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CORRELATION BETWEEN KINEMATICAL VARIABLES OF CROSS-COUNTRY SKIING TECHNIQUE AND SKIER'S PERFORMANCE

INTRODUCTION

Within the comprehensive supervision of cross-country skiing training, it is necessary to pay attention to the monitoring of the technique, carried out by means of analysis of movement performed by competitors during competitions. By means of a computer program, the filmed shots are transformed into a humanoid, who performs movements in a coordinate space [4]. The calculation of the space coordinates represents the basis by means of which movement can be divided into individual segments and can be separately and independently observed and analysed.

In several studies [2, 3] researchers have attempted to analyze kinematic variables and their relationship to velocity during Olympic and World Cup competitions. Their intent was to identify the characteristics common for successful competitors. The measurements were undertaken at different slope inclinations, requiring execution of different elements of the cross-country skiing technique. To negotiate more demanding ascents in the skating technique, the so-called shorter two-skating stride, also called V1 skate, "alternate stride" or "offset" skate [1] is used. With respect to the highly demanding level of race trails in competitions of the highest rank, the said component represents one of the most important elements in the structure of the competition result attained by cross-country skier.

The aim of the study was to examine a component of cross-country skiing technique – the shorter two-skate stride in competition situations. The study of the selected kinematic variables was made possible with the use of 3-D kinematic analysis. As the analysis was carried out both times in the same section of the competition trail and in the same conditions, the first goal was to establish if statistically important differences in individual kinematic variables under study occurred over the race distance. We were also interested in what proportion of the variability of the criterion variable can be explained in the respective analysed parts of the race distance by the thus selected cluster of kinematic variables.

METHODS

The sample of subjects consisted of 30 cross-country skiers competing in a 15 km event in the World Cup competition. In our research the personal time (in seconds) of a competitor in the analysed cross-country skiing race was used as a criterion variable (TIME) of competitive performance of measured subjects.

The competitors raced on a course of 2 x 7.5 km. Measurements were carried out two times on the same section of the race course: first time they were carried out at the 1st km, and then at the 8.5 th km of the competition distance. The competitors were filmed by two fixed and synchronized video cameras JVC TK1281 (resolution 720 x 576, PAL standard), operating at 50 Hz and located at 90° to each other to allow optimal conditions for 3-D coordinates reconstruction, in a section of 10 m. The gradient of the terrain where filming was performed amounted to 12°. The skiers were filmed in the middle of a section of the race trail that was approximately 35 m long and where terrain configuration did not vary. The weather was cloudy, the snow dry powder, the air temperature was 2°C, and the snow temperature 5°C. The calibration of the space was carried out by means of 4 cubes with a 1 m long side. After filming, the video shots were processed by the following procedure: digitalization of pictures or determination of the space coordinates of individual segments of the body; smoothing the coordinates; and

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numerical presentation of the results. The APAS system for kinematic analysis was used. A 25-point model was used to produce digitized image of each skier. The digitized points were the head, shoulder, elbow, wrist, hip, knee, ankle, heel, toe, ski pole basket, ski pole grip, ski tail and ski tip. The skier's center of mass was calculated using body segment parameter data from Dempster. The raw data points were smoothed using a digital filter with 7 Hz. The direct linear transformation method (APAS) was used to determine the three-dimensional coordinates.

Various kinematic parameters were calculated for the cycle of motion: length (m) of movement cycle (CL). It is the length of the course covered by the cross-country skier in one movement cycle; and the time (s) of movement cycle (CT). It is the time in which the cross-country skier completes one movement cycle in the shorter two-skate stride; length (m) of gliding on the stronger ski (GLS); length (m) of gliding on the weaker ski (GLW); time (s) of gliding on the stronger ski (GTS); time (s) of gliding on the weaker ski (GTW); angle (°) of placing the stronger ski (SAS). It is the angle at which the skier places his stronger ski relative to the forward direction of motion (some virtual fall line of the terrain) and angle (°) of placing the weaker ski (SAW). It is the angle at which the skier places his weaker ski relative to the forward direction of motion. The cycle length was defined as the displacement of the center of mass position between two consecutive weak-side pole plants. The cycle time was identified as the time between two consecutive weak-side pole plants. Ski angles were the acute angles measured with respect to the forward direction of motion. They were calculated as the mean angles while the skis were in contact with the snow. Temporal data describing the skating (gliding) phases of the cycle were obtained by identifying video frame numbers at the weighting and unweighting of the skis [1].

The results obtained were processed on a PC with a statistical software package (SPSS). Basic statistical characteristics of the variables were calculated. To establish statistical significance of the differences in the kinematic variables measured at the first and 8.5th km of the race distance, the t-test for dependent samples was used. To establish the correlation between the cluster of kinematic variables and the criterion variable, multiple regression analysis was used. The level of significance was set at $\alpha = 0.05$.

