CHANGING CONDITIONS ON THE SLALOM SKI COURSE AFFECT COMPETITORS' PERFORMANCES

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Abstract:

It is instinctively known that changing conditions on the ski course affect competitors' performances. It may be furthermore affirmed that the effect of changing conditions cannot be avoided completely in outdoor, natural circumstances. This project is based on 3D kinematical measurements taken on the slalom ski course with an investigation of five world cup level ski racers. It deals with an investigation of the effect of changing conditions on several kinematic parameters such as the centre of gravity's and arithmetic mean of the skis' velocity, the length of the centre of gravity's and arithmetic mean of the skis' trajectory, the horizontal as well as vertical point of the beginning and end of the turn and the time needed to complete a turn. The results show a significant effect on several of the inspected parameters that give us a basic idea about the consequences.

Key words: *alpine skiing, slalom, changing conditions, 3D kinematic measurements*

WECHSELNDE WETTERBEDINGUNGEN AUF DER SLALOMSTRECKE BEEINFLUSSEN DIE LEISTUNG DER TEILNEHMER

Zusammenfassung:

Es ist uns wohl bekannt, dass die wechselnden Wetterbedingungen auf der Skistrecke die Leistung der Skifahrer beeinträchtigen kann. Außerdem kann im Freien, d.h. unter natürlichen Bedingungen die Wirkung der wechselnden Wetterbedingungen bei weitem nicht völlig vermieden werden. Dieses Projekt basiert auf 3D kinematische Messungen, die an der Slalomstrecke durchgeführt wurden, wobei die Leistung der fünf an Weltmeisterschaften teilnehmenden Skifahrer gemessen wurde. Es untersucht die Wirkung der wechselnden Wetterbedingungen auf einige kinematische Parameter, wie z. B. die Geschwindigkeit des Schwerpunkts von Skiern und das arithmetische Mittel der Geschwindigkeit von Skiern, die Länge der Flugbahn des Schwerpunkts und das arithmetische Mittel der Flugbahn der Skier, den horizontalen sowie den vertikalen Punkt des Beginns und des Endes der Kurve und die notwendige Zeit, um die Kurve auszufahren. Die Ergebnisse zeigen eine signifikante Wirkung auf einige untersuchte Parameter, die uns eine Grundidee über die Konsequenzen vermitteln.

Schlüsselwörter: *Ski Alpin, Slalom, wechselnde Wetterbedingungen, 3D kinematische Messungen*

Introduction

Changing conditions on ski courses make the World Cup races unfair to racers and more interesting for spectators. In the past years the organizing committee of the World Cup races tried to improve races in order to make them fairer and more interesting. One of the most significant attempts to avoid an advantage of the best racers because of better course conditions was to invert the starting list in the second run starting with the fifteenth result from the first run. Recently, it has even been tried to invert the results of thirty racers for the second run. Even more, the best racers draw the starting numbers to avoid the first starting numbers having the best conditions. These are only the most obvious rules changed among many of them, which will result in making the World Cup races fairer and more interesting.

It is instinctively known that changing conditions on ski course affect results. Sometimes, this affects a skier's run more, sometimes less. Furthermore, it may be affirmed that the effect of changing conditions cannot be avoided completely in outdoor, natural circumstances. This is the reason why we wanted to study this issue even though it is not possible to find a general solution to the problem. Several investigations in alpine skiing using 3D kinematics have been performed in the past years, where many of them have considered the centre of gravity and arithmetic mean of skis (Schaff & Hauser, 1993; Brown, Hoffman, & Heinzmann, 1996; Erdmann & Giovanis, 1997; Ikegami et al., 1997, Kugovnik, Nemec, Pogačar, & Čoh, 2000; Raschner et al., 2001; Supej, Kugovnik, & Nemec, 2003; Pozzo, Canclini, Cotelli, & Baroni, 2004; Schiefermueller, Lindinger, Raschner, & Mueller, 2004; Supej, Kugovnik, & Nemec, 2004; etc.). The model and measurements presented in this paper are based on the trajectories and on the points of the beginning and the end of the turns (Supej, Kugovnik, & Nemec, 2003).

