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FINAL REPORT

VALIDITY OF AN AUTOMATED GNSS-IMU SYSTEM IN TEMPORAL BIATHLON RANGE WORK ANALYSIS

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ABSTRACT

Previous studies among skiing sports have showed that a GNSS together with IMU sensors seem to be able to detect sport-specific events, distinguish between sub-techniques, provide cycle characteristics and within-cycle changes in speed reasonably well. These recent technological advances suggest that it could be possible to perform temporal biathlon range work analyses automatically with high precision and without interrupting the athlete. Therefore, the aim of the present study was to examine the validity of a commercial wearable wireless GNSS-IMU system in automated temporal biathlon range work analysis. A total of twelve biathletes (age 21 ± 4 years old) volunteered for the study and performed a typical biathlon range work training session using their own rifles and skiing equipment. Each biathlete skied twelve laps around the shooting range and performed six times a 5-shot set of biathlon shooting from the prone and the standing postures. All data were simultaneously collected using a wearable Naos sensor placed inside a vest on the biathlete's upper back and a high-speed video camera. The Naos sensor measured 3D location, 3D speed, 3D acceleration and 3D angular velocity using a GNSS sensor at 10 Hz, an IMU at 208 Hz and a barometer at 12.5 Hz data rate. The video camera recorded at 180 Hz (shutter speed: between 1/1300 and 1/2000; FHD: 1920 x 1080) from a location where the whole shooting range was visible. The wearable system detected all events that were obtained from the camera footage. In both shooting postures, differences between temporal parameters derived from the wearable system and camera footage were generally small. In prone shooting, minor significant differences were observed in approaching (-0.43 ± 0.37s), shot interval (-0.003 ± 0.006 s), total shooting (-0.01 ± 0.02 s), mat off (-0.09 ± 0.17 s), leaving (0.44 ± 0.33 s), range (-0.11 ± 0.18 s) and mat (-0.10 ± 0.29 s) times (all $p < 0.01$). No difference was observed in preparing time (0.00 ± 0.25 s). In standing shooting, minor significant differences were observed in preparing (-0.20 ± 0.28 s), shot intervals (-0.007 ± 0.012 s), total shooting (-0.03 ± 0.04 s), mat off (0.07 ± 0.18 s), leaving (0.19 ± 0.29 s) and mat (-0.16 ± 0.30 s) times (all $p < 0.01$). Differences in approaching (-0.08 ± 0.36 s) and range (-0.03 ± 0.19 s) times were not significant. Good to excellent levels of agreement (ICC from 0.71 to 1.00) and strong relationships (r_s from 0.87 to 1.00, all $p < 0.001$) between the methods were observed for all temporal biathlon range work characteristics. The main finding was that the wearable system was able to detect approaching time, preparing time, shot intervals, total shooting time, mat off time, leaving time, range time and mat time with reasonable accuracy as compared to the corresponding video-derived time instants. The system can be used to collect temporal biathlon range work characteristics for coaching and research purposes with reasonable accuracy.

Keywords**:** *wearables, feedback, coaching, shooting, performance analysis*

SUMMARY

Overall performance in biathlon is determined by skiing speed, time spent on the shooting range and number of missed targets. However, thorough elite level competition analyses looking at speed variations, cycle characteristics, sub-techniques used, and detailed temporal range work information are thus far lacking. Typically, coaches measure temporal biathlon range characteristics in training sessions using a stopwatch. In competitions, some temporal range work characteristics are automatically measured by the competition timing system, whereas others are added manually by the competition staff.

Recent technological advances could enable such analyses automatically with high precision and without interrupting the athlete. Previous studies among skiing sports have showed that a GNSS together with IMU sensors seem to be able to detect sport-specific events, distinguish between sub-techniques, provide cycle characteristics and within-cycle changes in speed reasonably well. However, some metrics may not be precise, especially those related to the absolute location of the athlete, highlighting the need for sport-specific validations. Therefore, the aim of the present study was to examine the validity of a commercial wearable wireless GNSS-IMU system in automated temporal biathlon range work analysis.

A total of twelve biathletes (age 21 ± 4 years old) volunteered for the study and performed a typical biathlon range work training session using their own rifles and skiing equipment. Each biathlete skied twelve laps around the shooting range and performed six times a 5-shot set of biathlon shooting from the prone and the standing postures.

All data were simultaneously collected using a wearable Naos sensor (Archinisis, Switzerland) placed inside a vest on the biathlete's upper back and a high-speed video camera (LUMIX DC-GH5, Panasonic Corporation, Japan). The Naos sensor measured 3D location, 3D speed, 3D acceleration and 3D angular velocity using a GNSS sensor at 10 Hz, an IMU at 208 Hz and a barometer at 12.5 Hz data rate. The video camera recorded at 180 Hz (shutter speed: between 1/1300 and 1/2000; FHD: 1920 x 1080) from a location where the whole shooting range was visible.