RESULTS

Table 1. Coefficients of the basic statistical characteristics, normality test of the distribution and results of establishing the differences of variables measured on the both sections of the competition distance (at the 1st and 8.5th km)

Variables	M		S.D.		MIN		MAX		K-S Z		p(K-S)Z	
	1. km	8.5 km	1. km	8.5 km	1. km	8.5 km	1. km	8.5 km	1. km	8.5 km	1. km	8.5 km
CL (m)	5.37	4.90	0.43	0.38	4.35	4.00	6.14	5.90	0.54	0.46	0.92	0.98
CT (s)	1.12	1.16	0.09	0.09	0.94	0.97	1.30	1.32	0.85	0.54	0.45	0.93
GLS (m)	2.51	2.34	0.37	0.37	1.68	1.67	3.04	3.28	0.65	0.52	0.77	0.94
GLW (m)	2.62	2.38	0.39	0.35	1.74	1.39	3.56	3.25	0.51	0.67	0.95	0.75
GTS (s)	0.65	0.67	0.07	0.08	0.52	0.55	0.77	0.84	0.71	0.76	0.69	0.61
GTW (s)	0.73	0.75	0.07	0.08	0.53	0.61	0.90	0.93	0.59	0.83	0.86	0.48
SAS (°)	17.41	18.15	2.72	2.80	13.47	12.87	24.24	26.49	0.72	0.59	0.67	0.86
SAW (°)	15.85	16.72	2.62	1.98	11.70	13.03	22.76	20.55	0.65	0.51	0.78	0.95

T – test

Variables	T	p(t)
CL1 – CL8	5.89	0.00
CT1 – CT8	–2.39	0.02
GLS1 – GLS8	1.94	0.06
GLW1 – GLW8	2.91	0.01
GTS1 – GTS8	–1.34	0.18
GTW1 – GTW8	–1.71	0.09
SAS1 – SAS8	–0.87	0.38
SAW1 – SAW8	–1.73	0.09

M – mean
S.D. – standard deviation
KUR – kurtosis
K-S Z – K-S Z value
p(t) – statistical significance of the t-test
p(K-S)Z – two-tailed testing of the significance of the K-S Z value
MIN – minimum value
MAX – maximum value
SKEW – skewness
T – t-test values

Table 2. Regression analysis of the kinematic variables at 1 km and 8.5 km

VAR.	B (1 km)	B (8.5 km)	Beta (1 km)	Beta (8.5 km)	r (1 km)	r (8.5 km)	T (1 km)	T (8.5 km)	p(T) (1 km)	p(T) (8.5 km)
CL	–18.95	–54.04	–0.09	–0.27	–0.15	0.00	–0.35	–0.87	0.72	0.39
CT	–62.62	497.68	–0.08	0.58	0.18	0.28	–0.13	1.02	0.89	0.31
GLS	–51.38	22.84	–0.25	0.11	–0.44	–0.02	–1.18	0.40	0.25	0.68
GLW	–128.78	–17.12	–0.62	–0.07	–0.13	–0.03	–1.94	–0.29	0.06	0.76
GTS	–332.11	–473.65	–0.33	–0.47	–0.12	–0.13	–0.92	–1.51	0.36	0.14
GTW	700.75	111.86	0.74	0.12	0.22	0.38	1.38	0.23	0.18	0.81
SAS	8.28	–2.82	0.29	–0.10	0.40	–0.09	1.76	–0.49	0.09	0.62
SAW	0.86	7.87	0.03	0.20	–0.02	0.33	0.13	0.94	0.89	0.35
Konst	2452.70	2092.70					9.15	5.81	0.00	0.00

	Mult. R	R-Square	F	p(F)
1. km	0.75	0.57	3.11	0.02
8.5 km	0.62	0.39	1.48	0.22

B – coefficient of partial regression of predictor variables on the criterion variable
r – correlation coefficient between the predictor variable and criterion
p(T) – significance of the beta coefficient of individual predictor variables
Beta – standardised partial regression coefficient   T – t value
p(F) – significance of multiple correlation coefficient   F – F value
R – Square – coefficient of determination   Mult. R – multiple correlation

DISCUSSION

Table 1 shows that the cycle length (CL) was on average by 0.47 m shorter at 8.5 km. The average gliding time in a movement cycle was slightly shorter at 1 km than at 8.5 km and amounted to 1.12 sec. In both measurements, the competitors glided, in terms of length (m), longer on the so-called weaker ski within one movement cycle. In both measurements, the average gliding time was slightly longer on the weaker ski; similar findings were established by other authors [1]. A larger average angle of placing the skis was established for the so-called stronger ski in both measurements.

The system of predictor variables (Table 2) was, at 1 km, statistically significantly correlated with the results attained in the World Cup competition (p(F) = 0.02). In the measurement taken at 8.5 km of the race trail using a set of kinematical variables we failed to explain the criterion variable in terms of statistical significance.

The movement pattern of the shorter two-skate stride obviously changed in the second measurement to the extent that the whole cluster of kinematic variables did not explain the statistically significantly criterion variable as it was the case in the first measurement. The most important reason for it is probably the factor of fatigue. As the result of the covered competition distance, the latter obviously caused, in the majority of competitors, changes in the structure of the movement pattern of the shorter two-skate stride relative to 1 km. The results of the t-test for dependent samples in Table 1 show that during competition, statistically significant changes in some kinematic parameters of the shorter two-skate stride occurred between the 1 km and 8.5 km. The length of the cycle decreased significantly (on average by 0.47 m), which was also due to the fact that the length of gliding on the weaker ski (GLW) also decreased significantly. The cycle time (CT) increased statistically significantly. The above is an obvious consequence of weaker push-off impulses produced by the poles and skis in comparison with the 1 km of the race distance. The established changes in these parameters obviously resulted in the formation of the movement pattern, which, however, from the aspect of the studied kinematic variables did not explain statistically significantly the criterion of competition performance (TIME) at 8.5 km.

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