

CORRELATION BETWEEN THE LENGTH OF THE SKI TRACK AND THE VELOCITY OF TOP SLALOM SKIERS

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Submitted in February, 2007

Theoretically, the shortest possible line of skiing (ski track) is the best one. But in practice it is very difficult to carry this out and besides it is very risky. It can therefore be only a part of the tactics of the best competitors.

With the help of a kinematic analysis, differences in the choice of a line of skiing between individual competitors were established based on a sample of top competitors in the World Cup in Kranjska Gora. We tried to establish whether the competitors achieved higher velocities with such a line of skiing, thus achieving faster sliding among the slalom gates and in the end a better time.

In the first part of our research it was proven that none of the competitors had an extremely short line of skiing in the first two successive turns. It was also found out that the competitors who had the shortest lines of skiing in the first analysed turn had, as a rule, the longest lines of skiing in the second turn and vice versa. Based on these findings, it could be claimed that under present conditions, it is extremely difficult, possibly even impossible, to ski in such a way that the line of skiing would be very short in several successive turns.

The second part of our research focussed on the establishment of the correlation between the trajectories of the skis and the velocity of skiing. The calculations of the correlations proved a statistically significant correlation between the average velocity of skiing and an average distance of the length of the line of skiing from the y-axis in the entire measured segment. It was established that the measured space was covered faster by the competitors whose line of skiing was shorter, which means more direct.

Keywords: Alpine skiing, technique, slalom, kinematics, velocity of skiing, line of skiing.

INTRODUCTION

In top Alpine skiing, the choice of technical and tactical elements is still left primarily to the momentary intuitive choices of an individual and his/her coach. These choices are probably most important but many times insufficient. In future, the process of coaching should therefore be more oriented towards the perfection of competitive skiing technique under various conditions and in various circumstances. The use of most modern methods of measuring is thus inevitable.

Due to the tendency towards faster skiing, the most obvious step forward concerning the choice of the line of skiing among the gates has been noticeable lately. The choice of a line of skiing and the distance of the line of turns from the gates is undoubtedly an important factor in competitions, especially in technical disciplines. On the basis of the established trajectories in specific segments of skiing it is possible to precisely analyse the segments of the performed movement. The technique that has been significantly improved in the past few years can be defined by these segments (Müller & Schwameder, 2003).

Modern slalom technique has improved to such an extent also due to the development of equipment (geometry of skis). Interestingly, skis with a pronounced side curve became established as late as the 1999/2000 season. There are numerous reasons for this, among other things also a worse quality of materials from which skis were made at the beginning of their development (worse torsion resistance). To make a turn along the edges is conditioned by a marked angling of edges. Due to this, the angle between the skis and the snow surface increases. Increasingly faster skiing causes great loads in turns (Lüthi et al., 2005). Often the skis did not perform well in the turn because of worse torsion resistance. The consequences of this were side slides and imprecise turns.

Today, top competitors strive for increasingly faster skiing along the shortest possible line of skiing. Such a way of skiing is demanding and risky and consequently often not the right way to success. In a competition, success depends on many factors. From the point of view of technique, a good result is a consequence of the best relationship between the velocity of sliding and the choice of the line of turns in a particular pole setting (Pozzo et al., 2005).

We are interested in what is going on with the velocity of skiing in the slalom track. The fundamental question can be raised as to whether top competitors who ski nearer to the pole with a more direct, i.e. shorter, line also reach higher velocities.

A competitor whose line of skiing is more direct at the entry into a turn probably retains the velocity of skiing to a greater extent or he may even increase it. In this case an optimum direction of sliding can be retained only by a physically strong competitor with a perfect technique. Quick changing and angling of edges as well as steering the skis as directly as possible towards the next gate makes a shorter line of skiing from gate to gate possible. Consequently, the velocity and shorter line of skiing cause increased pressure on skis in the phase of making a turn. If a competitor finds the pressure too strong, he must adjust (decrease) the velocity of skiing. Whenever he fails to do it, he must "correct" the selected line of skiing as soon as he reaches the next gate.

Our aim was to find out the average velocities reached by competitors in the measured space. Therefore average velocities that were reached were calculated for each competitor based on velocities reached at the first and the second poles as well as when they changed edges. Simultaneously, we tried to establish whether the average velocity of competitors who ski along a shorter line of skiing is higher than the velocity of competitors who choose a longer line of skiing.

Does a shorter line of skiing ensure faster skiing among the gates?

