8	109.1	7.2	129.2	22.8	136.8	12.0
3rd phase point	56.3	2.1	51.1	7.4	180.8	11.3	167.5	12.0	140.0	10.9

The differences in position of the hip were also found in the bigger flexion in Group 1. The differences were significant for the first and second phase point (pI = 0.004, pII = 0.033); the difference in angles between Group 1 and II in the first and second phase point was 8.3° and 6.4° in the first and second phase point respectively.

Interesting results were discovered for knee joint angle changes. Group 1 demonstrated a sharper angle in the knee joint for the 1st and 2nd phase points and opener joints for the last point. However, differences between groups were significant only for the first phase point (8°, pI=0.001). Group 1 showed more range of movement in flexion between 1st and 2nd phase point (9.1°) and also for extension (between points 2 and 3 – 11.9°). Group 2 assumed nearly the same position for points 1 and 2 and the whole range motion (6.0°) was small during all the half movement cycle and insignificant.

During the arm push off of both groups, the angles of elbow joints were gradually increased. For all phase points, we determined the opener elbow joint with Group 2. Significant differences between groups were discovered for the first and second point (pI = 0.04, pII = 0.07) with the difference sizes of 17.3° and 17.4°, respectively. For both groups, no significant differences for range of movement at flexion phase were discovered, but all differences between the 2nd and 3rd points and for whole half movement cycle (between points 1 and 3) were significant for both groups' average value of pole push off (p = 0.000).

Table 4: The results of average angular motion range of investigated variables (in degrees) for both groups during half of the ski movement cycle.

	Group 1		Group 2	
	x	SD	x	SD
Trunk	15.7	2.4	15.2	2.8
Head	16.6	4.0	14.4	4.7
Hip	82.7	5.4	76.8	11.5
Elbow	69.3	7.9	53.7	12.3
Knee	23.9	9.8	19.1	8.0

The average movement range of the surveyed parts of the body was calculated from the investigated half movement cycle. We can see that the all investigated variables of Group 2 had a smaller range of motion, but the significant differences between groups were determined for the movement of the elbow ($p = 0.005$) and knee ($p = 0.054$) only.

Discussion

Specific posture differences and concordance of diagonal stride technique were determined among the top skiers, divided according to their level of performance. We determined significant differences for 60% of investigated variables. The most differences were determined for the 1st and 2nd phase points; these phases are most important for the initiation. The realisation of skier propulsive force and the posture of body at the beginning of movement cycle determine the realisation of the right technique (Dvořák & Mašková, 1991; Kračmar et al., 2006).

Competitors at lower performance levels ski with a more erect trunk during the start of kick (phase points 1); significant differences of trunk posture between groups were determined only for this point. A more bent trunk is suitable for realization of a longer kick in lower inclinations of the track. The trunk range of motion shows similarities with Ramenskaja's results (2001); she presents 15°, and our values are 15.7° and 15.2°.

The position of the head is a highly individual variable,[1] however, for quadrupedal locomotion (such as a cross-country skiing), good orientation in changing terrain with help of the sight is important. Therefore, skiing is better realizable with the head sufficiently erect for good view of the track (Kračmar et al., 2006). The competitors with better performance run with their heads bent forwards and this angle is connected with their position of trunk. The range of head movement was smaller for Group 2 and it can be linked with a smaller range of motion of the trunk. This smaller range of trunk and head movement can have a positive impact on the mechanical efficiency of competitor energy load (Norman & Komi, 1987).

The perfect technique and sufficient range of motion in hip joint is important for creating propulsive force. The motion of hip between the points 1 and 2 can be characterized as a flexion and between points 2 and 3 as an extension. The competitors of better performance showed a sharper angle in the hip for phase points 1 and 2. At point 1, it is connected with lower position of trunk and sharper angle of knee. Ramenskaja (170.0°) (2001) and Gagnon (158.4°) (1980) present the results of hip extension after finishing the kick. Our top competitors finished the kick with the leg more to the back position (182.0°and 180.8°) and it is more suitable for better relaxation of muscles.