The concurrent validity of the range variables obtained from the wearable system were evaluated by using corresponding variables obtained from the high-speed camera as the comparison. The Wilcoxon signed rank-test (mean bias), mean absolute error (MAE), root mean squared coefficient of variation percentage ($CV\%_{RMS}$), the two-tailed Spearman correlation (r_s) and intra-class correlation coefficient (calculated for absolute agreement, ICC) were analyzed.

The wearable system detected all events that were obtained from the camera footage. In both shooting postures, differences between temporal parameters derived from the wearable system and camera footage were minor. In prone shooting, significant differences were observed in approaching (mean bias -0.43 ± 0.37; MAE 0.47 ± 0.31 s; $CV\%_{RMS}$ 4.1), shot interval (-0.003 ± 0.006 s; 0.006 ± 0.004 s; 0.1), total shooting (-0.01 ± 0.02 s; 0.02 ± 0.01 s; 0.1), mat off (-0.09 ± 0.17 s; 0.14 ± 0.13 s; 2.5), leaving (0.44 ± 0.33 s; 0.46 ± 0.31 s; 3.7), range (-0.11 ± 0.18 s; 0.17 ± 0.12 s; 0.2) and mat (-0.10 ± 0.29 s; 0.24 0.20 s; 0.5) times (all $p < 0.01$). No difference was observed in preparing time (0.00 ± 0.25 s; 0.19 ± 0.17 s; 0.9). In standing shooting, significant differences were observed in preparing (-0.20 ± 0.28 s; 0.29 ± 0.19 s; 1.4), shot intervals (-0.007 ± 0.012 s; 0.009 ± 0.010 s; 0.3), total shooting (-0.03 ± 0.04 s; 0.03 ± 0.04 s; 0.2), mat off (0.07 ± 0.18 s; 0.15 ± 0.11 s; 2.9), leaving (0.19 ± 0.29 s; 0.29 ± 0.18 s; 2.4) and mat (-0.16 ± 0.30 s; 0.28 ± 0.20 s; 0.7) times (all $p < 0.01$). Differences in approaching (-0.08 ± 0.36 s; 0.27 ± 0.26 s; 2.9) and range (-0.03 ± 0.19 s; 0.15 ± 0.11 s; 0.2) times were not significant.

Good to excellent levels of agreement (ICC from 0.71 to 1.00) and strong relationships (r_s from 0.87 to 1.00, all $p < 0.001$) between the methods were observed for all temporal biathlon range work characteristics.

The main finding was that the wearable system was able to detect approaching time, preparing time, shot intervals, total shooting time, mat off time, leaving time, range time and mat time with reasonable accuracy as compared to the corresponding video-derived time instants. The greatest differences were observed in approaching and leaving times. These could be related to absolute position errors which have been also observed in previous studies. However, the observed mean absolute errors of less than 0.5 seconds in approaching and leaving times are well acceptable in biathlon training. Bland-Altman plots revealed that in standing shooting, some shot intervals derived from the wearable system deviated considerably more than most form the video-derived shot intervals. It is possible that obtaining shots from the camera footage using the time instants when smoke came out from the rifle barrel after triggering caused some inaccuracy in shot times. However, from the coaching point of view, even though these least accurate shot intervals would be caused by an inaccurate detection by the wearable sensor, the precision is within an acceptable range.

As the wearable system was observed to be valid, it can be used in the future to collect data on biathletes' race and training performance. The system provides useful information for the athletes about their range work and helps coaches by collecting and storing the data automatically. The information can be used to guide training prescription and follow progress. It also allows for collecting a high amount of research data on biathletes' race and training performance, which could help researchers to catch up with the sport enabling protocols with high ecological validity in real training and competition environment. Further, as IMU sensors have demonstrated promising results in postural sway assessment, development of new algorithms could make it possible to use the same system e.g. for postural sway measurements during competitions without interrupting the biathlete.

INTRODUCTION

Biathlon is an Olympic winter sport combining cross-country skiing and rifle shooting, where overall performance is determined by skiing speed, shooting performance, and shooting time. A biathlon competition consists of periods of high intensity skiing separated by short recovery intervals (two or four times during the competition depending on the competition type) during which shooting is performed in the prone or standing position. (IBU 2021). Shooting is performed with small-bore rifles, with targets 50 m away from the shooting lane where the diameter of the hit area for prone and standing shooting targets is 4.5 cm and 11.5 cm, respectively. During each shooting bout in individual competitions, five shots are fired at the targets.