A shorter line of skiing means a shorter distance or a shorter route of a skier from one gate to another (in the measured space) and is an important factor when studying a given skiing technique. Skis with a pronounced side curve enable competitors to make turns on edges. The condition that has to be satisfied if a competitor wants to start a turn in an optimum way is unweighting and quick changing of edges, angling of edges and steering the skis into a new turn (Matijevc, 2003). Here it has to be mentioned that greater centripetal acceleration is achieved by means of a shorter line of skiing at the same velocity (Žvan, 1997). A modern competitive technique and shorter skis with a more pronounced side curve make this possible. We have to be aware of the fact that in making such turns, friction between the skis and the snow is increased, which results in a greater reduction in velocity in the final part of the turn. Therefore we are faced with a dilemma in which the manner of steering skis through the turn is faster and consequently more successful in the competitive Alpine skiing (Lešnik, 1999).

The present skis are faster in turns. The aim of each competitor is to make the entire turn along the edges without the so called rotation of the skis, which always

causes smaller or greater side sliding. The rotation of the skis into a turn was typical of the old technique, and today, it represents only a method of controlling the velocity when skiing between the gates.

The primary task of each coach is to teach a young competitor how to achieve a perfection of technique in skiing. A correct technical performance is a precondition for the further development of a young skier. An ideal model of movement on skis is determined based on the laws of biomechanics from the point of view of the rationality of movement in space, consumption of time and use of physical quantities (Kugovnik et al., 2000). The study of a competitive skiing technique is most realistically based on the analyses of motor structures under competitive conditions. Here we must concentrate on the movement of the competitors in particular segments of the turn. The sequence of movements of the entire body or its parts (points) is important. With the help of suitable parameters, we are trying to analyse complex movement which is described as a skiing turn along an optimum line of skiing over the course.

The choice of the line of skiing among the gates

As has already been stated, several factors exert influence on success in Alpine skiing. Only some of the most important factors will be discussed. Among them, a more or less direct line of a turn at the highest possible velocity must be stressed.

In every sport, the development of an individual sportsperson is based on a pre-developed and determined programme, and Alpine skiing is no exception. Of course, it happens many times that the programme of work and its effective realization begin to diverge. In this case, the programme must be redesigned and adapted to new circumstances that exist in the programme – competitor relationship. First, young competitors must learn a proper technique which is improved in the course of time until it brings about top performance. Later, the priority of coaching the technique should primarily be the development of the highest quality possible of the method of skiing and retaining the highest possible velocity during skiing. During skiing, the velocity keeps changing and it is the task of a competitor to preserve the optimum relationship between decreasing and increasing the velocity (Kugovnik et al., 2005).

In this study, we aimed to resolve the following research problems

- To establish the differences in the choice of the line of skiing between individual competitors in the World Cup and to determine the distance of their lines of skiing from the pole (fall line) and
- to establish whether the competitors with a shorter line of skiing in the pole setting achieve higher velocities and consequently faster sliding among the slalom gates and finally a better result.

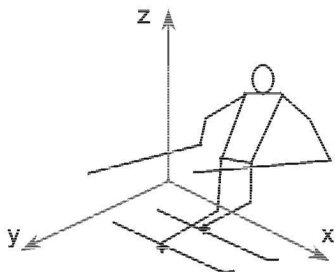
METHODS

The characteristics of the slalom technique were studied on the basis of kinematic measurements taken during the 2004 Vitranc World Cup slalom competition in Kranjska Gora. The test subjects were the best Alpine skiers in the world who competed in the World Cup competitions under the auspices of FIS. The sample of the test subjects comprises 18 competitors chosen from start numbers 2 to 69. This enabled us to take into account the competitors from the whole slalom ranking list who competed in the 2004 World Cup.

The data obtained were processed at the Institute of sport at the Faculty of Sport of the University of Ljubljana. Each competitor was filmed with three pairs of synchronized cameras with the frequency of 25 Hz (one picture per 0.04 second). We know that the computation of the velocity takes a long period of time, but it was the only one available. The recordings were then analysed with the program for biomechanical analyses (APAS system for kinematic analyses). In this way we obtained the coordinates of the points of ends of segments in space (x and y).

