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Trajectory matching by low-cost GNSS allows continuous time comparisons during cross-country skiing

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Introduction

In most endurance sports, including cross-country (XC) skiing, the fastest athlete wins the race. Successful performance requires an optimal pacing strategy i.e., effective distribution of work and energy throughout a race (Abbiss & Laursen, 2008). For any given lap of a race, no more than a few split times are usually available, due to the complex logistics of setting up a timing system. However, optimal tracking of pacing (speed) during a race requires determination of more split times at regular and shorter intervals. For example, a high-end Global Navigation Satellite System (GNSS) can be used to easily obtain a high number of split times based on a comparison of positions (Andersson et al., 2010; Supej & Holmberg, 2011). Accordingly, the aim here was to determine whether comparison of position at one-meter intervals using a standard GNSS gives reliable split times during XC skiing.

Methods

Each of three junior XC skiers equipped with a miniature standard GNSS (FieldWiz 2, Advanced Sport Instruments SA, Lausanne, Switzerland) that recorded his position at 10 Hz skied four laps employing the skating technique. The beginning and end of each lap were segmented manually. The horizontal position data was linearly resampled to obtain one sample every meter. One lap was chosen arbitrarily as the reference and the trajectories of all other laps were matched to this reference lap with respect to their shape (Belongie, Malik, & Puzicha, 2002; Jonker & Volgenant, 1987). Next, thin plate splines were used to deform these laps onto the reference lap (Donato & Belongie, 2002). For each position sampled, the split time was defined as the difference in run time between the matched and reference laps.

To validate the accuracy of timing, a 20-m section marked with a black line was filmed at 120 Hz (Hero 6, GoPro, San Mateo, CA, USA) and the resulting video synchronized with the GPS time to obtain the absolute time when the line was crossed. The position of the line on the reference lap was employed to assess the GNSS line crossing data for all other laps. The absolute error in time was the difference between this value and the time indicated by the video recording.

Results

All of the laps except one could be matched and mapped onto the reference run with a median timing error of -0.06 s (2.5th and 97.5th percentiles: -0.16 s and 0.16 s, or without matching and mapping: -0.37 s and 0.17 s, respectively). Error standard deviation was 0.12 s and root mean square error was 0.12 s (with matching and mapping). A representative continuous split time curve is shown in Fig. 1.

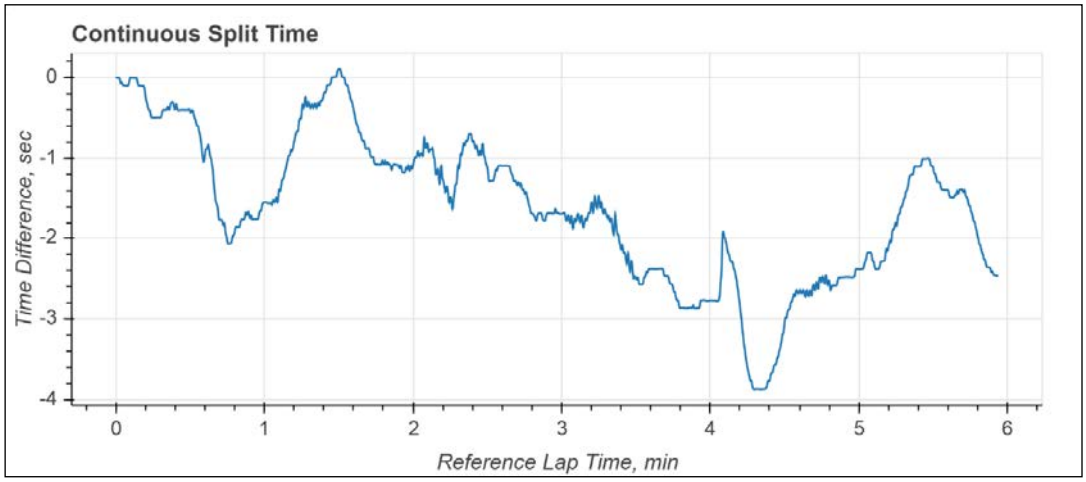

Fig. 1 Representative continuous split time for one lap. Negative values indicate that skiing on the reference lap was slower.

Discussion

The method described allowed split times to be obtained at one-meter intervals employing a standard GNSS. The 95% confidence interval for absolute timing was 0.32 sec. Precision was limited primarily by the low sampling frequency (10 Hz), as well as by resampling of the trajectory to points 1 m apart. More frequent sampling and finer resampling should improve this precision. Nevertheless, since time differences between XC skiers are normally in the order of seconds, this approach can already be used as is to analyse pacing strategies. Moreover, the trajectory matching provides high-resolution determination of differences in speed and, thereby, more detailed analysis of performance. By choosing a different reference lap, continuous split times can be obtained for any two laps. In the future, this system should be validated on a larger dataset and compared to photocell-based timing.

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