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Human Kinetics
BRIEF REPORT

Eleven Years' Monitoring of the World's Most Successful Male Biathlete of the Last Decade

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Purpose: To report the changes in the training characteristics, performance, and heart-rate variability (HRV) of the world's most successful male biathlete of the last decade. ***Method:*** During the analyzed 11-year (2009–2019) period, the participant won 7 big crystal globes, corresponding to the winner of the International Biathlon Union World Cup. The training characteristics are reported as yearly volume (in hours) of low-intensity training (LIT), moderate- and high-intensity training, and speed and strength training. Performance was quantified by the number of World Cup top-3 positions per season. HRV was expressed as low- and high-frequency spectral power (in milliseconds squared), root-mean-square difference of successive R–R interval (in milliseconds), and heart rate (in beats per minute). ***Results:*** The training volume increased from 530 to ~700 hours per year in 2009–2019, with a large polarization in training intensity distribution (ie, LIT 86.3% [2.9%]; moderate-intensity training 3.4% [1.5%]; high-intensity training 4.0% [0.7%]; strength 6.3% [1.6%]). The number of top-3 positions increased from 2 to 24–26 in 2009–2018 but decreased to 6 in 2019. The mean supine values in the root-mean-square difference of successive R–R interval and high-frequency spectral power divided by heart rate increased until 2015, which were stable over 2016–2018 but decreased in 2019. The number of top-3 positions was related to the total ($r = .66$, $P = .02$) and LIT ($r = .92$, $P < .001$) volume and to several markers of supine parasympathetic activity. ***Conclusion:*** The improvement in performance of the participant was mainly determined by the progressive increase in training volume, especially performed at low intensity, and was correlated to parasympathetic activity markers. This case study confirms the effectiveness of the training method, with a large amount of LIT in an elite endurance athlete, and of regular HRV monitoring.

Keywords: biathlon, endurance performance, heart-rate variability, training intensity, training volume

For many years, the French Nordic-ski national teams periodized their training loads with the "polarized" principle.[1] This method emphasizes the major influence of high training volume performed at low intensity.[2–5] The "polarized" principle,[1] with a "75-5-20" training intensity distribution across 3 intensity zones (low-intensity training [LIT], moderate-intensity training [MIT], and high-intensity training [HIT]), separated by the first and the second lactate thresholds (LT1 and LT2), respectively, is preconized in endurance disciplines.[6] For many years, the French Nordic-ski national teams periodized their training loads with even more than 75% of LIT. This method is in line with recent studies that emphasized the major influence of high training volume performed at low intensity.[2–5] Such distribution has been observed in many endurance sports and is commonly used by elite cross-country skiers.[1,5,7,8]

Biathlon combines cross-country skiing and rifle shooting, and requires considerable physiological demands, similar to those associated with competitive cross-country skiing,[9,10] while also requiring precise fine motor control for fast and accurate shooting under mental pressure. World-class male biathletes demonstrate a high maximal oxygen uptake of >80 mL·kg^{-1}·min^{-1}[9] and perform 700 to 900 hours of physical training annually, including ~80% at LIT, 4% to 5% at MIT, 5% to 6% at HIT, and ~10% of strength and speed training.[10] This volume is slightly lower than in cross-country skiers[8,11] due to the training time for shooting (150–200 h).[8]

It is known that the training components (intensity and volume) influence heart-rate variability (HRV) responses, owing to a modulation in autonomic nervous system activity.[12,13] Endurance training stimulates the parasympathetic activity, represented by the high-frequency spectral power (HF) and the root mean square differences of successive R–R intervals (RMSSD) in frequency and time domains, respectively. HIT stimulates the sympathetic activity, mainly represented by the low-frequency spectral power (LF). Training at LIT is therefore generally believed to enhance parasympathetic autonomic activity[14,15] and generally associated to a good state of health and fitness in athletes. Moreover, our research group has previously reported that HRV was related to training volume at LIT in elite Nordic-skiers[1] and that the analysis of combined supine and standing HRV spectral parameters led to the definition of 4 different patterns of fatigue.[16]

Case studies in world-class athletes are of high interest in exercise physiology and provide unique data on their physiological development and their training content.[7] However, to our knowledge, there is no study reporting training characteristics and HRV data over a long period (>10 y) in athletes of this performance level. So, the aim of this study was to describe the overall training, as well as the relationship between the development of key load factors (volume and intensity distribution) in the training and how these affect the heart variability and performance development report of the world's most successful male biathlete of the last decade.

