The application and utility of wearable sensors for athlete monitoring in biathlon

Mid Sweden University

Dr Craig Staunton

Dr Glenn Björklund

Dr Mikael Swaren

Mr Andreas Kårström

Dr Marko Laaksonen

Final Report

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Abstract

Background: Training compliance refers to an athlete's conformity to a coach's planned training programme. Imperfect training compliance (i.e., discrepancies between coach plan and athlete execution) could cause maladaptation to the training program and either under- or over-training (Wallace et al., 2009). This study will utilise objective measures of exercise such as GNSS sensors, accelerometers and HR monitoring measured from wearable technologies advancing the understanding of the application and utility of wearable sensor technology for athlete monitoring in biathlon, with a particular focus on training compliance.

Methods: Over a 5-week training block, 10 elite youth biathletes wore GNSS sensors with integrated accelerometers and HR monitors during all training sessions in order to determine the agreement between the coach's planned training and the athletes performed training. The coaches' planned training sessions were collected through an online training platform (Maxpulse). This information included a prescription of duration within a five-zone heart rate -based exercise intensity zones in addition with the total prescribed training time. In addition, the total time athletes spent in various speed zones was determined from GNSS sensors. High speed skiing (Speed3+) was calculated as the accumulation of all speeds from speed zone 3 and above ≥ 4 $m \cdot s^{-1}$. Finally, PlayerLoad™ (PL) and PL per minute (PL/min) were calculated from the integrated accelerometer within the wearable GNSS device.

Results: The total executed training duration was, on average 7 ± 21 minutes under the planned training. More specifically, during training sessions performed with rifle, the total executed training duration was 9 ± 18 minutes under the planned training. During training sessions performed without rifle, the total executed training duration was 3 ± 26 minutes under the planned training. The total executed training duration for LIT was 8 ± 21 minutes under the planned training. This corresponded with an average of 92% training compliance for session duration. The total executed training duration for HIT was 6 ± 19 minutes under the planned training. This corresponded with an average of 94% training compliance for session duration. Training time spent performing very-slow speed movements (<1m/s) was influenced by training session type (LIT/HIT or Rifle/no-Rifle). On average, across all training sessions 20 ± 9 minutes of training duration was spent performing very-slow speed movements. Of particular interest was LIT sessions performed without the rifle. These training sessions were designed to be long, continuous low-intensity training sessions. Despite this, these sessions were still associated with an average of 17.5 ± 8.1 minutes of very-slow speed movements. Finally, there were very large positive correlations between PL and training duration ($r = 0.802$, $p < 0.001$). In addition, large positive relationships were shown between PL/min and speed3+ ($r = 0.512$, $p < 0.001$) indicating that PL/min might have convergent validity as a surrogate for training intensity during a biathlon training programme.

Conclusions and Practical Recommendations: These analyses firstly identify the utility and application of wearable technology for athlete monitoring in biathlon. All athletes wore these wearable sensors without impact to training sessions. Further, this study has evaluated the application and utility of wearable sensors for athlete monitoring in a biathlon training programme through the investigation of training compliance. The results demonstrate that the coaches' training plan impacts the degree of compliance. Equipped with this knowledge, coaches are empowered to better predict and understand the actual training dose performed by athletes and how this might impact on training adaptations and performance. Wearable GNSS sensors, coupled with accelerometers and HR monitoring provides objective data to coaches and athletes with convergent validity. In particular, this study had demonstrated the application of and utility of utilising GNSS sensors to investigate low-speed movements as well as accelerometer-based metrics, such as PL, for providing further insights into the exercise dose throughout a biathlon training programme.

Keywords: Accelerometers**,** biathlon**,** GNSS, heart rate, training compliance, wearable sensors

Project Scope

The original aims of this project were to establish the application and utility of wearable sensors for athlete monitoring in biathlon. The original plan was to collect two sets of data from two-weeks of training on bare-ground and two-weeks of training on-snow, within elite youth biathletes. Specifically, we aimed to:

1) Establish if wearable sensors are applicable to athlete monitoring in biathlon. Is it practical and cost efficient for biathlon athletes and coaches?
2) Determine the validity and reliability of these devices for athlete monitoring in biathlon.
3) Determine the utility for these sensors to inform training and competition practice.
4) Determine if wearable sensors can detect mechanical differences between various phases of training throughout the competition period (i.e, off-season vs. in-season training).