Fig. 1

Model of a human being; 3D system of stiff bodies used for kinematic analysis

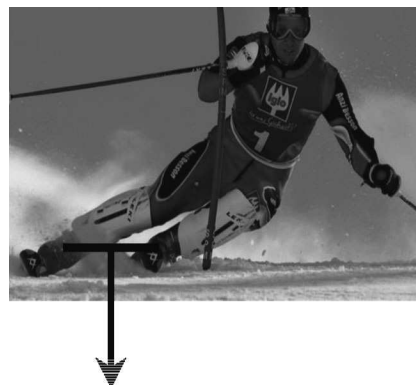


On the basis of the distance of points of trajectories of the left and right ankles (arithmetic mean) we calculated for each individual competitor the average distance of the line of skiing from the fall line ($y = 0$) within the measured space. The measured space comprised two slalom turns. The experience of other researchers shows that the assessment of a skier's successfulness can best be made only if we analyse both turns and we also share this belief. The beginning of the new (and the end of the previous) turn was defined in the measured space for each competitor by means of the moment/place of crossing the trajectories of skis (arithmetic mean of the left and right ankles) and trajectories of the centre of gravity of the skier. The trajectory of the turn is therefore represented by the arithmetic mean of the trajectories of the left and right ankles around two poles (Fig. 2) which were part of the entire pole setting in the first run. The average distance of the line of skiing of the skier from

point $y = 0$ (fall line) was calculated on the basis of the distance of all the points of the trajectory of the skis.

Fig. 2

Representation of the calculation of the arithmetic mean of the position of the skier's ankles. These data were used to calculate the trajectory of the line of skiing (<http://www.pranger.cc>, 2005)



Arithmetic mean of the position of the skier's ankles

The second variable was the calculation of the average velocities of the skis (arithmetic mean of the ankles) in the measured segment of the slalom course in the competition. The average velocities were calculated on the basis of absolute velocities of the competitors at the first pole, crossing of the trajectories of skis and the centre of gravity of the body (the change of edges) as well as at the second pole. On the basis of the absolute velocity in the points mentioned, the average velocity of an individual competitor was calculated in the measured segment (V_{avg}) – average velocity of the competitor in the measured segment ($v \text{ m/s}$).

The average gradient of the slope in the measured space was 23.85 ± 2 degrees. After the kinematic analysis the data obtained were processed with the SPSS statistical program. Besides average values of velocities of individual segments of the body (arithmetic mean of the position of the skiers' ankles), the correlation between individual variables which were determined regarding the goals that we had set was calculated.

RESULTS

Analysis of the trajectories of skis of individual competitors in the slalom pole setting

Based on calculation of the trajectory of skis (arithmetic mean of the position of the skiers' ankles), the point of the trajectory closest to the first and second poles was determined for each competitor. In this way we tried to establish whether the distance of the line of skiing at the first and the second poles was similar in top competitors and to what an extent it differed.

TABLE 1 presents the values of the distances of trajectories of skis (from y-axis = 0) at the first pole for each individual competitor and the differences between the lines of competitors in comparison to the competitor (no. 32), who skied closest to the first pole. According to our observations, the lines of skiing can differ by up to more than half a metre. Competitor no. 32 skied closest to the pole at the first gate (difference = 0.0 m), whereas the distance of competitor no. 10 from the first pole was as many as 0.504 metres.

TABLE 1

Differences between competitors regarding the distance of the line of skiing from the y-axis at the first pole

Order	Start no.	Distance at the 1st pole (m)	Difference (m)
1.	32	2.664	0.000
2.	4	2.679	0.015
3.	43	2.718	0.054
4.	9	2.739	0.075
5.	3	2.759	0.095
6.	69	2.795	0.131
7.	2	2.801	0.137
8.	22	2.821	0.157
9.	27	2.832	0.168
10.	21	2.852	0.188
11.	44	2.856	0.192
12.	5	2.870	0.206
13.	55	2.908	0.244
14.	60	2.957	0.293
15.	15	2.964	0.300
16.	6	2.993	0.329
17.	17	3.044	0.380
18.	10	3.168	0.504

TABLE 2 presents the values of the distances of trajectories of skis (from y-axis = 0) at the second pole for each individual competitor and the differences between the lines of competitors in comparison to the competitor (no. 2) who skied closest to the second pole. According to our observations, the distances from the pole do not differ to such an extent (fewer than 30 cm) in comparison to the lines around the first pole. Competitor no. 2 skied closest to the pole at the second gate, whereas the distance of competitor no. 32 from the second pole was as many as 0.289 metres.