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Methods

Participant

The participant (born in 1988; aged 21–31 y; height 184 cm; weight 80 kg; VO_2max 83 $mL·mn^{-1}·kg^{-1}$) is the most successful male biathlete of the last decade. VO_2max tests were performed in roller ski at 1200 m of altitude in the French national training center of Prémanon. He is the all-time biathlon record holder of overall World Cup (WC) titles, with 7 big crystal globes in a row (2012–2018), corresponding to the winner of the International Biathlon Union WC. Over an 11-year period (2009–2019), he won 76 WC events and 140 top-3 WC positions. He is a 5-time Olympic champion (Sochi 2014, PyeongChang 2018).

Overall Design

The period studied was from the 2009 to 2019 season.

Training and Performance Characteristics

The training characteristics were extracted from his training log and are reported as yearly volume (in hours) of LIT, MIT, HIT, and speed and strength training. These intensity zones were defined regularly from incremental tests performed by the French team under the supervision of the same physiologist (L.S.) and are separated by the LT1 and LT2. The LT1 corresponds to the first increase in lactate above resting value and LT2 to the first break-point of the lactate curve during an incremental test. Roller-ski tests to measure VO_2max and LTs were performed every year on road or treadmill at 1200 m of altitude in June and October at the French national training center of Prémanon.

The performance level was quantified by the number of WC top-3 positions per season.

Moreover, the shooting performance was quantified as the percentage of targets hit, extracted from the International Biathlon Union database. We decided not to extract and analyze the skiing performance per se, since it is affected by too many factors (snow quality, altitude, equipment, waxing, tactical concerns, etc).

Heart-Rate Variability

The HRV tests were scheduled regularly during each year to record HRV data at least twice during each 4-week mesocycle: 1 test during the first 2 weeks and 1 at the end of the fourth week during the recovery microcycle. No training session at an intensity equal to or above the LT2 was performed 2 days preceding the HRV tests. During the competition period, the tests were performed after 2 full days of recovery (aerobic training), following the last competition. The protocol has been previously described[1,16]: it was performed in the same conditions at wake-up before breakfast, at rest in both the supine and standing positions, and expressed as LF and HF (in millisecond squared), RMSSD (in milliseconds), and heart rate (HR, in beats per minute). During the competition period, the tests were performed after 2 full days of recovery (aerobic training), following the last competition. The head physiologist of the French national Nordic ski teams (L.S.) was the sole investigator to analyze the data.

Statistical Analysis

All data from the 2009 to 2019 period are presented as mean (SD) of each year. A 1-way analysis of variance was used to test the statistical difference in the HR and HRV parameters between the 11 seasons. The Spearman rank-order correlation coefficient (r) was used to analyze the relationship between season values in performances, training characteristics, and HRV data. All analyses were completed using SigmaStat (version 3.5; Systat Software®, San Jose, CA). Statistical significance was accepted at $P < .05$.

Results

Performance

For the entire studied period, the number of top-3 positions in WC events increased from 2 to 24–26 in 2009–2018 but decreased to 6 in 2019 (Figure 1A).

Training volume increased from 530 to ~700 hours per year in 2009–2019, with a large polarization in training intensity distribution (ie, LIT: 86.3% [2.9%]; MIT: 3.4% [1.5%]; HIT: 4.0% [0.7%]; strength: 6.3% [1.6%]; Figure 1B). MIT that ranged between 1.6% and 3.6% from 2009 to 2018 was increased (7.4%) in 2019.

Figure 1C describes the training volume performed in the different forms of training used year by year.

Two altitude training camps of 15 days at 1700 to 1850 m with the living high-training high method were regularly performed in August and November every year.

The shooting sessions were not quantified by their duration but by the number of cartridges (ie, between 12,000 and 15,000) fired every year. The specific shooting-only sessions were estimated at ~30% of the number of cartridges fired per year.