Overall performance in biathlon is determined by skiing speed, time spent on the shooting range and number of missed targets (Björklund et al., 2022; Björklund & Laaksonen, 2022; Luchsinger et al., 2018, 2019, 2020). In the sprint competition, skiing time explains approximately 60% and shooting performance almost 40% of the performance difference between those finishing in the top-10 and those finishing among ranks 21-30 (Luchsinger et al., 2018). In the individual competition the corresponding numbers are 50% and 50% for both, probably caused by the greater penalty for each missed shot (Luchsinger et al., 2019). The influence of shooting performance is high also in the pursuit competition, where it explains approximately 40-50% of the race performance, increasing up to 60-70% when excluding start time determined by the preceding sprint race (Luchsinger et al., 2020). Accordingly, skiing speed is important for final performance in biathlon, but better shooting performance discriminates the podium rank biathletes from their lower ranked counterparts(Björklund et al., 2022; Björklund & Laaksonen, 2022).

Demands for a high-level endurance capacity are similar to that in cross-country skiing (Tønnessen et al., 2015), in which males can reach values of 80 – 90 mL/kg/min (Holmberg et al., 2007; Sandbakk & Holmberg, 2014; Tønnessen et al., 2015) and females exhibit 10 – 15 % lower values (Sandbakk et al., 2014, 2016; Tønnessen et al., 2015). By using skate skiing techniques which are used in biathlon, elite cross-country skiers can attain VO2 values very close to their VO2max (Losnegard et al., 2013). Moreover, economy has been considered even as the most discriminating factor between elite and national level athletes (Sandbakk et al., 2010). Considerably increased average speeds in biathlon races has led to similar development as in cross-country skiing, placing more demands on anaerobic capacity and power along with function of the neuromuscular system, especially in the upper body (Sandbakk & Holmberg, 2014).

Biathlon shooting has been extensively studied from the shooting technical perspective. In the prone shooting position, the biathlete has three support points, both elbows and the lower body. In the study by Sattlecker et al. (2017), vertical rifle sway was observed to be related to shooting performance. Recent findings also suggest that in addition to stability of hold, also aiming accuracy, cleanness of triggering and timing of triggering play an important role in biathlon prone shooting (Köykkä et al., 2022). Furthermore, high pre-shot trigger force values and a flat trigger force curve inclination during triggering has been observed to increase rifle stability (Köykkä et al., 2022; Sattlecker et al., 2017). In the standing position, the base of support forms between the feet. The smaller base of support area and higher center of gravity location of the body-rifle combination in the standing position makes controlling the sway considerably more difficult compared to the prone position. In the standing shooting position, stability of hold (Ihalainen et al., 2018; Sattlecker et al., 2014, 2017) and cleanness of triggering (Ihalainen et al., 2018) have been observed to be related to shooting performance. A recent study also suggested that biathletes might use different aiming strategies, hold and timing, and that the strategy used would affect performance-related factors (Köykkä et al., 2021). Regarding postural control, both antero-posterior (perpendicular to shooting line) (Sattlecker et al., 2017) and medio-lateral (parallel to shooting line) (Ihalainen et al., 2018) sway have been observed to have a negative effect on standing shooting performance. Postural control has an indirect effect on shooting performance as well, as it has been shown to be related to variables relating to movements of the aiming point (Ihalainen et al., 2018). Further, when compared to their younger counterparts, national top-level biathletes have demonstrated better shooting performance (Ihalainen et al., 2018; Sattlecker et al., 2014), postural balance (Ihalainen et al., 2018) and stability of hold (Sattlecker et al., 2014).

Pacing strategies in biathlon competitions have been investigated recently. In the sprint (Luchsinger et al., 2018), individual (Luchsinger et al., 2019) and pursuit (Björklund et al., 2022) competitions biathletes tend to have fastest skiing speed on their first lap, slow down for successive loops, and increase the speed again for the final lap. In contrast, the mass start competition seems to begin with a slow lap and the second lap is the fastest (Björklund et al., 2022). However, thorough elite level competition analyses looking at speed variations, cycle characteristics, sub-techniques used, and detailed range work information are thus far lacking.

Typically, coaches measure temporal biathlon range characteristics in training sessions using a stopwatch. In competitions, some temporal range work characteristics are automatically measured by the competition timing system, whereas others are added manually competition staff. Recent technological advances could enable such analyses automatically with high precision and without interrupting the athlete. Previous studies among skiing sports have showed that a GNSS together with IMU sensors seem to be able to detect sport-specific events, distinguish between sub-techniques, provide cycle characteristics and within-cycle changes in speed reasonably well (Jølstad et al., 2021; Neuwirth et al., 2020; Rindal et al., 2017; Stöggl et al., 2014; Takeda et al., 2019). However, some metrics may not be precise, especially those related to the absolute location of the athlete (Jølstad et al., 2021), highlighting the need for sport-specific validations. Therefore, the aim of the present study was to examine the validity of a commercial wearable wireless GNSS-IMU system in automated temporal biathlon range work analysis.

