GATE-TO-GATE SYNCRHONIZED COMPARISON OF VELOCITY RETRIEVED FROM A HIGH-END GLOBAL NAVIGATION SATELLITE SYSTEM IN ALPINE SKIING

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The aim of this study was to develop a new methodology based on Global Navigation Satellite System (GNSS) measurements of skiers' velocity (*v*) along the course setup, thereby enabling a direct *v* comparison of them. Nine skiers were measured using GNSS on a 36-gate long giant slalom course. Gate-to-gate times (*t*) and *v* were calculated for each skier. The velocities were synchronized between each pair of adjacent gates using *t*. Several changes in *t* as well as in *v* were observed. The results demonstrated that the shortest *t* was not completely aligned with the highest *v* and vice versa. In conclusion, the new methodology enhances the analysis and can be used 1) in daily praxis to compare skiers, 2) automatically with programming routines and the results can be retrieved promptly after the training session in order to enhance feedback.

KEY WORDS: giant slalom, glonass, gnss, gps, performance, time.

INTRODUCTION: Alpine skiing is a complex sport discipline in which coaches need detailed analyses in order to be able to provide an accurate feedback to athletes. In order to save time and quickly improve performance, feedback should be available as soon as possible. Timing using photocells is a common procedure of measuring performance during daily training. Global Navigation Satellite Systems (GNSS) are constantly improving in terms of accuracy and usability, and they have been proven to be useful of retrieving gate-to-gate times in alpine skiing (Supej & Holmberg, 2010). However, it has also been proven that the time of a short section strongly depends on the performance in the previous section (Supej, Kipp, & Holmberg, 2011), and that maintaining high velocity without dissipating a huge portion of available mechanical energy is advantageous (Supej, 2008). Therefore, being able to measure time as well as to directly compare velocity among racers along the course would significantly improve feedback to athletes. The aim of this study was to develop a methodology based on GNSS measurements to synchronize velocity along the course setup, thereby enabling a direct velocity comparison among the analysed skiers.

METHODS: Nine male and female skiers, members of the junior national team and candidates for the 2012 Youth Olympic Games (age: 16–17y) participated in the study. The procedures were explained in detail prior to participants signing a written informed consent. All procedures were approved by the Ethical Committee of the Faculty of Sport in Ljubljana, Slovenia and the study was conducted according to the Declaration of Helsinki.
A giant slalom course setup of 36 turning gates was set on a glacier during late autumn pre-season preparation period. The slope had various slope inclinations as well as transitions from flat to steep slope and vice versa. Each of the participants was recorded with a high-end GNSS real time kinematics (RTK) system. The rover and reference station for the GNSS system consisted of 1) Leica GX1230 GG, 72 channel, dual frequency L1/L2 receivers, 2) Leica AX1202 GG survey antennas and 3) Leica GFU14 Satelline 3AS radio modems (Leica Geosystems AG, Heerbrugg, Switzerland). The system simultaneously receives signals from both the American and Russian global navigation systems (GPS and GLONASS) and surveys positions with 1 cm + 1 ppm and 2 cm + 1 ppm horizontal and vertical accuracy respectively, at a 20 Hz sampling rate in RTK mode (99.99% position accuracy reliability, according to the manufacturer), but in favourable conditions the position accuracy can be even higher (Takac & Walford, 2006). During the measurements, the reference station stood

