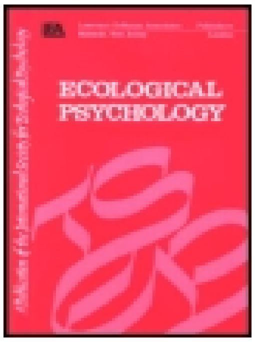

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In a Heartbeat: Prospective Control of Cardiac Responses for Upcoming Action Demands during Biathlon

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ABSTRACT

Biathlon is an Olympic winter sport combining the endurance sport of cross-country skiing with precision rifle shooting. Here, the need to prepare the body for upcoming events is particularly evident. As a high heart rate can be detrimental to shooting performance, it might be beneficial for biathletes to decrease their heart rate when approaching the shooting range, whereas heart rate should ideally be increased at the start and when facing an uphill section to cater for physiological demands. Ten national-level, junior male biathletes skied 6–8 laps in a standardized 2 km biathlon course with competition intensity, where each lap was followed by 5 shots in the standing position. Electrocardiography was continuously measured, and changes in heart rate during the 30 s leading up to the start, the uphill section, and the shooting event were analyzed. Instantaneous heart rate (IHR) increased significantly before the start and before the beginning of the uphill, whereas IHR decreased significantly before arriving at the shooting range. These findings provide evidence that biathletes anticipate forthcoming events by prospectively adjusting their heart rate upwards and downwards depending on task demands. Being able to use perceptual predictive information to optimally prepare the body for challenges that lie ahead, may have implications for expert performance in several different sports, as well as in other fields where purposeful regulation of heart rate is important for success.

Introduction

All movements must be controlled by perceiving what is going to happen next. This means that movements cannot be represented in any preprogrammed, context-insensitive way (Van der Meer et al., 1995). Acting successfully in any given environment requires the pick-up of perceptual information to foresee what is going to happen in the near future, an ability that has been termed prospective control (Lee, 2009). Prospective control is about combining perceptual and motor information to guide

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upcoming actions (Agyei et al., 2016; Lee, 1993; Turvey, 2019; Van der Meer & Van der Weel, 2020). In humans, the visual and auditory systems are important perceptual systems for prospective control (Snapp-Childs et al., 2013; Van der Meer & Van der Weel, 2011), and especially for sport performance depending on athletes' ability to perform desired movements to reach predetermined goals. Prospective control is thought to help athletes accommodate to expected or unexpected changes in dynamic environments (Fajen et al., 2009; Williams & Jackson, 2019). There is evidence for the use of prospective control in several sport skills, including long-jumping (Lee et al., 1982), tennis (Montagne, 2005), table tennis (Bootsma & Van Wieringen, 1990), somersaulting (Bardy & Laurent, 1998; Lee et al., 1992), golf putting (Craig et al., 2000), and batting (Katsumata & Russell, 2012). All the above sport skills involve the precise coordination of body parts with regards to rapidly changing environments.

It is also reasonable to believe that prospective control plays an important role in endurance sports, especially those that involve dynamical situations where it is crucial to be prepared for upcoming events. In such cases, the cardiac regulation is controlled by the activity of a division of the peripheral nervous system, namely the autonomic nervous system (ANS; see details in Horn & Swanson, 2013). Hence, studying the heart rate responses during dynamic situations in endurance events would provide novel information about prospective control. In the present study, we will examine this by using biathlon as our model-sport, an Olympic event that combines two essentially different sport skills, namely cross-country skiing and rifle shooting. In a biathlon competition, the biathletes ski several 2–5 km laps in hilly terrain, interspersed with five shots of rifle shooting, alternating between the prone and the standing position (International Biathlon Union, 2016a). The 45 mm prone and 115 mm standing position targets are placed 150 m away, and for each miss at the shooting range, either the biathlete has to complete an extra 150 m of skiing or a 1-minute penalty is added to the final competition time (International Biathlon Union, 2016b). Successful performance in biathlon thus depends on a high aerobic power and well-developed skiing efficiency, as well as precise and rapid shooting abilities (Luchsinger et al., 2016).