MATERIALS AND METHODS

Participants

A total of 12 biathletes (age 21 ± 4 years old) volunteered for the study. Before participating in the measurements, all subjects gave their written informed consent, after being informed of the purpose, nature and potential risks of the study. The study was conducted according to the declaration of Helsinki.

Experimental task

Each biathlete performed a typical biathlon range work training session using their own rifles and skiing equipment. The session consisted of skiing 12 laps around the shooting range, carrying the rifle. A 5-shot series of biathlon shooting was performed during each lap, six times from the prone and the standing position. In one prone and one standing trial, the biathlete only shot four shots due to a reloading mistake and not having spare rounds available. The biathletes were instructed to perform as they would do in a competition.

Data collection

All data were simultaneously collected using a wearable Naos sensor (Archinisis, Switzerland) placed inside a vest on the biathlete's upper back and a high-speed video camera (LUMIX DC-GH5, Panasonic Corporation, Japan). The sensor (weight 78 grams; dimensions 81 x 53 x 17 mm) measures 3D location, 3D speed, 3D acceleration and 3D angular velocity using a GNSS sensor at 10 Hz, an IMU at 208 Hz and a barometer at 12.5 Hz data rate, and featured the u-blox M10 prototype GNSS chip limited to three satellite constellations and a maximum of 16 satellites. The IMU possesses a dynamic measurement range of ± 16 g for the accelerometer and ± 2000 degrees/second for the gyroscope. Fifteen minutes prior to the mounting of the wearable sensor on the athlete's back, it was turned on and placed outside in an open environment to allow for finding satellite signals. The video camera recorded at 180 Hz (shutter speed: between 1/1300 and 1/2000; FHD: 1920 x 1080) from a location where the whole shooting range was visible. An overall schematic of the measurement set-up used has been illustrated in Figure 1.

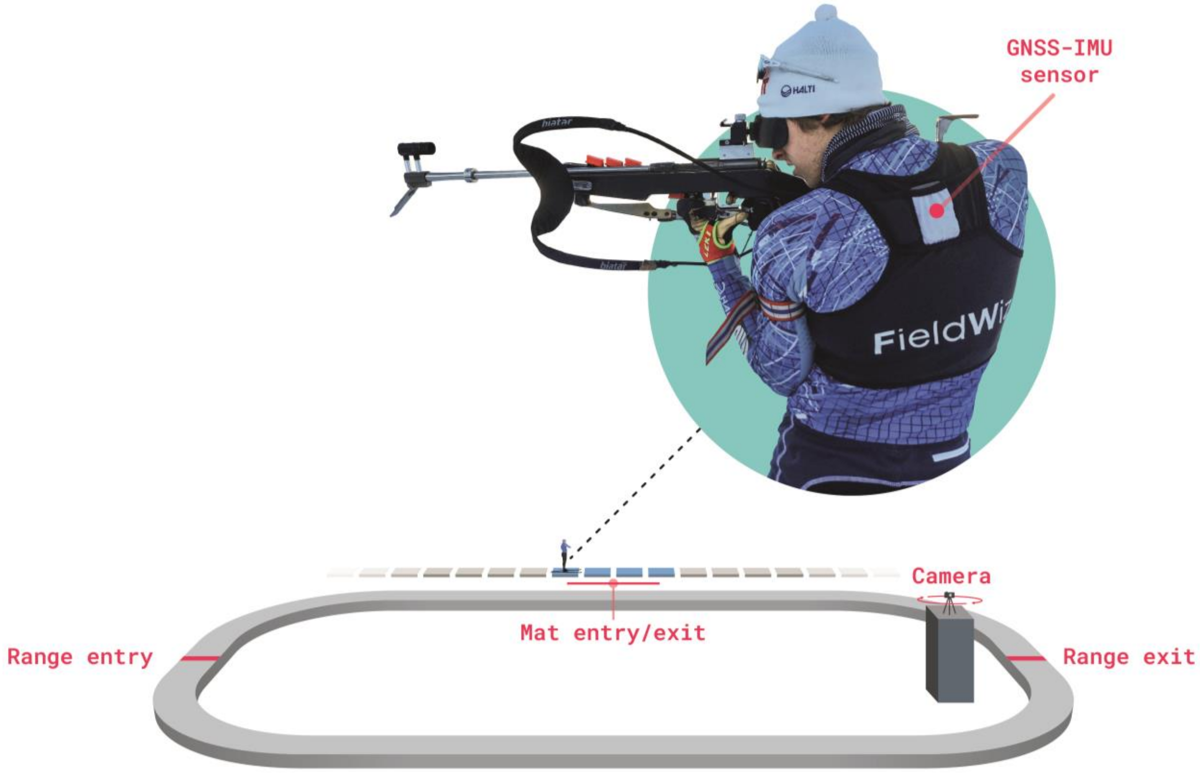

Figure 1. An overall schematic of the measurement set-up and the skiing route around the shooting range.