Due to logistical problems with access to the wearable sensor technology, the project was modified from the original plan. The modified project has instead collected 5-weeks of training data during on-snow skiing only.

Accordingly, the aims of the project have shifted from the original plan. Nevertheless, the modified project has, in fact, collected more data than originally planned and still provides useful information related to the application and utility of wearable sensor technology for athlete monitoring in biathlon.

Introduction

Training compliance refers to an athlete's conformity to a coach's prescribed training programme. Imperfect training compliance (i.e., discrepancies between coach prescription and athlete execution) could cause maladaptation to the training program and either under- or over-training.[1]

A multitude of previous research has identified imperfect training compliance, predominately in team sports. For example, differences between the coaches' intended perception of effort and the athletes' actual perceptions of effort are widely acknowledged.[2-7] Previous research has identified that different intensities and/or different training drills can influence the mismatch between perceptions of effort.[1,4,5] For example, volleyball coaches underestimated the perceived exertion of players, particularly during high-intensity physical conditioning drills.[5] However, the volume of technical–tactical drills prescribed with moderate-intensity closely matched the executed exercise dose.[5] Additionally, during basketball a pre-season training block,[8] the coach underestimated the exercise intensity and volume of training drills intended to be a lighter intensity.

A limitation common to these studies is the use of subjective ratings of perceived exertion (RPE) to determine the exercise dose executed by athletes. RPE includes components of emotion, which can influence the score reported during physical effort.[9] Objective measurement is required to remove the emotional component of perceived exertion in order to isolate the actual exercise dose executed by athletes. Consequently, objectively determined exercise dose, using technology such as global navigation satellite system (GNSS) devices, accelerometers and/or heart rate (HR) monitors are commonly used to explain the potential mediating influences related to training compliance.

Unfortunately, another limitation of these studies is that the majority have been conducted in team sport athletes, with lesser attention paid to individual endurance sports, such as biathlon. Accordingly, little is understood about training compliance in these individual endurance sports. Biathlon is a unique sport that encompasses both cross-country skiing and precision shooting. Accordingly, biathletes must train for both the high energy demanding cross-country skiing component, but also the highly technical skill required for marksmanship.

Given the lack of understanding surrounding training compliance in biathlon, this study aims to examine relationships between the coaches' intended training and the athletes' executed training, within a biathlon training programme. In particular, this study will utilise objective measures of exercise such as GNSS sensors, accelerometers and HR monitoring measured from wearable technologies advancing the understanding of the application and utility of wearable sensor technology for athlete monitoring in biathlon.

Methods

Participants

Ten elite youth biathletes (6 females; 4 males) volunteered to participate in this study. All athletes were a part of a specialised biathlon youth academy school program and therefore classified as Tier 3 level athletes according to the sports participant classification framework.[10] The regional ethical review board in (The regional ethical review board in Umeå, Sweden (registration number: 2016-506- 31M) preapproved the research techniques and experimental protocol. All participants provided written informed consent and agreed to participate in this study. All research was conducted in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

Design

Over a 5-week training block, athletes wore Global Navigation Satellite System (GNSS) sensors (10 Hz; Catapult Vector, Australia; Figure 1) with inbuilt triaxial accelerometers (100 Hz; Dynamic Range: ± 12 g) and HR monitors (H10, Polar, Finland) during all coach-led training sessions, in order to determine the agreement between the coach's planned training and the athletes executed training as well as examine the application and utility of wearable sensor technology for athlete monitoring in biathlon. In total, data from 13 training sessions were collected (range 5 – 13), with a total of 107 individual training session observations.