Methods

Sample

The slalom course during training sessions, at the beginning of a racing season, was taken under investigation. Five top-level slalom racers, members of the Slovenian national ski team, were measured: J. K., M. K., A. M., U. P. and M. V. They performed 3 runs each on the same course set-up. Altogether 14 runs were recorded, because M. K. fell out in the second run. The gates in the measurement region were placed with an absolute distances d_{s1} = 12.37 m and d_{s2} = 12.75 m between each other and a displacement of d_r = 3.88 m (Figure 1). The slope inclination was 18.5° ± 1°. The air temperature was +3°C in the morning (before the measurements) and the upper layer of snow was well prepared and hard, but became soft as foreseen since the weather was warm enough including a warm wind to make this study possible. Therefore the upper layer became broken on the course soon after a few skiers' runs. At the end of measurements the air temperature was approximately +8.5°C.

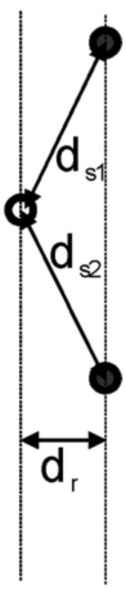

Figure 1. The schematic diagram shows the absolute distance between the neighbouring gates d_{s1}, d_{s2} and the displacement d_r between the gates.

Measuring device

Standard 17-point 3D kinematic measurements were taken (Shaff & Hauser, 1993, etc.) using 4 camcorders covering 2 kinematic subspaces at 50 frames per second (Kugovnik et al., 2000, etc.) even though pan – tilt – zooming systems have already been proven in alpine skiing (Drenk, 1994; Mossner, Kaps, & Nachbauer, 1996). Synchronized Sony DV-CAM camcorders were used covering two subspaces joined in the middle. Additionally, Sony mini-DV camcorders were used covering the same spaces from different angles and covering a longer area of the ski course. Each subspace was calibrated using two cubes with a base of 1 metre. The cubes were always placed wide apart to achieve maximum calibration accuracy. APAS Ariel 3D kinematic software was used to digitise joint points and to transform double 2D data to 3D data.

Data analysis

To analyse the raw data as they emerged from the APAS software, specially designed software KinSki was used (Supej, Kugovnik, & Nemec, 2004) that enabled an analysis of the videos and simultaneous employment over 60 of the calculated parameters essential for the analysis of skiing (Figure 2). All descriptions of parameters calculated in KinSki software are presented in the next section.

Calculation of the investigated parameters

We described the skier's trajectories of motion for each point in a three-dimensional Cartesian co-ordinate system. In this case the beginning of a ski turn as well as the end of it can be calculated as a cross-section of the projected trajectory of the centre of gravity on the ski-trajectory-surface and of the arithmetic mean of the skis (Supej, Kugovnik, & Nemec, 2003).

Beside these two points the lengths of the centre of gravity trajectories and the lengths of the arithmetic mean of the skis' trajectories were also calculated from the point of the beginning of the turn and to the point of the end of the turn as previously discussed. All lengths were calculated by the polygon-lines and a simple linear approximation. Furthermore, the turn times needed and the average turn speeds were calculated during the inspected