Multiple shooting range related variables were analyzed using the commercial cloud-based web software (Archinisis, Switzerland) as well as from camera footage (Table 1). For the wearable system, range entry and exit location were determined manually by the Archinisis team based on satellite images and with the help of a calibration measurement. For the calibration measurement, a researcher walked five times along the desired range entry and exit lines holding one wearable sensor horizontally in his hand (Figure 2). The corresponding lines were marked on the ground so that they were visible in the camera footage. The time instants when the biathlete's leading ankle crossed the line at range entry and exit were used as range entry and exit times obtained from the camera footage. A line was also marked on the ground 20 cm in front of the shooting mat. For mat entry, the time instant when the biathlete’s leading ankle crossed the line was used. For mat exit, the time instant when the trailing ankle crossed the line was used. Shots were detected as the time instants when smoke came out from the rifle barrel after triggering. Video brightness and contrast were modified when necessary to make the event more clearly perceivable.

Table 1. Variable descriptions.

Variable	Description
Approaching	Time elapsed between range entry and mat entry
Preparing	Time elapsed between mat entry and the 1st shot
Shot interval	Time elapsed between consecutive shots
Total shooting	Time elapsed between the 1st and last shot
Mat off	Time elapsed between the last shot and mat exit
Leaving	Time elapsed between mat exit and range exit
Range time	Time elapsed between range entry and range exit
Mat time	Time elapsed between mat entry and mat exit

Figure 2. The satellite image that was used by the Archinisis team to define range entry and exit lines for the wearable system based on the calibration recording.

Statistical analysis

Eight prone and six standing shot intervals were excluded from the analyses because the shot moments were not detectable from the camera footage. In two prone trials and one standing trial, the first and last shots were excluded, and therefore it was not possible to calculate preparing time, total shooting time and mat off time. In one standing trial, the video file was corrupted starting right after the biathlete had crossed the mat entry line, leading to missing leaving time, total shooting time, mat off time, mat time, range time and four shot intervals. The resulting sample sizes are reported in Table 2.

Data from all subjects and from all trials were pooled and analyzed separately for the prone and standing postures. All data are reported as mean ± standard deviation where applicable. As the Shapiro-Wilk test revealed that all variables violated the normality assumption in both systems, nonparametric tests were used where necessary.

The concurrent validity of the range variables obtained from the wearable system were evaluated by using corresponding variables obtained from the high-speed camera as the comparison. To assess differences between the results derived from the wearable system and from videos, mean bias was evaluated with the Wilcoxon signed rank-test and 95 % limits of agreement and mean absolute error (MAE) and root mean squared coefficient of variation percentage ($CV\%_{RMS}$) were analyzed.

Relationships between the methods were examined using the two-tailed Spearman correlation (r_s) and intra-class correlation coefficient (calculated for absolute agreement, ICC). ICCs were used to indicate the agreement, with values of <0.40, 0.40 to <0.60, 0.60 to <0.75, and ≥ 0.75 representing the qualitative thresholds for poor, fair, good, and excellent levels of agreement, respectively (Cicchetti, 1994). Further, Bland-Altman plots (Bland & Altman, 1986) were used to visualize the agreement between the methods.

Statistical significance was set at $p < 0.05$. Statistical analyses were conducted with IBM SPSS Statistics 26.0 software (IBM Corp., Armonk, NY, USA) and R version 4.1.2 (https://www.R-project.org/).

RESULTS

The wearable system detected all events that were obtained from the camera footage. In prone shooting, minor significant differences were observed in approaching (-0.43 ± 0.37 s), shot interval (-0.003 ± 0.006 s), total shooting (-0.01 ± 0.02 s), mat off (-0.13 ± 0.17 s), leaving (0.44 ± 0.33 s), range (-0.11 ± 0.18 s) and mat (-0.10 ± 0.29 s) times (all $p < 0.01$). In standing shooting, minor significant differences were observed in preparing (-0.20 ± 0.28 s), shot intervals (-0.007 ± 0.012 s), total shooting (-0.03 ± 0.04 s), mat off (0.07 ± 0.18 s), leaving (0.19 ± 0.29 s) and mat (-0.16 ± 0.30 s) times (all $p < 0.01$). Good to excellent levels of agreement (ICC from 0.71 to 1.00) and strong relationships (r_s from 0.87 to 1.00, all $p < 0.001$) between the methods were observed for all temporal biathlon range work characteristics. (Table 2). High agreements between the methods are visualized in Figures 2 and 3.