on a fixed tripod <800 m from all surveyed points to assure maximum accuracy. The rover was stacked into a specially designed small backpack carried by the skiers (total weight ~1.64 kg). The antenna was positioned at the height of the skier's upper back (level Th2-Th4) to ensure minimum disturbance to the skiers and good visibility of the sensor to the satellites. The receiver and modem (the heavier part of the system) were positioned in the lowest part of the backpack, slightly above the waist. Only the antenna (the lighter and smaller part of the system) was stationed on the upper back. To survey the terrain properties and all the ski gates, the GNSS antenna was attached to a 2 m long carbon geodetic pole with on-board inclinometer (Leica Geosystems AG, Heerbrugg, Switzerland). In addition to turning gates, a "flying starting position" was surveyed, which was determined approximately 1 m below the actual starting gate. To minimize errors from the GNSS measurements, the giant slalom course was chosen to be on "open" terrain without adjacent forest and on a high altitude on the glacier. All tests were carried out between 8:15 AM and 11.00 AM. This time frame had high satellite availability and resulted in 10–17 visible satellites above the 15° azimuth angle during all measurements. During the runs, the skiers were filmed continuously with one camcorder (JVC GR-DV4000E). The GNSS system and the video were time synchronized using an isolated rapid vertical squat movement prior to each measurement. Before each measurement, the satellite availability, GDOP (Geometric Dilution of Precision) value and position error were verified.

Before the calculation, the GNSS raw trajectory was filtered with the Rauch-Tung-Striebel algorithm (Rauch, Tung, & Striebel, 1965), which uses two unscented Kalman filters running forward and backward in time and performs fixed-interval offline smoothing of the estimated signals. The accuracies of the trajectory's points returned by the GNSS were used to set the lowest filter's frequency to be utilized under the assumption that each smoothed point is not moved more than its position accuracy. The process of Kalman filtering optimally estimates non-measurable states, which was used to retrieve velocity. The optimally estimated velocity and filtered position enabled calculation of the following parameters absolute velocity (v), and gate-to-gate times (t) with equal accuracy compared to photocells (Supej & Holmberg, 2010). Gate-to-gate times were thereafter used to synchronize v among skiers between each pair of adjacent gates along the course. A cubic spline interpolation was used in order to calculate one hundred values of v evenly distributed in time between each two gates. Finally, the skier's velocity was plotted against gate numbers instead of time. For clarity of the diagrams, only four male skiers were selected for analysis. The data obtained from the GNSS were also synchronized with video recordings for easier analysis, using a custom build application DGPSana.

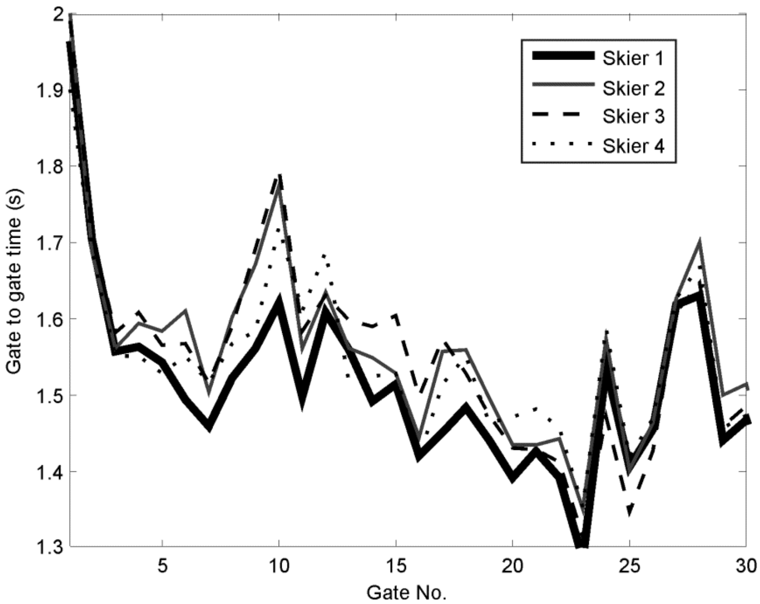

Figure 1: Gate-to-gate times for four selected male skiers for the first 30 gates.