It is necessary to point out that the data for the line of skiing of an individual are a result of the arithmetic mean of the position of the skiers' ankles. Different distances between both skis, very often also a more/less stretched out outer leg and therefore the outer ski that is further from or closer to the pole can exert influence on that. The above mentioned data can therefore serve us as mere support in further analyses.

TABLE 2

Differences between competitors regarding the distance of the line of skiing from the y-axis at the second pole

Order	Start no.	Distance at the 2nd pole (m)	Difference (m)
1.	2	3.310	0.000
2.	60	3.350	0.040
3.	15	3.404	0.094
4.	10	3.427	0.117
5.	5	3.443	0.133
6.	43	3.452	0.142
7.	3	3.457	0.147
8.	6	3.480	0.170
9.	22	3.480	0.170
10.	27	3.484	0.174
11.	9	3.489	0.179
12.	4	3.517	0.207
13.	55	3.534	0.224
14.	17	3.540	0.230
15.	44	3.570	0.260
16.	69	3.582	0.272
17.	21	3.590	0.280
18.	32	3.599	0.289

With the help of the calculation of correlations between the distances from the first pole and the distances from the second one, we established whether the distances of the competitors' lines of skiing from the first pole and from the second one were approximately equal. That means that the competitors whose lines of skiing were closer to the first pole were, as a rule, further away from the second pole and vice versa.

TABLE 3

The calculation of the correlation between the distances of the competitors' lines of skiing from the y-axis at the first and second poles

		Correlation	
		Distance at the 1 st pole	Distance at the 2 nd pole
Distance at the 1 st pole	Pearson correlation	1	-.256
	Sig. (2-tailed)	.	.304
	N	18	18
Distance at the 2 nd pole	Pearson correlation	-.256	1
	Sig. (2-tailed)	.304	.
	N	18	18

Legend

Distance at the first pole → distance of the middle part of the ankles along the y-axis at the first pole (in metres)

Distance at the second pole → distance of the middle part of the ankles along the y-axis at the second pole (in metres)

Pearson correlation → value of the correlation coefficient

Sig. (2. tailed) → statistical significance of the correlation coefficient

N → number of test subjects

As a rule, the competitors whose lines of skiing were the shortest in the first turn analysed had the longest lines of skiing in the second turn and vice versa. The shortest line of skiing does not guarantee an optimum entry into a turn, which is also proved by a low and statistically insignificant level of correlation between the distances of the competitors' lines of skiing from the y-axis = 0 at the first and second poles (TABLE 3, Pearson's correlation coefficient = -0.256, Sig. = 0.305). A typical example is competitor no. 32, whose line of skiing was closest to the first pole and furthest from the second pole. At the same time, we have to stress that no competitor had a very short line of skiing at both successive poles in the measured space. No competitor was very far away from both poles from point 0 regarding the y-axis. The question whether it is possible to ski in this way around several successive gates and if it is therefore appropriate. It can be claimed that in slalom it is impossible to talk about the ideal line of skiing and that the optimum line of skiing is the one which guarantees the skier the smallest loss of velocity in turns (Wimmer & Holzner, 1997, 208).

TABLE 4

Competitors listed according to average velocities reached (Vavg) and according to average values of the distance of the line of skiing (line/AVG) from the y-axis (y = 0) in the measured segment

Place	Start no.	Vavg	Place	Start no.	Line/AVG
1	15	12.535 m/s	1	4	1.267 m
2	10	12.403 m/s	2	10	1.268 m
3	3	12.389 m/s	3	55	1.305 m
4	2	12.382 m/s	4	2	1.344 m
5	5	12.208 m/s	5	43	1.351 m
6	44	12.166 m/s	6	5	1.359 m
7	17	12.165 m/s	7	21	1.366 m
8	4	12.042 m/s	8	44	1.383 m
9	6	12.038 m/s	9	32	1.397 m
10	22	11.845 m/s	10	3	1.410 m
11	55	11.831 m/s	11	15	1.435 m
12	21	11.796 m/s	12	9	1.489 m
13	9	11.666 m/s	13	22	1.525 m
14	27	11.637 m/s	14	27	1.537 m
15	69	11.532 m/s	15	6	1.573 m
16	32	11.499 m/s	16	69	1.574 m
17	43	11.493 m/s	17	17	1.623 m
18	60	10.82 m/s	18	60	1.811 m
Mean		11.914 m/s	Mean		1.445 m