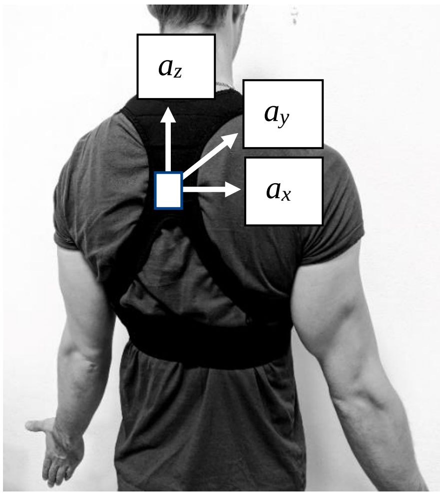

Figure 1. *Location of GNSS units worn by biathletes, which are integrated with a triaxial accelerometer. a_x = mediolateral accelerometer; a_y = anteroposterior accelerometer; a_z = vertical accelerometer.*

The coaches' plan for training sessions was collected through an online training platform (Maxpulse). This information included a plan of duration within a five-zone heart rate-based exercise intensity model used by the Swedish Biathlon Federation[11] (Table 1), in addition with the total planned training time.

Table 1. The five exercise intensity zones used by the Swedish Biathlon Federation

Zones	RPE	Typical HR (%max)	Blood lactate
A1	10-14	54-73	< 1.2
A2	14-16	74-83	1.3-2.0
A3-	16-18	84-88	2.1-3.6
A3	18-19	89-93	3.7-5.7
A3+	19-20	>94	>5.8

RPE = Rating of perceived exertion.

Data Analyses

GNSS, accelerometer and HR data were firstly edited to only include data from the start to the end of the training session. The HR data from each training session was subsequently extracted and the total time spent performing exercise within each training zone was calculated for each athlete. In addition, the total time athletes spent in various speed zones was determined from GNSS sensors (Table 2). High speed skiing (Speed3+) was calculated as the accumulation of all speeds from speed zone 3 and above.

Table 2. The five speed zones derived from GNSS devices.

Speed_0	Speed_1	Speed_2	Speed_3	Speed_4	Speed_5
0–1	1–2	2–4	4–6	6–8	>8

All data reported in metres per second.

Finally, PlayerLoad™ (PL), a manufacturer specific vector magnitude algorithm,[12,13] was determined from triaxial accelerations using the embedded accelerometer (Figure 1) according to Equation 1. In addition, PlayerLoad™ per minute (PL/min) was calculated from the accumulated PL divided by the total session duration. These metrics, originally intended to be used as indicators of the external training demands in team sports like rugby or football have more recently been extended to biathlon.[14]

$$\text{PlayerLoad}^{\text{TM}} = \sqrt{\left(a_{x_{t=i+1}} - a_{x_{t=i}}\right)^2 + \left(a_{y_{t=i+1}} - a_{y_{t=i}}\right)^2 + \left(a_{z_{t=i+1}} - a_{z_{t=i}}\right)^2}$$

Equation 1. Instantaneous PlayerLoad™ algorithm (developed by Catapult Sports™, Melbourne, Australia). *a_x = mediolateral accelerometer; a_y = anteroposterior accelerometer; a_z = vertical accelerometer.*[12]

Training sessions were divided into those performed without (0) or with (1) the biathlon rifle as well, as those planned as low-intensity training (LIT) or those planned with high-intensity training (HIT). LIT was defined as any training planned within zones A1 and A2. HIT was defined as any training session that involved any prescription with zones A3- or higher.

Statistical Analyses

Statistical analyses were performed using IBM SPSS Statistics (Version 27.0; IBM Corporation, NY). Group data were expressed as mean ± standard deviation (SD). Descriptive statistics were calculated to compare the coaches' training plan to the athletes' executed training. Agreement between the coaches' training plan to the athletes' executed training was assessed using methods described by Bland and Altman.[15] Pearson's correlation coefficient was used to determine the strength of relationships between PL and PL/min and other training metrics. Strength of relationships determined according to Hopkins.[16] Small correlations were 0.0–0.1; small correlations were 0.1–0.3; moderate correlations were 0.3–0.5; large correlations were 0.5–0.7; very large correlations were 0.7–0.9 and nearly perfect correlations were 0.9–1.0.

Results

Table 3 below displays the coaches' planned total training duration for the five-week training block, along with the planned duration within each of the five HR-based training zones. Planned training duration was 100 ± 24 mins (range 79 – 150 mins).