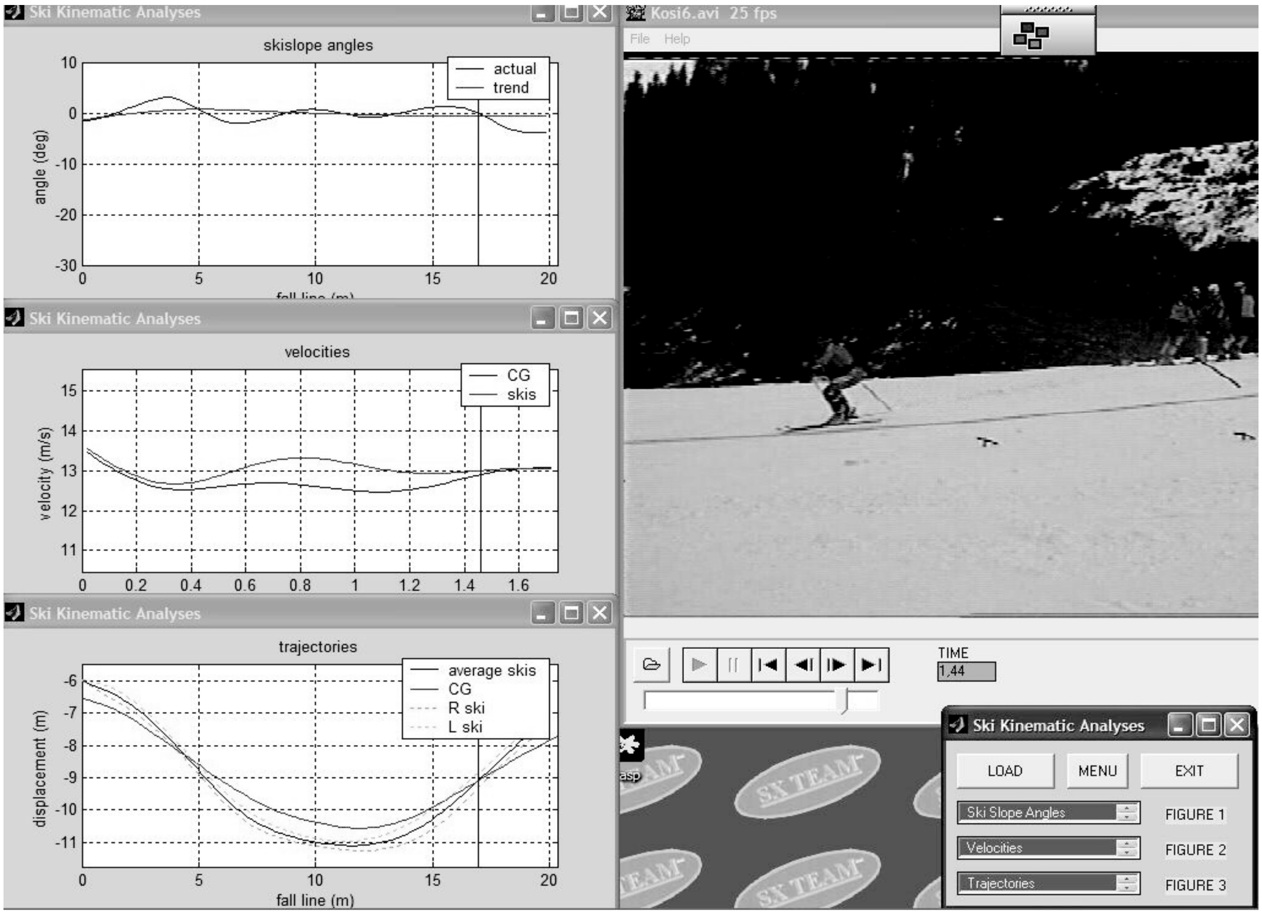

Figure 2. Some of the most important biomechanical parameters in skiing are presented graphically and simultaneously with the video recordings using the KinSki computer program. The skier is stopped at the point of ending the previous and beginning the next turn. The vertical lines in the diagrams show corresponding values (the skier measured: J. K.).