The percentage of targets hit ranged between 85% in 2009 and 90.7% in 2017. The shooting performance was stabilized over the last 3 seasons (90.7%, 90.2%, and 89.3% in 2017, 2018, and 2019, respectively).

The shooting performance was correlated to the following HRV parameters: HR in the supine ($r = -.83$, $P < .001$) and standing ($r = -.79$, $P < .01$) positions, as well as RMSSD ($r = .72$, $P < .01$), LF ($r = .73$, $P < .01$), HF ($r = .68$, $P < .05$), and $HF·HR^{-1}$ ($r = -0.73$, $P < .01$) in the standing position.

The mean (SD) values of the HR and HRV parameters are presented in Table 1.

The mean supine values in RMSSD (from 31 [12] to 114 [14] ms) and HF (from 817 [284] to 2910 [342] ms^2) increased until 2015 and were stable over 2016–2018 but decreased in 2019 (94 [28] ms; 1815 [821] ms^2). Similarly, the supine HR decreased from 44.4 [3.4] to 33.5 [1.7] bpm in 2018 but increased in 2019 (35.9 [1.8] bpm). The ratio of $HF·HR^{-1}$ measured in the supine position is shown in Figure 1D. Over the period, the HRV parameters measured in the standing position increased continuously (Table 1).

Three different periods were characterized in the 11 years studied, as follows:

- From 2009 to 2013, the number of top-3 positions in WC events increased gradually from 2 to 24. The annual training volume increased regularly from 530 to ~637 hours per year, with a large polarization in training intensity distribution during this period (ie, LIT: 88.5% [1.2%]; MIT: 2.5% [0.7%]; HIT: 3.9% [0.4%]; strength: 5.1% [0.3%]). The mean supine values in RMSSD (31 [12] to 90 [13] ms) and HF (817 [284] to 2234 [217] ms^2) increased. Similarly, the supine HR decreased from 44.4 (3.4) to 37.3 (3.3) beats per minute.
- From 2014 to 2018, the number of top-3 positions in WC events decreased in 2014 and 2015 (16 and 15) and increased again in 2016, 2017, and 2018 (19, 26, and 24, respectively). The annual training volume was stabilized from 680 to 711 hours per year,