Table 3. Descriptive data from the five-week training block.

Rifle	LIT/HIT	Planned_Dur[min]	Plan_A1[min]	Plan_A2[min]	Plan_A3-[min]	Plan_A3[min]	Plan_A3+[min]
0	HIT	90 ± 0	60 ± 0	22.5 ± 13.9	0	7.50 ± 13.9	0
	LIT	136 ± 22	129 ± 36	1.15 ± 5.88	0	0	0
1	HIT	82.6 ± 4.7	60 ± 0	0	1.56 ± 2.95	11.0 ± 12.9	10 ± 10
	LIT	93.2 ± 6.3	81.9 ± 26.1	11.4 ± 23.8	0	0	0

Mean ± SD. Plan_1 = Planned duration zone 1; Plan_2 = Planned duration zone 2 etc. Rifle 0 = No rifle; Rifle 1 = With-rifle; LIT = Low-Intensity Training; HIT = High-intensity training.

The total performed training duration was, on average 7 ± 21 minutes under the planned training (95% LOA -48 to + 33 min). More specifically, during training sessions performed with rifle, the total performed training duration was 9 ± 18 minutes under the planned training. During training sessions performed without rifle, the total performed training duration was 3 ± 26 minutes under the planned training. Figure 1 below shows these values expressed as a proportion of the total planned training duration. On average, without rifle this 101%; With rifle this was 89%.

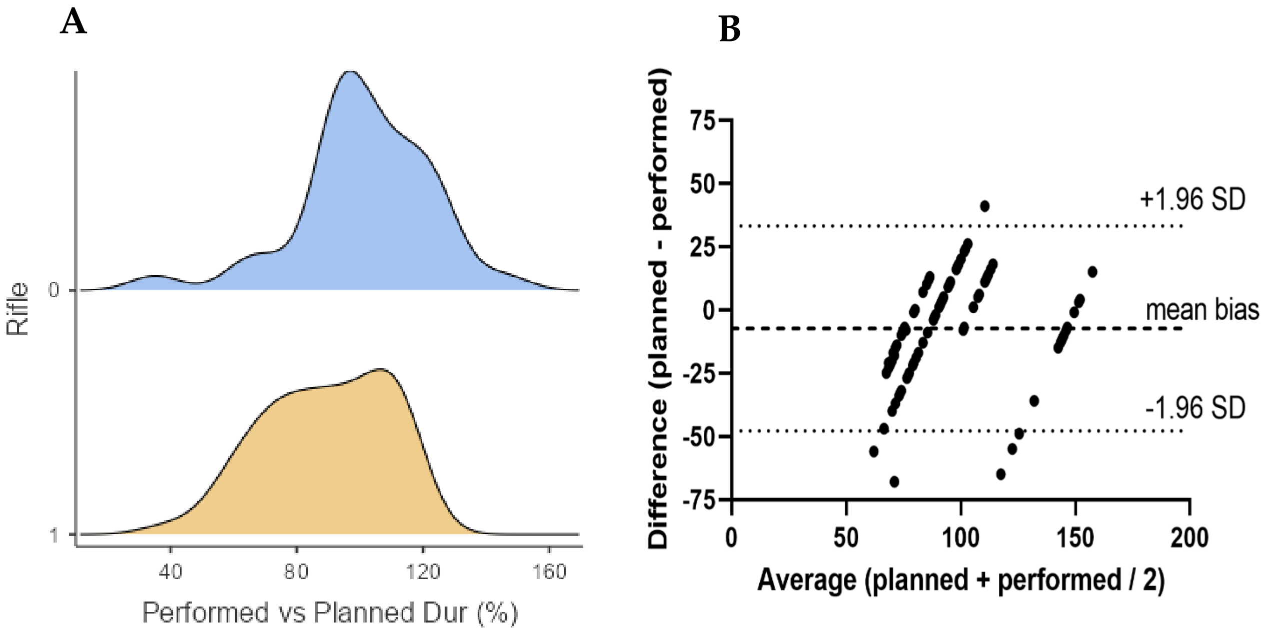

Figure 1: A) *Performed training duration as a proportion of planned training duration for training sessions without-rifle (0; blue) and with-rifle (1; beige);* **B)** *Bland and Altman plot displaying the mean bias with 95% limits of agreement between planned and performed training duration.*

Figure 2 below shows the executed training duration as a proportion of the planned training duration, separated by session intensity (LIT *vs.* HIT). The total executed training duration for LIT was 8 ± 21 minutes under the planned training. This corresponded with an average of 92% training compliance for session duration. The total executed training duration for HIT was 6 ± 19 minutes under the planned training. This corresponded with an average of 94% training compliance for session duration.