DISCUSSION

The aim of the present study was to examine the validity of a wearable wireless GNSS-IMU system in automated temporal biathlon range work analysis. The main finding was that the wearable system was able to detect approaching time, preparing time, shot intervals, total shooting time, mat off time, leaving time, range time and mat time with high accuracy as compared to the corresponding video-derived time instants.

These findings are in line with previous studies. In classical style cross-country skiing, a high-precision kinematic GNSS was observed to precisely detect the type of sub-technique, skiing cycle characteristics, skiing duration and speed, and distance covered at all parts of a track (Takeda et al., 2019). In alpine skiing, a classifier based on GNSS and IMU data was able to detect different ski turn styles with a high precision (Neuwirth et al., 2020). Another study on alpine skiing suggested that some sport-specific metrics given by a GNSS-IMU system

(AdMos) are valid, such as the number of turns per run, and can be trusted per se, whereas some can be useful after averaging over a certain time period (Jølstad et al., 2021).

The wearable system detected shots with a good precision resulting in accurate shot intervals and total shooting time (Table 2). The mean bias and mean absolute errors were approximately the duration of one video frame (1/180 s). However, Bland-Altman plots revealed that in standing shooting, some shots deviated considerably more than others from the mean ± 1.96 standard deviation range (Figure 3). It is possible that obtaining shots from the camera footage using the time instants when smoke came out from the rifle barrel after triggering caused some inaccuracy in shot times. However, video frame rate and shutter speed did not allow for detecting the bullet coming out from the rifle barrel in most shots. Further, as only one camera was used to record all events, the distance between the cameraman and the biathlete was too high to allow for detecting the trigger pull or recoil events unambiguously. From the coaching point of view, even though these least accurate shot intervals would be caused by an inaccurate detection by the wearable sensor, the precision is well within an acceptable range.

Approach and leaving times demonstrated weakest agreements between the methods (Table 2). The results might suggest that the errors may be related to imprecisions in detecting the exact moment when the biathlete crosses a certain line, i.e. an absolute position error. The exact algorithms behind the variables are not available, but certain characteristics may support this. When approaching to shoot from the prone posture, the biathlete stops moving close to the mat entry line (Figure 1) and goes down on one's knees to start building the prone posture. Similarly, after the shooting the biathlete first gets up and then starts skiing again. A previous study in cross-country skiing showed that even a GNSS sensor only can detect vertical oscillations of the head during classical style skiing, along with changes in skiing speed (Takeda et al., 2019). These events could allow for detecting mat entry and exit in prone shooting by looking only vertical oscillations and changes in speed of the sensor. In standing shooting, the biathlete stops close to the centre of the shooting mat to start shooting, allowing for the algorithm to look at changes in speed. When crossing range entry and exit lines, only position data could be used. The errors observed in approaching and leaving also seem to cancel each other out. As range time was exact for both shooting postures, it could be suggested that the sensor possesses an absolute position error, which is equal in size but opposite direction at both ends of the shooting range.

These errors are comparable to the position errors observed in previous studies using similar GNSS sensors (Gløersen et al., 2018; Jølstad et al., 2021), and could also be related to the calibration procedure to determine the range entry and exit positions. The calibration measurement was performed on a different day than the actual trials, which may have caused some proportion of these errors. To study within and between session variations in the global position accuracy of the sensor, a future study could repeat the measurement protocol and perform the calibration measurement at the beginning and end of each measurement day. However, the observed mean absolute errors of less than 0.5 seconds are well acceptable in biathlon training. Hence, it can be concluded that in practice, the calibration procedure that was used provides a satisfactory accuracy.

Furthermore, a limitation of the study is that the sensor was placed on the biathletes' upper back, whereas the time instants when the biathlete crossed range and shooting mat entry and exit positions was determined from the ankles. However, this was considered acceptable as the time difference between the upper back and ankle crossing certain lines was small and it was easier to estimate the ankle's horizontal position in reference to the entry or exit line.

As the wearable system was observed to be valid, it can be used in the future to collect data on biathletes' race and training performance. The system provides useful information for the athletes about their range work and helps coaches by collecting and storing the data automatically. The information can be used to guide training prescription and follow progress. It also allows for collecting a high amount of research data on biathletes' race and training performance, which could help researchers to catch up with the sport enabling protocols with high ecological validity in real training and competition environment. Further, as IMU sensors have demonstrated promising results in postural sway assessment (Ghislieri et al., 2019), development of new algorithms could make it possible to use the same system e.g. for postural sway measurements during competitions without interrupting the biathlete.

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Table 2. Comparison between the temporal mean ± SD pooled video-based and wearable-based biathlon range work characteristics.