RESULTS: Gate-to-gate times are presented for four selected male skiers in Figure 1. The skiers' time curves show differences between skiers as well as overall differences in time needed for different gates along the course. The gate-to-gate times varied along the course almost at each gate. However, some decreases and increases in time were more noteworthy: e.g. a decrease in the first three gates (from ~1.95 s to ~1.57 s), a decrease from gate 5 to gate 7 (from ~1.57 s to ~1.48 s), an increase from gate 7 to gate 10 (from ~1.5 s to ~1.7 s), a slight but constant decrease from gate 10 to gate 23 (from ~1.7 s to ~1.35 s). In addition to overall changes in *t*, there were also changes where one or another skier was achieving the shortest times. For example, Skier 1 had the shortest *t* between gates: 5 and 12, 13 and 14, 21 and 23 as well as 28 and 36 with the highest gain of time was almost 0.18 s per gate between gate 9 and 10 against Skier 3. However, Skier 1 had the highest time lag (~0.07 s) between gate 23 and 24, while Skier 3 had the shortest *t*.

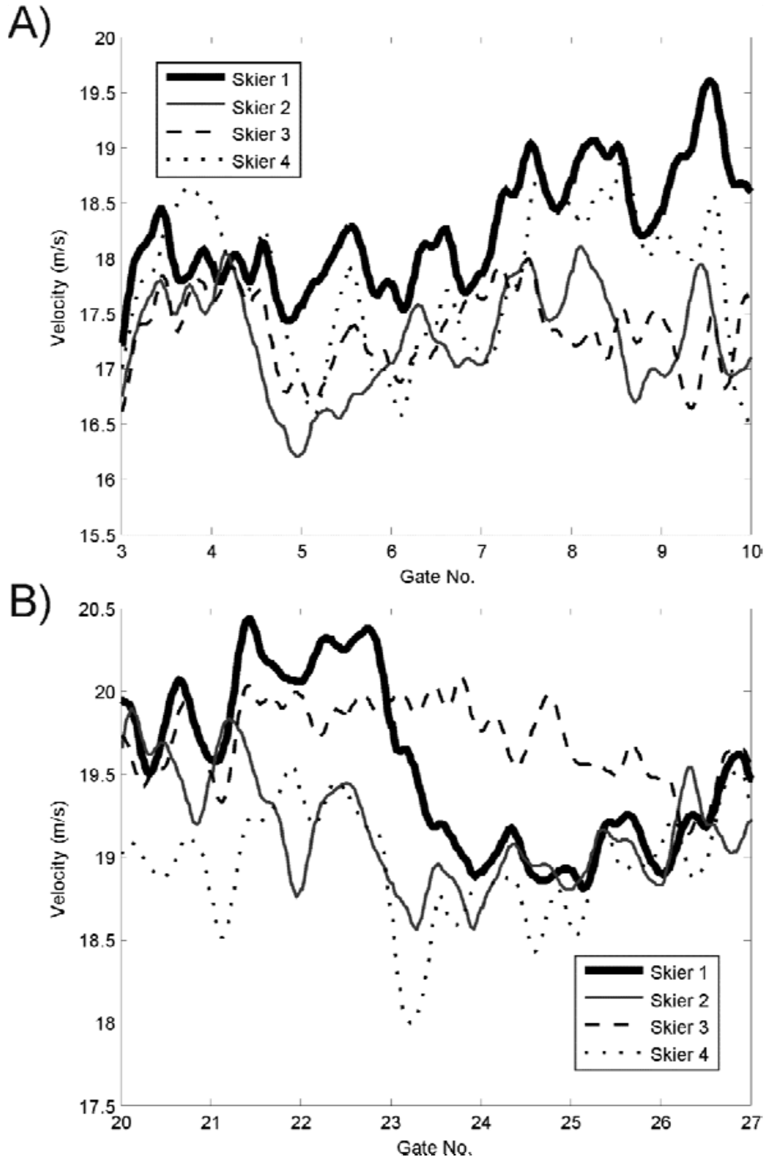

Figure 2: Skiers' velocities plotted against giant slalom gates for sections between gates 3 and 10 (A) and between 20 and 27 (B).