Legend

Vavg → average velocity of the competitor in the measured segment ($v \text{ m/s}$)
Line/AVG → average value of the distance of the line of skiing (from the y-axis) in the measured segment (in metres)

It is evident from the results (TABLE 4) that competitor no. 15 reached the highest velocity (12.535 m/s) in the measured segment. But as many as 10 competi-

tors skied with a shorter line (1.435 m) in the measured space in comparison to the line of competitor no. 15. The shortest route between the two poles was that of competitor no. 4 (1.267 m), although the same competitor was placed eighth (12.042 m/s) if we take into account the average velocity of sliding within the measured space. Competitor no. 10 is a typical example of fast skiing with the shortest line. He reached the second highest average velocity (12.403 m/s) in the measured space; at the same time, he only slightly lagged behind the first competitor (no. 4) in the distance of the line (1.268 m). Competitor no. 60 was the slowest (10.820 m/s) to cover the measured segment and he also made the longest line (1.811 m). Based on these findings, it can be concluded that individuals can ski faster or the fastest along a shorter or the shortest line (competitor no. 10); on the other hand, competitors whose lengths of lines of skiing exceeded the calculated average (1.445 m) skied, as a rule, through the measured segment with the lowest average velocities.

The sample of test subjects proves that the shortest line of skiing right at the pole does not ensure the optimum entry into the next turn. TABLE 4 shows that competitors with lines of skiing shorter than the average ones covered the measured segment with different velocities. According to the length of lines of skiing (average distance from y-axis = 0), "only" seven out of the first eleven competitors covered the measured segment with velocity higher than the average (no. 4, 10, 2, 5, 44, 3, and 15).

TABLE 5

Calculation of the correlation of average velocities and average values of the length of two turns in the measured segment of the course in the 2004 Vitranc Cup competition

		Correlation	
		Velocity/AVG	Line/AVG
Velocity/AVG	Pearson correlation	1	-.551*
	Sig. (2-tailed)	.	.018
	N	18	18
Line/AVG	Pearson correlation	-.551*	1
	Sig. (2-tailed)	.018	.
	N	18	18

Correlation is significant at the 0.05 level (2 tailed)

Legend

Velocity/avg → calculated values of the correlation coefficient and statistical significance of velocities in the measured segment
Line/AVG → calculated values of the correlation coefficient and statistical significance of the distance of the line of skiing in the measured segment
Pearson correlation → value of the correlation coefficient
Sig. (2. tailed) → statistical significance of the correlation coefficient
N → number of test subjects

As regards the above mentioned comparisons and results presented in TABLE 4, we also wanted to find

out whether the correlation between the average velocity of skiing and the average distance of the length of the line of skiing from the y-axis in the whole measured segment is statistically significant.

The correlation coefficient (Pearson's correlation coefficient = -0.551) proves that the correlation between the average velocity of skiing and the average distance of the length of the line of skiing from the y-axis in the whole measured segment is statistically significant (Sig. = 0.0018). It has to be pointed out that this is a calculation of the data obtained in two slalom turns skied by competitors using a more or less direct line and reaching particular average velocities. In the measured sample (N = 18), the length of the line of skiing in the whole measured segment (in two successive slalom turns) is correlated with the velocity of skiing in a statistically significant way, which means that the competitors with a smaller average distance from the y-axis in the pole setting (shorter line) reached higher average velocities as a rule. On the other hand, the average velocities of competitors with longer average lines of skiing were lower. It can be concluded that on the basis of an empirical experiment a shorter and more direct line of sliding increases the likelihood of reaching higher velocities and consequently better results.

CONCLUSION

In solving problems in sport it is difficult or even impossible to deal with various aspects; that is the reason why we focussed only on the part of a movement technique that is, in the process of coaching, closely connected with tactics used in the competition; in skiing as well as probably in other sports they are often of crucial importance.

In practice, coaches and competitors believe that a shorter line of sliding is also the fastest one in Alpine skiing. This statement is simple and logical but only if we disregard the fact that the velocity in the turn on skis depends on several factors. When decreasing the length of the radius of a turn the skier's velocity can increase to a borderline and often critical level which still enables the skier to make a turn (using edges). How to choose a line of skiing in a particular pole setting depends on technical and tactical skills, ability, equipment, and numerous other laws (of biomechanics), but the velocity is the factor which conditions the time achieved by a competitor. The limits of the ability to cover the course in a particular pole setting are certainly the highest in competitors who take part in the World Cup competitions. That is why we tried to get the answers to our fundamental questions from these competitors.