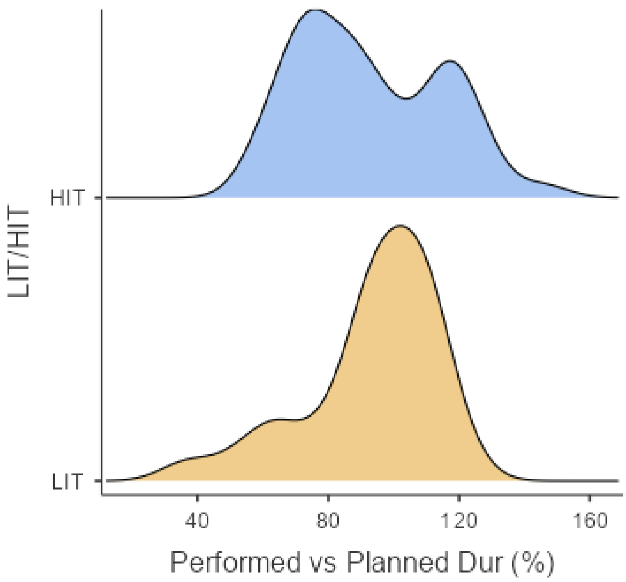

Figure 2: *Performed training duration as a proportion of planned training duration for training sessions with high-intensity (HIT; blue) and low-intensity (LIT; beige).*

Training time spent performing very-slow speed movements (<1 $m{\cdot}s^{-1}$) was influenced by training session type (LIT/HIT or Rifle/no-Rifle). On average, across all training sessions 20 ± 9 minutes of training duration was spent performing very-slow speed movements. Of particular interest was LIT sessions performed without the rifle. These training sessions were designed to be long, continuous low-intensity training sessions. Despite this, these sessions were still associated with an average of 17.5 ± 8.1 minutes of very-slow speed movements.

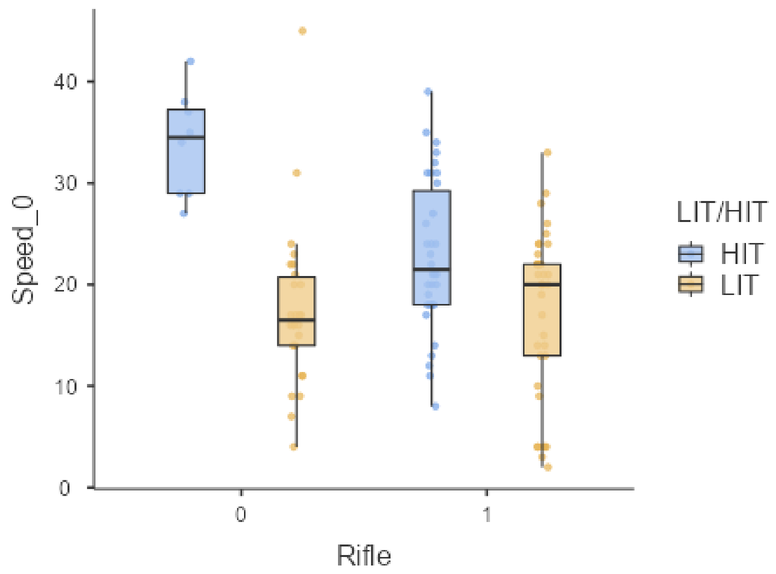

Figure 3: *Training duration (in minutes) spent performing very-slow speed movements (<1 $m{\cdot}s^{-1}$) separated by training session without rifle (0) or with-rifle (1) and for training sessions with high-intensity (HIT; blue) and low-intensity (LIT; beige).*

There were very large positive correlations between PL and training duration ($r = 0.802$, $p < 0.001$). In addition, large positive relationships were shown between PL/min and speed3+ ($r = 0.512$, $p < 0.001$) indicating that PL/min might have convergent validity as a surrogate for training intensity during a biathlon training programme (Figure 4).