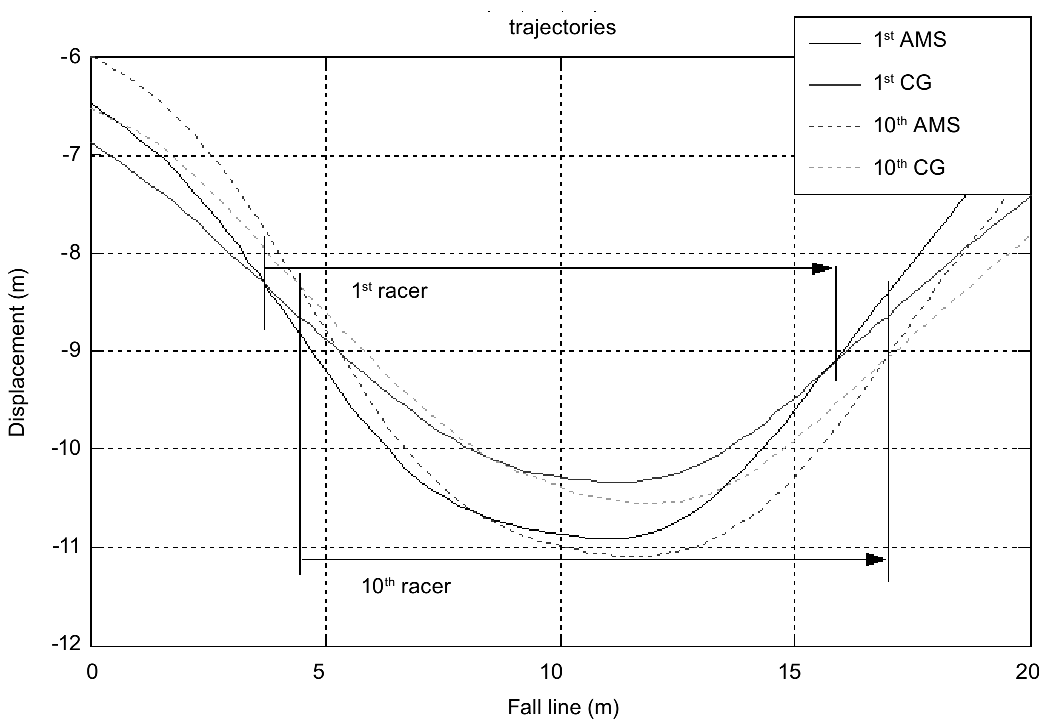

Figure 3. Centre of gravity's (CG) and arithmetic mean of skis' (AMS) trajectories for the 1st passing and for the 10th passing through the gate combination. The trajectories belong to J.K.'s 1st and 3rd run. The beginnings and ends of the inspected turns are marked by solid vertical lines (KinSki Computer Program).

turn. Therefore, the exact times of the beginning of the turns and the end of the turns for each racer were calculated using the previously described cross-section points and velocity of the surrounding interval. The time to complete the inspected turn is consequently a difference between the calculated time points. Dividing the length of the turn trajectory by the turn time results in average velocity.

All diagrams are presented with the Matlab's prediction plot using the least squares method for linear regression. The bounds on the diagrams are non-simultaneous and curved showing a 95% confidence interval. Similarly, the upper and the lower 95% bounds for all the linear regression parameters are presented in the table (Figure 10).

Results

An example of trajectories of the centre of gravity and arithmetic mean of skis is presented in Figure 2 for two different runs of the same skier (J.K.). A pair of trajectories belongs to the 1st run and a pair to the 3rd run, which is equal to the 1st passing and to the 10th passing through the gate combination.

The most obvious parameters showing the effect of changing conditions on a slalom ski course are the points of the beginning and the end of the turn. The diagrams in Figure 4 show where the ends according to the skiers' runs are in the fall line. The linear coefficient for the trend line amounts approximately to 0.1 m/run for the ends of turns (see also Figure 10). The linear coefficient for the beginnings of turns does not show any statistical significant deviation from zero.

Similarly, the diagram in Figure 5 presents displacements of the ends of turns according to the skiers' runs. In this case the linear coefficient amounts to -0.0476 m/run (see also Figure 10).

Despite the point of beginnings and ends also the centre of gravities' and arithmetic mean of skis' trajectories are spoiled during the runs due to the differences in lengths (see also Figure 3). The diagrams in Figure 6 and Figure 7 show the prolongations of trajectories. The linear coefficients of the trend lines are similar as expected. They are 0.138 m/run and 0.126 m/run for the centre of gravities' trajectories and for the arithmetic mean of skis' trajectories, respectively (see also Figure 10).

We have already seen how changing conditions on a ski course affect trajectories and points of the beginning and end of a turn. Nevertheless, two other parameters are most important in racing skiing: the time needed to complete the run and the average velocity. The diagram in Figure 8 presents the times needed to complete the inspected turn and

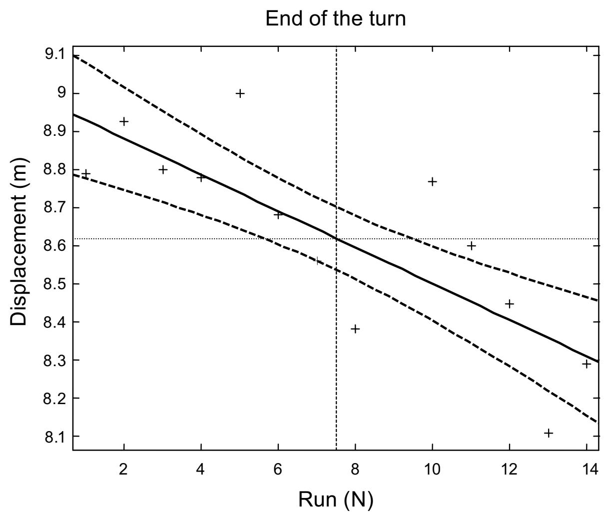

Figure 5. Points of displacement of the turns' ends according to the skiers' runs with an added linear trend line (solid line) and predicted bounds (dotted line).