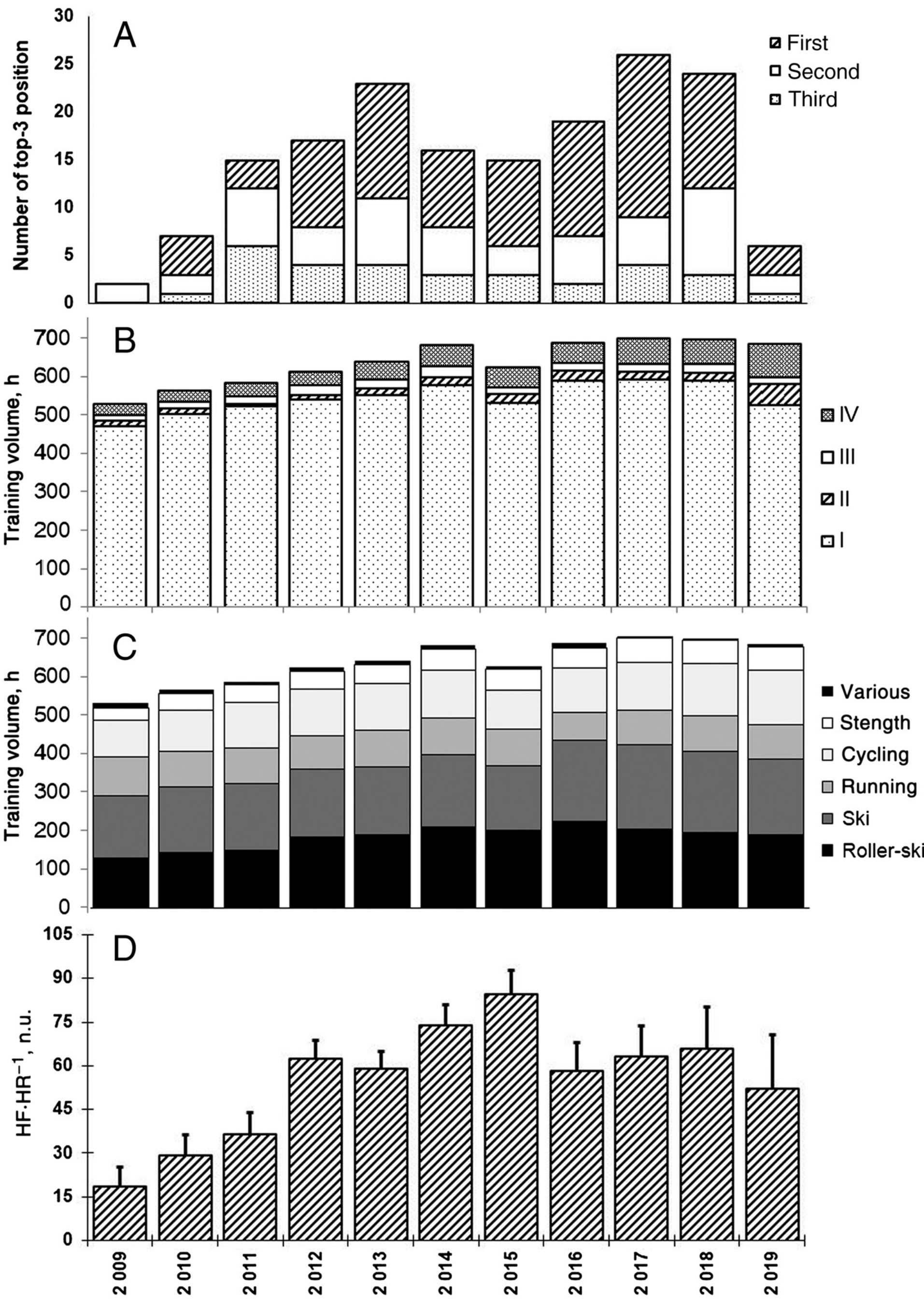

Figure 1 — From season 2009 to 2019: (A) number of top-3 positions in International Biathlon Union World Cup events (first, second, and third positions). (B) Training volume and intensity distribution: I, LIT (below first lactate threshold); II, MIT (between first and second lactate thresholds); III, HIT (above second lactate threshold); and IV, speed and strength training. (C) Training volume in the different forms of activity (roller-ski, ski, running, cycling, strength, and various). (D) HF (in milliseconds squared) divided by HR (in beats per minute); HF·HR^{-1} (in normalized units [n.u.]). HF indicates high-frequency spectral power; HIT, high-intensity training; HR, heart rate; LIT, low-intensity training; MIT, moderate-intensity training.

with a polarization in training intensity distribution over the period (ie, LIT: 85.5% [0.6%]; MIT: 3.5% [0.6%]; HIT: 4.2% [1.0%]; strength: 6.8% [0.6%]). The mean supine values in RMSSD increased from 91 [14] to 108 [16] milliseconds. The HF decreased moderately from 2649 (297) to 2187 (588) milliseconds squared. Similarly, the supine HR decreased from 36.5 (3.3) to 33.5 (1.7) beats per minute.

- In 2019, performance showed an important decrease, with only 6 top-3 positions in WC events. The annual training volume was similar to the 2 preceding seasons, with 691 hours per year, but some changes were observed in the training intensity distribution, with a decrease in LIT and increases in MIT and strength training (ie, LIT: 79.1%; MIT: 7.4%; HIT: 3.4%; strength: 10%). When compared with the previous season, the mean supine values in RMSSD and HF decreased, while the supine HR increased.

Relationships Between Performances, Training Characteristics, and HRV Parameters

The number of top-3 positions per season was related to the yearly total ($r = .73$, $P = .009$) and LIT ($r = .92$, $P < .001$; Figure 2A) volume and to several markers of supine parasympathetic activity as HF·HR^{-1} ($r = .57$, $P = .05$; Figure 2B), HR ($r = –.66$, $P = .02$; Figure 2C), and RMSSD ($r = .58$, $P = .05$; Figure 2D).