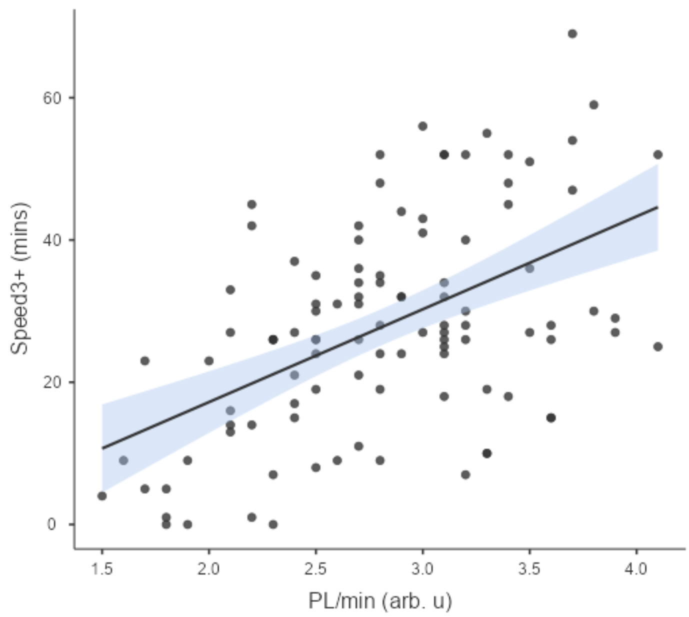

Figure 4. Scatterplot showing the relationship between PL/min and Speed3+

Discussion

This study aimed to examine relationships between the coaches' planned training and the athletes' performed training, within a biathlon training programme. In particular, this study utilised objective measures of exercise such as GNSS sensors, accelerometers and heart rate monitoring. A secondary aim of this project was to investigate the application and utility of wearable sensors for athlete monitoring within a biathlon training program.

The main findings from this study were: 1) Coach training plans impacted the degree of training compliance. For example, the total performed training duration for training sessions that involved rifle-carriage poorly conformed to the coaches' plan. Conversely, the total performed training duration for training sessions that did not involve rifle-carriage conformed well to the coaches' plan; 2) During long continuous training sessions, little very-slow speed movements were expected, yet an average of 17.5 ± 8.1 minutes of very-slow speed movements were observed during these training types; 3) Accelerometer data, in this instance the PL/min metric, might be useful as an indicator of training intensity because of large correlations with higher speed skiing efforts (speed 3+); and 4) This research has identified the utility and application of wearable technology for athlete monitoring in biathlon. All athletes wore these wearable sensors without impact to training sessions and data obtained provides useful insights into the training quantity and quality within the biathlon training programme.

Convergent validity refers to the degree to which two measures that theoretically should be related, are in fact related.[17] As such, the ability to determine training compliance from wearable sensors can be a factor in determining the convergent validity of the device. For example, when the coach prescribes heavy training sessions but the device shows light training, this might indicate poor convergent validity. On the other hand, good agreement between the coaches' training plan and training intensity/volume as determined for a wearable device might indicate convergent validity to be used as a surrogate for the quantification of training.

The agreement between the coaches' planned training durations and the athletes' performed training duration in this study was highly variable. In some instances, as low as 40% of the planned training duration was being met. On the other hand, as much as 130% of the planned training duration was being performed. A high degree of variability in the agreement between planned and performed training demonstrate that some athletes are capable, and others are not as capable, at adjusting their training in order to conform to the coaches' plan. A mismatch between the coaches' planned training and the athletes' performed training can lead to over- or under-training and maladaptation to the training programme.[2,3] Quantification of the training programme using wearable sensors can provide valuable objective feedback to coaches and athletes regarding these relationships.