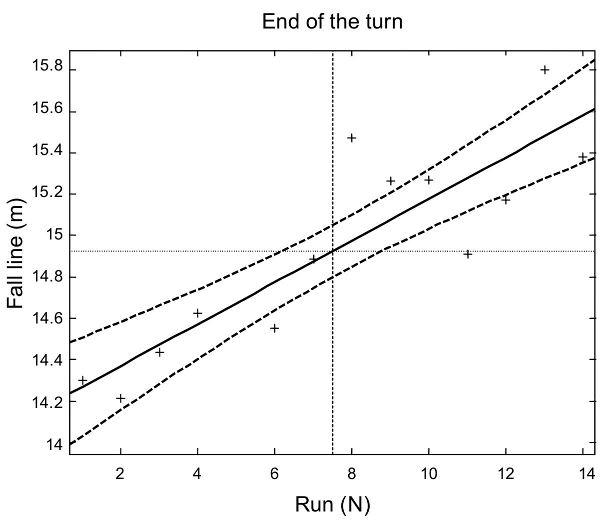

Figure 4. Points on the fall line of the ends of turns according to skiers' runs with an added linear trend line (solid line) and predicted bounds (dotted line).

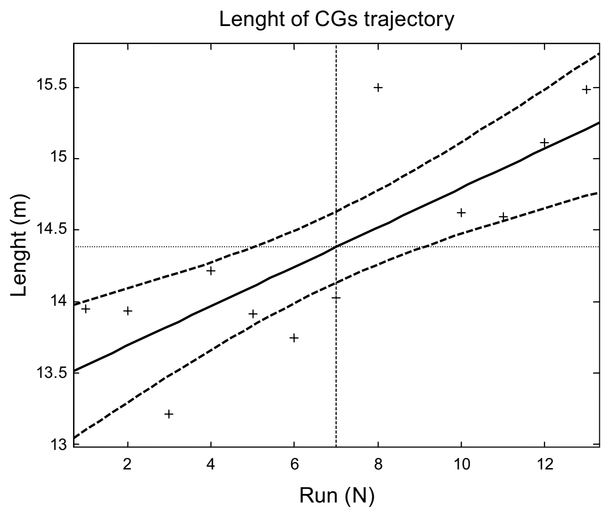

Figure 6. Prolongations of the centre of gravities' trajectories - trajectories according to the skiers' runs with an added linear trend line (solid line) and predicted bounds (dotted line).

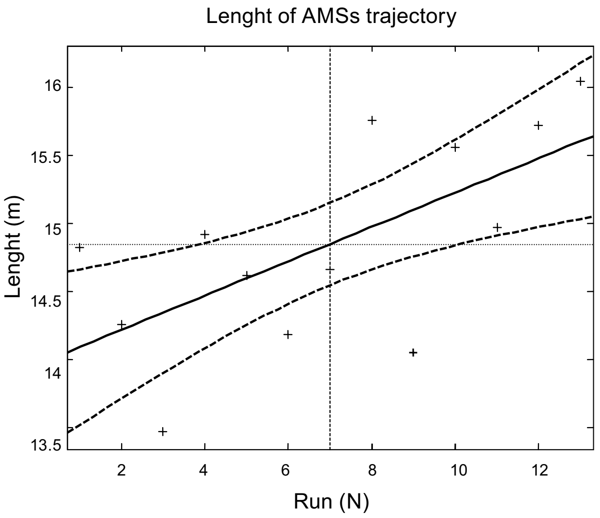

Figure 7. Prolongations of the arithmetic mean of skis' trajectories - trajectories according to skiers' runs with an added linear trend line (solid line) and predicted bounds (dotted line).