Analysing the velocities plotted against gate number in Figure 2 for two chosen sections revealed skiers' behaviours in greater detail compared to gate-to-gate timing. Compared to Skier 3, Skier 1 started to increase *v* right after gate 4, and compared to Skier 4, just before gate number 5 (Figure 2A). Thereafter, Skier 1 had been skiing with the highest *v* almost at all times until gate 10. When concentrating on the *v* of the Skier 1 for the section between gates 21 and 24 (Figure 2B) it can be observed that Skier 1 achieved the highest *v* approximately 0.2 turns after passing gate 21 and maintained the highest *v* almost exactly until passing gate 23. Skier 1 had ~0.5 $m \cdot s^{-1}$ higher *v* just before gate 23 and ~1.1 $m \cdot s^{-1}$ lower *v* around gate 24 compared to Skier 3. Skier 3 skied with the highest *v* between gates 23 and 26.

DISCUSSION: The results demonstrated that relatively high differences in gate-to-gate times between the racers occur along the course. Additionally, the same skier did not have the shortest *t* along the whole course. The changes in who is having the shortest *t* often occurred at rhythm changes, i.e. when *t* for all skier decreased or increased suddenly (e.g. from gate 4 to 7 and from gate 7 to 10) which is in line with previous findings (Supej & Holmberg, 2010). It should be pointed out that *v* was not directly aligned with the time changes. For example, Skier 1 already gained the highest *v* between gate 4 and 5, but the shortest *t* was achieved only after gate 5. However, Skier 1 did not ski with the highest *v* through gates 21 to 23, but still achieved the shortest *t*. It can be concluded that the synchronized *v* reflected in much more detail, where the skier started to ski "better" or "worse" compared to gate-to-gate timing. Therefore, using the detailed information of *v* helps the skiers to realize where exactly they started to ski faster or slower; furthermore, in combination with synchronized video, the coaches can provide them with the probable reasons for this.
The limitation of the new proposed methodology was that the GNSS system surveyed the antenna position and not the centre of mass, which introduces some error in velocity analysis. However, the antenna was placed relatively close to the centre of mass in terms of the giant slalom dimensions and, as a consequence, the velocity differences among skiers were logical according to achieved gate-to-gate times. Still, this error could be even further minimized by appropriate mechanical modelling.

CONCLUSION: The main finding of the study was that the new methodology to synchronize velocity along the course using a Global Navigation Satellite System was developed and can be used in daily praxis to compare skiers' velocities along the course. Using the proper computer programming routines, the new methodology can be automated and the results can be retrieved promptly after the training session in order to enhance feedback. In addition, the same methodology can be used also to synchronize other performance parameters along the course, such differential specific mechanical energy (Supej, 2008), and can be used in other sports, e.g. cross country skiing.

REFERENCES:
Rauch, H. E., Tung, F., & Striebel, C. T. (1965). Maximum likelihood estimates of linear dynamic systems. *AIAA Journal, 3*(8), 1445-1450.
Supej, M. (2008). Differential specific mechanical energy as a quality parameter in racing alpine skiing. *Journal of Applied Biomechanics, 24*(2), 121-129.
Supej, M., & Holmberg, H. C. (2010). A new time measurement method using a high-end global navigation satellite system to analyze alpine skiing. *Research Quarterly for Exercise and Sport, 82*(3), 400-411.
Supej, M., Kipp, R., & Holmberg, H. C. (2011). Mechanical parameters as predictors of performance in alpine World Cup slalom racing. *Scandinavian Journal of Medicine & Science in Sports, 21*(6), e72-e81.
Takac, F., & Walford, J. (2006, September 26-29). *Leica System 1200 – High Performance GNSS Technology for RTK Applications.* Paper presented at the Proceedings of the 19th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS 2006), Fort Worth, TX.

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