Prone	**n**	**Video-based [s]**	**Wearable-based [s]**	**Bias (95 % CI) [s]**	**MAE [s]**	**ICC (95 % CI)**	**$CV\%_{RMS}$**	**r_s**
Approaching	72	9.46 ± 0.97	9.88 ± 0.97	-0.43 (-0.51 to -0.34)***	0.47 ± 0.31	0.84 (0.80 to 0.87)	4.1	0.92***
Preparing	70	20.18 ± 3.82	20.18 ± 3.87	0.00 (-0.06 to 0.07)	0.19 ± 0.17	1.00 (1.00 to 1.00)	0.9	1.00***
Shot interval	279	4.33 ± 1.57	4.33 ± 1.57	-0.003 (-0.004 to -0.003)***	0.006 ± 0.004	1.00 (1.00 to 1.00)	0.1	1.00***
Total shooting	70	17.25 ± 5.06	17.26 ± 5.07	-0.01 (-0.02 to -0.01)***	0.02 ± 0.01	1.00 (1.00 to 1.00)	0.1	1.00***
Mat off	70	5.46 ± 1.00	5.55 ± 0.98	-0.09 (-0.13 to -0.04)***	0.14 ± 0.13	0.98 (0.98 to 0.99)	2.5	0.98***
Leaving	72	10.57 ± 0.67	10.13 ± 0.69	0.44 (0.36 to 0.52)***	0.46 ± 0.31	0.71 (0.64 to 0.76)	3.7	0.88***
Range time	72	62.59 ± 8.30	62.69 ± 8.32	-0.11 (-0.15 to -0.06)***	0.17 ± 0.12	1.00 (1.00 to 1.00)	0.2	1.00***
Mat time	72	42.56 ± 8.25	42.66 ± 8.31	-0.10 (-0.17 to -0.03)**	0.24 ± 0.20	1.00 (1.00 to 1.00)	0.5	1.00***
Standing								
Approaching	72	9.12 ± 0.90	9.20 ± 0.79	-0.08 (-0.16 to 0.01)	0.27 ± 0.26	0.91 (0.88 to 0.92)	2.9	0.87***
Preparing	70	16.93 ± 2.83	17.13 ± 2.83	-0.20 (-0.27 to -0.14)***	0.29 ± 0.19	0.99 (0.99 to 0.99)	1.4	1.00***
Shot interval	279	3.50 ± 1.81	3.51 ± 1.81	-0.007 (-0.008 to -0.006)***	0.009 ± 0.010	1.00 (1.00 to 1.00)	0.3	1.00***
Total shooting	70	14.00 ± 4.12	14.03 ± 4.12	-0.03 (-0.04 to -0.02)***	0.03 ± 0.04	1.00 (1.00 to 1.00)	0.2	1.00***
Mat off	70	4.58 ± 0.87	4.51 ± 0.85	0.07 (0.02 to 0.11)**	0.15 ± 0.11	0.98 (0.97 to 0.98)	2.9	0.98***
Leaving	71	10.21 ± 0.58	10.02 ± 0.64	0.19 (0.12 to 0.26)***	0.29 ± 0.18	0.84 (0.81 to 0.87)	2.4	0.87***
Range time	71	54.74 ± 5.96	54.78 ± 5.93	-0.03 (-0.08 to 0.01)	0.15 ± 0.11	1.00 (1.00 to 1.00)	0.2	1.00***
Mat time	71	35.42 ± 5.86	35.58 ± 5.88	-0.16 (-0.23 to -0.09)***	0.28 ± 0.20	1.00 (1.00 to 1.00)	0.7	1.00***

CI = confidence interval, MAE = mean absolute error, ICC = intra-class correlation coefficient calculated for absolute agreement, $CV\%_{RMS}$ = root-mean-squared coefficient of variation percentage, *** = $p < 0.001$, ** = $p < 0.01$.