Shooting performance was correlated to the following HRV parameters of the studied period: HR in the supine ($r = –.83$, $P < .001$) and standing ($r = –.79$, $P < .01$) positions, as well as RMSSD ($r = .72$, $P < .01$), LF ($r = .73$, $P < .01$), HF ($r = .68$, $P < .05$), and HF·HR^{-1} ($r = –.73$, $P < .01$) in the standing position.

Discussion

This study reports the changes in training volume in the most successful male biathlete of the last decade, with a progressive increase from 530 to ~700 hours between 2009 and 2016 and a plateau over the last 3 years. This training volume is lower than that for a world-class cross-country skier (750–900 h).[5] The total training volume analyzed in this case study does not take into account the specific shooting sessions, which represent ~30% of the number of cartridges fired per year. From 2009 to 2018, the intensity distribution remained quite similar across the seasons,

Table 1 Yearly Mean Values of HR-Variability Parameters Measured at Rest in Supine and Standing Positions

	Supine				Standing			
Season	HR, bpm	RMSSD, ms	LF, ms^2	HF, ms^2	HR, bpm	RMSSD, ms	LF, ms^2	HF, ms^2
2009	44.4 (3.4)	31 (12)	1118 (275)	817 (284)	59.4 (4.6)	30 (11)	2439 (763)	281 (148)
2010	44.0 (3.1)	44 (13)	1083 (276)	1279 (298)	58.5 (4.1)	31 (11)	2611 (849)	297 (143)
2011	40.3 (3.3)**	51 (13)	2189 (417)	1485 (312)	57.7 (3.0)	34 (13)	2824 (1004)	356 (186)
2012	39.0 (3.3)	95 (13)**	2472 (391)	2412 (260)	58.1 (3.3)	34 (13)	2634 (1124)	335 (200)
2013	37.3 (3.3)	89 (13)	3421 (334)	2234 (217)	58.7 (2.3)***	31 (11)*	2559 (1069)	307 (170)*
2014	36.5 (3.3)	91 (14)	3337 (326)	2649 (297)	59.0 (1.9)**	32 (11)	2741 (1265)	330 (175)
2015	34.6 (3.3)*	114 (14)	3653 (367)	2910 (342)	58.6 (2.0)	34 (11)	3011 (1274)	337 (177)
2016	34.9 (2.2)	99 (15)*	1841 (495)***	2007 (418)**	58.8 (1.9)	35 (10)	3177 (1212)*	352 (172)**
2017	34.2 (1.6)	99 (17)	2211 (495)	2137 (455)	58.1 (2.1)	39 (11)	3670 (1237)	394 (155)
2018	33.5 (1.7)	108 (19)	1992 (497)	2187 (588)	58.4 (2.6)	40 (10)	3603 (1293)	398 (152)
2019	35.9 (1.8)**	94 (28)	1961 (489)	1815 (821)*	59.5 (3.8)	39 (11)	3346 (1496)	385 (164)
ANOVA, *P*	***	***	**	**		***	***	***

Abbreviations: ANOVA, analysis of variance; bpm, beats·min^{-1}; HF, high-frequency spectral power; HR, heart rate; LF, low-frequency spectral power; RMSSD, root-mean-square differences of successive R–R interval.
*$P < .05$, **$P < .01$, ***$P < .001$ for difference with previous season.