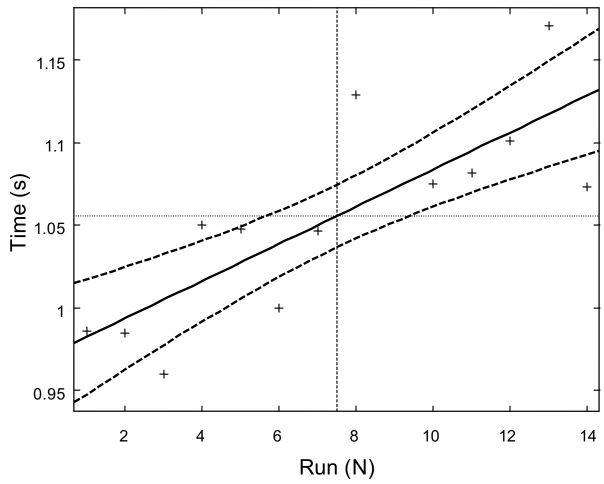

Figure 8. The times added for the completion of the inspected turn according to the skiers' runs with an added linear trend line (solid line) and predicted bounds (dotted line).

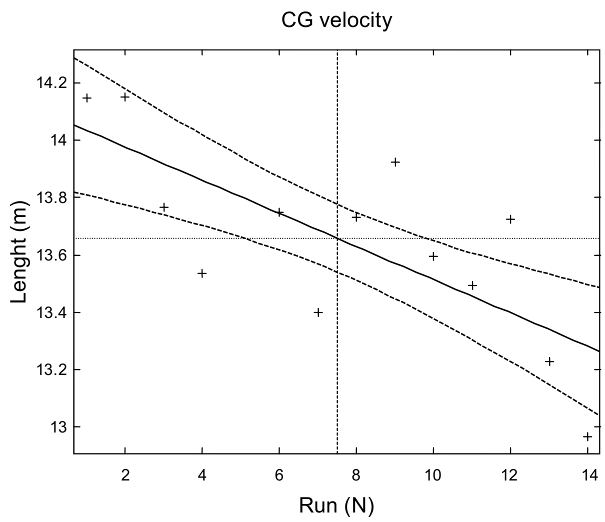

Figure 9. Average velocities of the centre of gravity according to the skiers' runs with an added linear trend line (solid line) and predicted bounds (dotted line).

the diagram in Figure 9 shows the average velocities of the centre of gravities (the diagram for the arithmetic mean of skis' velocities is very similar and therefore not presented). In all cases the trend lines and 95 % of the bounds are added for eye guiding. The linear coefficients are 0.011 s/run and -0.058 ms^{-1}/run for the times and average velocities respectively (see also Figure 10).

All the linear regression parameters with the bounds predicted up to 95 % are shown in Figure 10. They follow the notation of a simple linear equation y = k*x + n. Suffixes –low and –up are dedicated to the lower and upper bound. In this case the constant regression parameter *n* represents the result of a hypothetical zero passing.

Discussion and conclusions

The complete measurements were performed in order to find out the consequence of changing conditions of a slalom ski course. The conditions chosen changed greatly. Intentionally, five top-level skiers performed three runs down the same ski course to minimize the differences between the skiers' performances as it would have happened if each skier performed only one run through the gate combination (measurement course).

	k	k-low	k-up	n	n-low	n-up
Time [s]	**0.011**	0.007	0.016	**0.971**	0.933	1.010
Fall line [m]	**0.101**	0.071	0.131	**14.169**	13.904	14.434
Displacement [m]	**-0.048**	-0.067	-0.028	**8.976**	8.808	9.144
CG-traject. [m]	**0.138**	0.074	0.203	**13.414**	12.908	13.920
AMS-traject. [m]	**0.126**	0.045	0.207	**13.964**	13.322	14.606
CG-vel. [m/s]	**-0.058**	-0.087	-0.029	**14.092**	13.842	14.342

Figure 10. Linear regression parameters with upper and lower bounds for all parameters inspected. Abbreviations: CG – centre of gravity, AMS – arithmetic mean of skis.