For the range of hip movement, we can compare results with Komi, Norman & Caldwell, (1982) who presents the whole range of hip joint flexion and extension of two competitors: 85° and 72°, respectively. We determined the average value for our groups as 82.7° and 76.8°. From this point of view, the results of the present competitors' position and those of 20 years ago, we can be considered to be similar. The angular range of hip flexion was from 99.7° to 108.6° for our two groups and Komi & Norman (1987) presents 112°-105°. For extension, we determined the range from 103.4° to 182.0° and Komi & Norman (1987) 105°-172° and 118°-180° again for two competitors. Our investigated groups had a slightly sharper angle of hip flexion and at extension realized a more moderate range of motion.

[1] For example the distinctive posture of the head of the Finnish competitor Harri Kirvesniemi.

The position of the arm is important during the 1st and 2nd phase points; with a more stretched arm, it is possible to utilize the force of arms more effectively (sharper angle of pole to the surface); with more bent arms in the elbow, we can use more strength to the pole (Chovanec, Potměšil & Javorský, 1983; Dvorak, 1991). At all phase points, we can see sharper elbow angles for Group 1 and this can mean more pressure on the pole at the start of propulsive phase of movement cycle (significant for points 1 and 2). Ramenskaja (2001)presents the optimal angle of elbow (140°) at the time of start push off, and it is very different position in comparison with our groups (106.6° respective 115.9°). From the present praxis of the top competitors, we know that they try to start arm push off as early as possible and, therefore, set of pushing with more bent arms; with this position, they can press greater force on the pole.

In contrast, our competitors realized pole push off with more open elbow joints, in contrast to the results of Komi & Norman (1987). The angular motion range of elbow during flexion was determined to be between 106.6 and 129.2° and for extension 111.8°-167.5°. Komi & Norman (1987) presents 80°-120° (flexion) and 80°-154° (extension). The difference between our groups for the greater angular range of elbow joint movement was significant in favour of the better competitors ($p=0.005$), and it could be advantageous for creating more propulsive force.

The range in knee joint motion affects the vertical movement of the skier' body centre. If the movement of the body centre is relatively small, then the whole physical load is smaller. However, it is necessary to bend the knee joint under optimal angle for creating maximal kick force (Chovanec, Potměšil & Javorský, 1983; Jurdík, 1992). Better competitors start the leg kick under a sharper angle in the knee joint, but during next phase points differences are not significant.

For assessment of skier body posture changes, it is important to study the knee joint movement during half of the cycle movement of single groups. It is interesting that only changes between point 2 and 3 for Group 1 were significant. With Group 2, the changes during half of the movement cycle were too small (insignificant) because the knee joints worked in very small range. For range of knee joint angular movement during leg push off, Komi, Norman & Caldwell (1982) presents 29° and 24° for two skiers and the results of our groups were 23.9° and 19.1° (Table 4). With more angular knee motion, competitors can press a ski longer on the surface and create propulsive force. This means for the second group, a smaller range of knee angular motion; probably a competitor holding more standing posture can realize shorter track for kicking. Ramenskaja (160°) (1991) and Gagnon (127.4°) (1980) present a significant difference of this motion range between groups ($p = 0.054$). In our study, the knee angle in the third phase (after finishing the kick) shows 144.4° and 140.8°. The angular range motion of knee for extension by Komi & Norman (1987) was between 120°-153°, while we found 135.1° to 147.0°. The smaller range of angular movement could be affected from the larger part of our surveyed track (Komi & Norman's 3.5° (1987), compared to our 5.0°).

Group 1 showed a great range of motion between the 1st and 2nd phase point for those parts of body responsible for creating propulsive force (hip, knee and elbow) than the group with lower performance level (Group 1).

CONCLUSION

It appears that the top cross-country skiers divided according to their performance level had technique patterns similar in some ways but with some distinctions. The most important and interesting findings of the present study were that better competitors achieved a greater range of motion as found in the observed variables, that significant differences were determined primarily for the first and second phase points, when creating propulsive force, and that when finishing the kick, a difference was determined only for the posture of the head. We suppose that the first group can generate more pressure on the ski during the kick, because the competitors had a greater range of leg motion and can affect the resulting propulsion force for longer time during the kick.

For evaluation of cross-country skiers' technique, we can use simple PC programs and attempted kinematics analysis without special or expensive programs and tools. However, this way of analysis is more demanding for time and technical precision during the evaluation and interpretation.

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