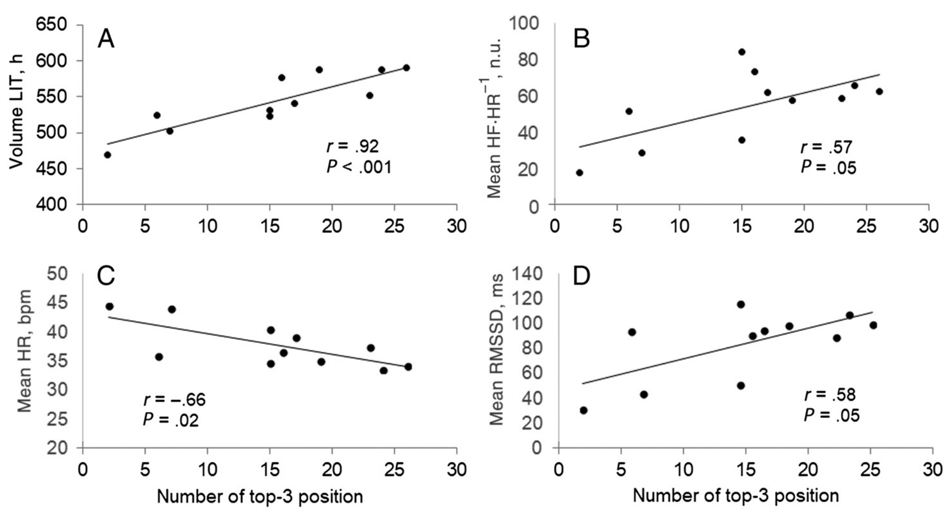

Figure 2 — Correlations between the number of top-3 positions per season over the 11-year period (2009–2019). (A) The volume at LIT below first lactate threshold, (B) resting supine mean yearly values in HF·HR^{-1} (in normalized units [n.u.]), (C) resting supine mean yearly values in HR (in beats per minute), and (D) resting supine mean yearly values in RMSSD (in milliseconds). HF·HR^{-1} indicates high-frequency spectral power divided by heart rate; HR, heart rate; LIT, low-intensity training; RMSSD, root-mean-square differences of successive R–R intervals.

with 87.0% (1.8%) at LIT. This large amount of LIT is higher than the 75% usually associated to the "polarized training" paradigm[6] but is in line with previous reports in cross-country skiers.[5,7,8] The correlation between his performance level and the total training volume, as well as the LIT volume, emphasizes the need for a large amount of aerobic training, not only during the early phase of the career in an endurance athlete but also even when he has achieved the highest level.

The improvement in shooting performance over the studied period was related to a decrease in HR in both the supine and standing positions, as well as an increase in the HRV parameters. It may come from either direct (ie, improved HR recovery and larger tachycardia facilitating the shooting when HF is higher) or indirect (ie, lower fatigue and/or higher confidence in shooting when his physical fitness was high, as associated with the HRV parameters) mechanisms.

Of high interest is the change observed in 2019, when the participant modified the training distribution by increasing the volume in MIT and decreasing the volume carried out in LIT. These changes in his intensity distribution were concomitant with a clear decrease in performance, although the training volume remained similar to the 3 previous years.

The HRV data also followed several phases over the period: from 2009 to 2015, the markers of the temporal (RMSSD) and spectral (LF, HF, LF + HF, and $LF{\cdot}HR^{-1}$) parasympathetic activities when measured in the supine position were regularly increasing. Then, there was a plateau, followed by a regression in the 2019 season, when these supine HRV parameters went back to the values measured in 2011–2014.

The standing HRV parameters did not display a similar trend and increased nonlinearly but continuously over the 11-year period. Overall, the respective changes in the supine (mainly HF and RMSSD, parasympathetic activity) and standing (LF, predominantly sympathetic activity) positions support the assumptions that (1) both the supine and standing measurements of HRV are valuable and (2) elite endurance performance requires a high level of both parasympathetic and sympathetic activities. However, the relationship between performance and HRV (especially HF, $HF{\cdot}HR^{-1}$, and RMSSD) appears to be stronger with markers of parasympathetic activity that is enhanced mainly by LIT.

Practical Applications

One important contribution of this study is that the annual performance development appears to be closely related to the training being "polarized," with an annual increase in the load in the form of an increased number of hours at low intensity.

Most of the supine and standing HRV parameters increased or remained very high over the period, except in 2019, which corresponded to a training "less polarized" and a decreased performance level. Overall, this case study confirms the effectiveness of a training method with a large amount of LIT in an elite endurance athlete. Moreover, it demonstrates the benefits of regular HRV monitoring.

Conclusion

The improvement in performance in the most successful male biathlete over the last decade is obviously the consequence of many factors. One of the most important factors appears to be the progressive increase in training volume, especially performed at low intensity. Since HRV and HR are correlated to the variation in performance, regular monitoring including these parameters appears to be effective. This case study confirms the effectiveness of a training method with a large amount of LIT in an elite endurance athlete and HRV monitoring in both the supine and standing positions.

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