Almost all the observed parameters result in differences and show that it is difficult or even impossible to assure conditions fair to all the racers under such weather/snow conditions. It should be pointed out that normally such changes do not happen over the whole ski course, but mostly only on one or more sections. Nevertheless, we calculated the predictions for the whole ski course several times in order to make the level of changes easier to envisage. On average, a 0.01-second difference was measured in the times for the inspected turn after each passing through the gate combination (Figure 8 and Figure 10). Even the lower bound amounts to 0.007 s/run. In the worst scenario this would mean approximately a half of a second over the whole slalom course. Of course, these time differences are too high, because in this gate combination the point of the end of the turn has a much higher tendency to decrease according to the fall line (11 cm/run or 7 cm/run minimum) than the point of the beginning of the turn which is even statistically insignificant (Figure 4). Consequently, the displacement had a higher tendency at the end of the turn than at the beginning of the turn, which was again statistically insignificant (Figure 5). Generally, it could be seen that the lengths of the centre of gravities' and the arithmetic mean of the skis' trajectories were prolonged by approximately 13 cm/run (Figure 6 & Figure 7) on average. This result means that the difference in length between the 1st skier's trajectory and the 14th is over 1 metre and this would mean over 50 metres in the whole course. These results are again, as previously discussed, too high, they would result in over a 3-second advantage in the whole slalom course in the worst scenario. Anyway, it can be argued that the trajectories should be longer, while the apex of the turn becomes lower and it is not at a gate anymore as can be seen from figure 3. This means that the displacement should be higher and consequently the length of the trajectory is expected to be longer as well.

Nevertheless, minimum differences when such changes would happen on the whole run can be quite accurately estimated when considering the average velocities. The decrease in average velocities is slightly surprising at first glance (Figure 9), but since the available potential energy in the whole run is the same for all the trajectories and the trajectories become longer, skiers dissipate more mechanical energy through air drag (friction and the skiers' work are neglected). Even when the same length of the trajectory was taken, for example 14 metres for one turn, and if it were multiplied by fifty turns, the result would be 700 metres of skiing in a slalom course. When the average velocity of the centre of gravity is 14 m/s instead of only 13.95 m/s (0.05 ms^{-1}/run is the average difference measured between the two following runs – Figure 8) that would result in 0.18 seconds in the course per run. It does not matter how the differences are calculated under "soft snow conditions", it can be seen that the courses or their sections are truly unfair to racers.

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PROMJENJIVI UVJETI NA SLALOMSKOJ SKIJAŠKOJ STAZI NEGATIVNO UTJEČU NA NATJECATELJSKU USPJEŠNOST

Sažetak

Uvod

Instinktivno se zna da promjenjivi uvjeti na slalomskoj skijaškoj stazi utječu negativno na natjecateljske rezultate. Isto je tako jasno da se učinak mijenjanja uvjeta ne može sasvim izbjeći u aktivnostima na otvorenome, u prirodi. To je i bio razlog zbog kojega smo ipak željeli proučiti taj problem iako smo svjesni da se za njega ne može pronaći konačno rješenje.

Metode

Ispitivali smo slalomsku stazu tijekom treninga na početku natjecateljske sezone. Izmjerili smo petoricu vrhunskih slalomaša, članova slovenske skijaške reprezentacije. Svaki je tri puta odvezao istu slalomsku stazu. Gornji sloj na stazi bio je dobro pripremljen i čvrst ujutro, ali je tijekom prijepodneva, očekivano, omekšao budući da se tempeatura zraka povećala, a zapuhao je i i topao vjetar.

Provedeno je standardno trodimenzionalno kinematičko mjerenje 17 točaka pomoću 4 kamere koje su pokrivale 2 kinematička podprostora brzinom od 50 sličica u sekundi. Za obradu sirovih podataka prikupljenih sustavom APAS upotrijebljen je specijalno dizajniran računalni program KinSki.

Opisali smo trajektoriju gibanja svake od sedamnaest točaka u trodimenzionalnom koordinatnom sustavu. U tom je slučaju bilo moguće izračunati početak i završetak zavoja kao presjek projicirane trajektorije težišta tijela na površinu određenu trajektorijom i skijom i aritmetičke sredine skija.

Osim te dvije točke, izračunate su i duljine trajektorija težišta tijela i duljine trajektorije aritmetičke sredine skija. Tijekom promatranih zavoja mjerena su vremena potrebna za izvedbu tih zavoja i prosječne brzine. Petorica vrhunskih skijaša planirano su izvela po tri vožnje istom slalomskom stazom kako bi se na najmanju mjeru smanjile moguće razlike među njihovim rezultatima, što bi se najvjerojatnije dogodilo da je svaki skijaš samo jednom prošao postavljenom stazom (mjernom stazom).