In the first part of the study we analysed lines of turns of the competitors at the first and second poles

within the measured space and proved that none of the competitors had an extremely short line of skiing in two successive turns (TABLE 1, 2). On the basis of these findings, it can be claimed that under present day conditions, it is extremely difficult, if not impossible, to ski in such a way that the line of skiing would be very short in several successive turns.

In the second part of the study, we investigated the correlation between the trajectories of skis and the velocity of skiing of the measured sample in the measured space (two slalom turns). With the calculated correlation we proved a statistically significant correlation between the average velocity of skiing and the average distance of the length of the line of skiing from the y-axis in the whole measured segment. That means that the competitors whose line of skiing was shorter and more direct skied through the measured segment faster.

It is well known that in skiing among gates the velocity changes during sliding, which depends on the line of sliding (Božič, 2005, 42). In skiing, a competitor decreases or increases the velocity in a turn, which undoubtedly contributes to faster skiing and better results in competitions (Petrović et al., 1987, 85).

The results obtained in the study would certainly be more objective if it had been possible to measure the whole pole setting in the given conditions (World Cup competition). Nevertheless, we managed to obtain some results in a relatively small measured space. These results at least generally prove the orientation towards the coaching of a slalom technique, searching for a possibility of a more direct entry into and performance of a turn. However, it was observed a long time ago that an individual who manages to unite the individual segments of the pole setting into a whole in the best way is successful in a competition.

Today, the difference between a good and the best skier in the World Cup is extremely minor. Therefore it is the selection of the line of skiing through the segment of the length analysed in our study that is an important and often also decisive factor on the basis of which it can be established who will be "only" a good Alpine skier and who the best one.

Tactics is probably the area which is worst developed in our field and we should pay more attention to it. We believe that it is in this area that experts could really make an important contribution to Alpine skiing. We wanted to objectively present the part of a coach's assessments and information that she/he shares with competitors and that are of the utmost importance to everyone. This is the assessment of the velocity of a competitor's skiing.

The difference between a competitor's and coach's perception, on the one hand, and the measured velocity of skiing, on the other, often results in incorrect guidelines in the development of a skier's skiing technique as

well as of his/her tactics. Especially the latter is becoming a decisive factor in the differentiation between good and best competitors.

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KORELACE MEZI DÉLKOU LYŽAŘSKÉ TRATĚ A RYCHLOSTÍ VRCHOLOVÝCH SLALOMÁŘŮ

(Souhrn anglického textu)

Teoreticky je nejlepší co nejkratší lyžařská dráha (lyžařská trať). V praxi je to však těžko proveditelné a kromě toho je to velmi riskantní. Může se proto stát pouze součástí taktiky těch nejlepších soutěžících.

Pomocí kinematické analýzy byly stanoveny rozdíly mezi volbou lyžařské dráhy u jednotlivých soutěžících, a to na základě vzorku vrcholových soutěžících ve světovém poháru v Kranjske Gore. Snažili jsme se zjistit, zda soutěžící dosahovali na takové lyžařské dráze vyšší rychlosti, tedy zda dosahovali rychlejšího pohybu mezi slalomovými brankami a tudíž v konečném důsledku i lepších časových výsledků.

V první části našeho výzkumu bylo prokázáno, že žádný ze soutěžících neměl v prvních dvou po sobě následujících obrazech extrémně krátkou lyžařskou dráhu. Bylo rovněž zjištěno, že soutěžící s nejkratšími lyžařskými drahami v prvním obratu měli zpravidla nejdelší lyžařské dráhy v obratu druhém a naopak. Na základě těchto zjištění bylo možno tvrdit, že za současných podmínek je mimořádně obtížné, a snad dokonce nemožné, lyžovat tak, aby lyžařský oblouk byl v několika po sobě následujících obrazech velmi krátký.

Druhá část našeho výzkumu se zaměřila na zjišťování korelace mezi trajektorií lyží a rychlostí lyžování. Výpočty korelací prokázaly statisticky významnou korelaci mezi průměrnou rychlostí lyžování a průměrnou vzdáleností délky lyžařské dráhy od osy y v celém měřeném úseku. Bylo zjištěno, že měřený prostor překonávali soutěžící s kratší, tedy přímější, lyžařskou dráhou rychleji.

Klíčová slova: vysokohorské lyžování, technika, slalom, kinematika, rychlost lyžování, lyžařská dráha.

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