In addition, this research identified strong correlations between PL and training duration as well as PL/min with higher speed skiing efforts (speed3+). These findings extend the results from a prior investigation that also reported strong correlations between PL/min skiing speeds during biathlon skiing with and without rifle carriage.[14] Collectively, these results strengthen the case for utilizing PL and PL/min as reliable metrics for quantifying training efforts. They serve as valuable surrogates, especially when other measures of external demand (e.g., skiing speeds) are unavailable due to unpredictable weather conditions. Nonetheless, additional research is necessary to delve deeper into these metrics and to explore how skiing sub-techniques and rifle carriage may influence their interpretation and application. By doing so, we can gain a more comprehensive understanding of their potential implications for training assessment and optimisation.

Analyses of the duration of training time spent with minimal impact to aerobic development (i.e., technical/tactical training, shooting practice or 'other') might be a useful practical application of GNSS sensor data within a biathlon training program. These data can indicate technical and tactical coaching or time spent within the shooting range. Surprisingly, this study made an interesting observation: even in training sessions specifically designed for long-continuous LIT without the rifle, significant portions of low-speed movements were still observed, averaging around 17.5 ± 8.1 minutes. Such information highlights the importance of evaluating training quality by examining these details gleaned from wearable GNSS sensors.

Furthermore, this research demonstrates the successful implementation and utility of wearable sensors for athlete monitoring in biathlon. Elite biathletes in the study wore the devices without any reported or documented issues. Importantly, placing the device between the scapulae had no adverse effects on the athletes' ability to carry the biathlon rifle or impact their training sessions. These findings strengthen the case for integrating wearable technologies into biathlon training programs, as they offer valuable data to enhance coaching strategies and optimise training regimens for improved performance and athletic development.

Practical Application

Objective feedback from wearable sensors plays a crucial role in empowering coaches to gain deeper insights into how their training plans influence athletes' executed training. For instance, analysis revealed that the total executed training duration for sessions with the rifle was, on average, 11% below the planned duration. In contrast, training sessions without the rifle were executed remarkably well, with durations closely aligning with 100% of the planned time. Moreover, coaches should be mindful of how training prescriptions affect the time spent on very-slow speed movements. While sessions with the rifle or high-intensity interval training (HIT) sessions might naturally involve such movements during shooting or rest intervals, their monitoring can provide valuable cues about training quality. Intriguingly, even during long continuous training sessions where minimal very-slow speed movements were anticipated, they were still observed. Hence, wearable technologies present an opportunity not only to monitor training session quality but also to facilitate comprehensive athlete monitoring and management. By leveraging the data from wearable sensors, coaches can make informed decisions, fine-tune training plans, and ensure optimal performance outcomes. The PL and PL/min metrics might provide evaluation of the external demands of training with convergent validity, especially when other measures of external demand (e.g., skiing speeds) are unavailable due to unpredictable weather conditions. This integration of objective feedback fosters a more efficient and effective training environment, ultimately leading to enhanced athletic development and achievement.

Conclusion

In conclusion, this study has evaluated the application and utility of wearable sensors for athlete monitoring in a biathlon training programme through the investigation of training compliance. The results demonstrate that the coaches' training plan impacts the degree of compliance. Equipped with this knowledge, coaches are empowered to better predict and understand the actual training dose executed by athletes and how this might impact on training adaptations and performance. Wearable GNSS sensors, coupled with accelerometers and HR monitoring provides objective data to coaches and athletes with convergent validity. In particular, this study had demonstrated the application of and utility of utilising GNSS sensors to investigate low-speed movements as well as accelerometer-based metrics, such as PL, for providing further insights into the exercise dose throughout a biathlon training programme.

Financial Report

We extend our gratitude to the IBU for the financial support provided for this project.

	SEK	%	Summa (SEK)	Sum (Euro) approx
Researcher Allowance (ongoing cost)	48,900	**50.3**	**48,900**	4657
License for sensors 'movesense' smartwatch 15 devices (purchased)	33,411,30	**34.4**		3000
Catapult Sports Openfield (purchased 1 year)	11,015,90	**11.3**		1000
Open Access Publication (upcoming cost)	3797.8	**3.9**		
Total	48,225		**48,225**	4593
Sum	**97,125**	**100**	**97,125**	9250

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