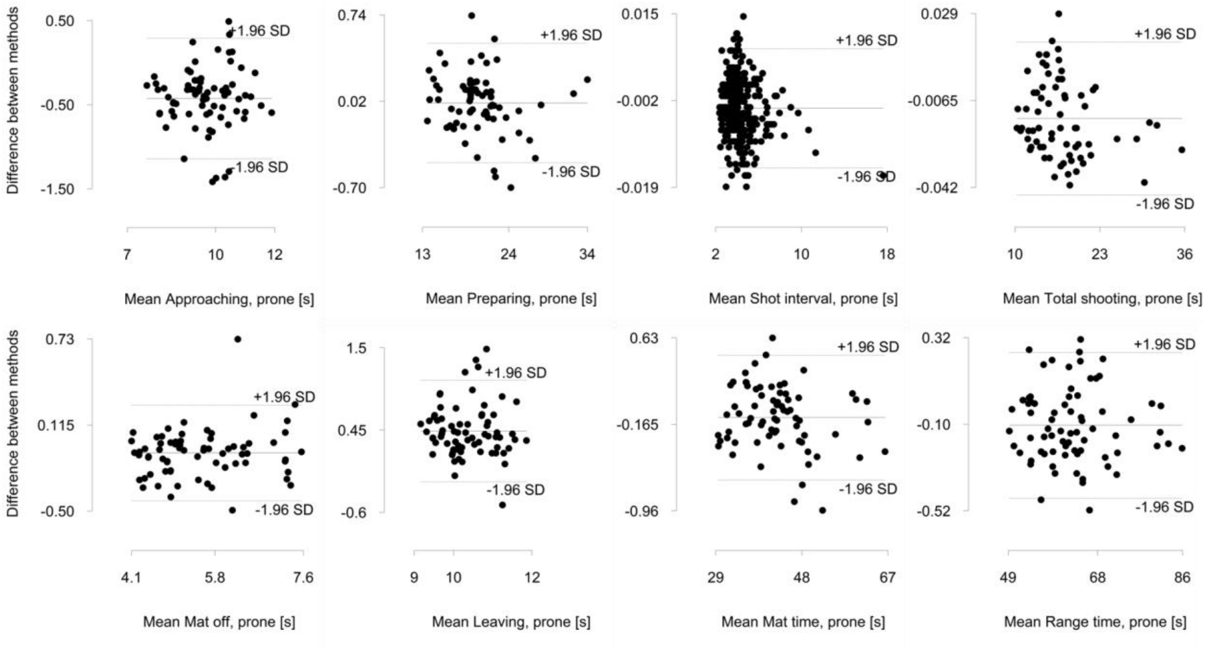

Figure 2. Bland-Altman plots representing the mean bias and limits of agreement (± 1.96 × SD of differences) between the video-based and wearable-based temporal biathlon range work characteristics in prone shooting.

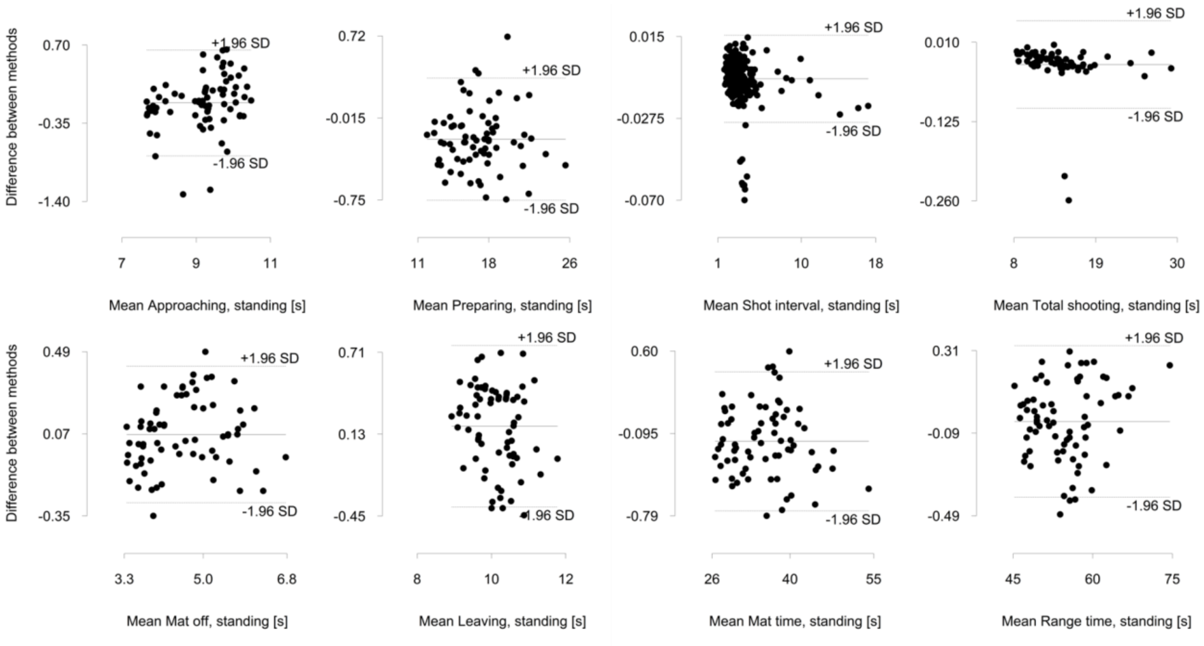

Figure 3. Bland-Altman plots representing the mean bias and limits of agreement (± 1.96 × SD of differences) between the video-based and wearable-based temporal biathlon range work characteristics in standing shooting.