Rezultati, rasprava i zaključak

Mjerenja su provedena da bi se otkrile posljedice promijenjenih uvjeta na slalomskoj skijaškoj stazi. Uvjeti na stazi znatno su se tijekom mjerenja promijenili.

U svim su se promatranim parametrima pojavile razlike, što je pokazalo da je, u takvim okolnostima, vrlo teško, ako ne i nemoguće, osigurati pravedne, tj. podjednake uvjete za sve natjecatelje. Valja istaknuti da se takove promjene normalno, u stvarnosti ne događaju na čitavoj stazi, već obično na jednom dijelu ili na nekoliko njenih dijelova. Mi smo, ipak, nekoliko puta izračunali predviđanja za ukupnu slalomsku stazu kako bismo zornije prikazali veličinu promjena. Primjer izračuna na temelju trajektorija težišta tijela i aritmetičke sredine skija prikazan je na slici 2 za dvije vožnje istoga skijaša (J.K.). Par putanja pripada skijaševoj prvoj i trećoj vožnji, što je odgovaralo prvom i desetom prolazu kroz postavljenu kombinaciju vrata. Prosječno, nakon svakog prolaska kroz postavljenu kombinaciju vrata izmjerena je razlika od 0,01 s u vremenu na promatranom zavoju (slike 8 i 10). Čak se i donja granica popela do 0,007 s/vožnja. Prema najgorem scenariju to bi značilo razliku od približno pola sekunde na čitavoj stazi. Naravno, te su vremenske razlike prevelike zato što je u našoj kombinaciji vrata točka završetka zavoja pokazivala veću tendenciju usporavanja u skladu s nagibom (11 cm/vožnja ili 7cm/vožnja najmanje) od točke početka zavoja, koja se i statistički pokazala neznačajnom (slika 4). Sukladno tome, veća je tendencija pomaka na kraju zavoja nego na početku, što je i opet bilo statistički neznačajno (slika 5). Općenito, vidi se da su se duljine putanje težišta tijela i aritmetičke sredine skija produljile prosječno za približno 13 cm/vožnja (slike 6 i 7). Taj rezultat znači da je razlika u duljini između 1. i 14. skijaševe trajektorije veća od jednog metra, a to bi onda značilo više od 50 metara za cijelu stazu. Ti su rezultati, kao što je već ranije rečeno, preveliki i, prema najgorem scenariju, rezultirali bi s prednošću većom od 3 s na čitavoj stazi. U svakom slučaju, moglo bi se tvrditi da bi trajektorije trebale biti duže usporedo sa spuštanjem vrha zavoja, a to tada više nije u blizini vrata, kao što se može vidjeti na slici 3. To znači da bi premještanje moralo biti više i onda se posljedično očekuje i veća duljina trajektorije.

Ipak, najmanje razlike mogu se, u našem slučaju, vrlo precizno procijeniti kao posljedica promijenjenih uvjeta promatraju li se prosječne brzine. Sniženje prosječnih brzina na prvi pogled iznenađuje (slika 9), no kako je količina raspoložive potencijalne energije za sve vožnje jednaka za sve trajektorije te kako trajektorije postaju duže, skijaši rasipaju puno mehaničke energije svladavajući otpor zraka (trenje i skijašev rad su zanemareni). Čak ako se u obzir uzme ista duljina putanje za sve zavoje, primjerice 14 m za jedan zavoj, i ako se to pomnoži sa pedeset zavoja, rezultat će biti 700 m skijanja po slalomskoj stazi. Ako je prosječna brzina težišta tijela 14 m/s umjesto samo 13,95 m/s (0,05 ms^{-1}/vožnja je prosječna razlika izmjerena između dviju uzastopnih vožnji, slika 8), tada bi to značilo razliku od 0,18 s po vožnji na čitavoj stazi. Nije važno kojom se metodom računaju razlike u "uvjetima mekog snijega". Vidi se da su u takvim uvjetima staza ili njeni dijelovi stvarno nepravedni prema natjecateljima.