Cardiac regulation during physical activity is controlled by the activity of a division of the peripheral nervous system, namely the autonomic nervous system (ANS) (Horn & Swanson, 2013). The ANS innervates heart muscle, smooth muscle and exocrine glands, and it is considered largely involuntary. It consists of two branches, the sympathetic nervous system and the parasympathetic (vagal) nervous system. It is commonly recognized that the sympathetic and vagal branches of the ANS exert antagonistic effects on different organs in the body, including the heart (Berg & Jensen, 2011). The ANS is involved in "fight-or-flight" functions, and there is a homeostatic balance between the sympathetic and vagal nervous system which helps maintain a constant level of autonomic activation (Levy, 1971). In general, the sympathetic nervous system enables humans to react quickly and appropriately to dangers in the environment, whereas the vagal nervous system promotes rest and digestion (Horn & Swanson, 2013).

When it comes to autonomic influences on the heart, there is a complicated interaction between the sympathetic and vagal nervous system (Levy, 1971). This is based on that the heart is dually innervated by both sympathetic and vagal fibers, and that peripheral interaction between sympathetic and vagal fibers also exists within the cardiac muscle itself. This duality makes the neural control of the heart very complex. Activation of the sympathetic nervous system results in a positive cardiac response represented by an increase in heart rate, whereas activation of the vagal nervous system elicits an opposite and negative cardiac response which decreases heart rate (Berg & Jensen, 2011). At the onset of physical activity, there is an instant decrease in cardiac vagal activity which results in the initial increase in heart rate (Coote, 2010). This is followed by a more gradual withdrawal of vagal activity, and as the heart rate increases, sympathetic activity starts to predominate. When physical activity ceases, heart rate decreases. This is largely due to vagal reactivation (Coote, 2010).

Biathletes usually ski at an intensity corresponding to 85–95% of maximum heart rate (HR_{max}) during competitions (Gallicchio et al., 2016). However, the high intensity work in biathlon includes a high heart rate accompanied by a high breathing frequency that can be detrimental to shooting performance through less precise shooting as the rifle needs to be held steady when aiming. Downregulation of heart rate through reduced sympathetic activity and activation of the vagal system when approaching the shooting range might therefore be beneficial. In addition, the biathletes face diverse types of terrain, requiring them to regulate the external work rate and metabolic intensity according to the demands of the different types of terrain (Sandbakk & Holmberg, 2017). Hill climbing in particular represents a considerable metabolic challenge, in which the biathletes' heart rate will increase because of increased sympathetic activity and thus avoid muscle fatigue due to increased oxygen delivery (Hoffman, 2014). Whether biathletes can increase their heart rate and breathing patterns prior to challenging uphill sections is currently unknown. The same type of heart regulation is expected to occur in connection with the start of the biathlon competition, when biathletes are standing at the starting line and getting ready to start. Overall, the requirements of dynamic and simultaneous activation of the sympathetic and vagal branch of the ANS have been termed a paradoxal activation (Jahnsen, 2010), which may be of special importance in biathlon due to the duality of the sport.

Although the ANS is considered mostly involuntary, many of the behaviors regulated by it are closely related to voluntary processes controlled by the somatic nervous system (Horn & Swanson, 2013). Furthermore, the ANS is not exclusively triggered by involuntary or unconscious processes (Jennings & Van der Molen, 2005). In some cases, it is activated when a person is forewarned of an upcoming action leading to alterations in several physiological measures, including heart rate (Bohlin & Kjellberg, 1979; Graham & Clifton, 1966). The use of cardiac control mechanisms may represent an optimal process for prospectively controlling forthcoming metabolic changes in the body, and it may thus help the heart prepare for the physiological efforts that lie ahead (Decety et al., 1993). Such preparatory mechanisms related to action can be measured by using electrocardiography (ECG) investigating the changes in heart rate in the final seconds preceding the execution of a motor skill (Cooke, 2013).

Based on this, the aim of the present study was to investigate whether preparatory heart rate patterns occur during simulated biathlon events to find evidence for prospective control. This was investigated in a field test by employing continuous ECG measurements in three central situations of biathlon: (a) at the start, (b) when approaching uphill terrain during skiing, and (c) before shooting. Heart rate was expected to increase

Table 1. Details of the ten male biathletes participating in the study.

	Mean	SD
Age (years)	17.4	1.3
Body height (cm)	181	6
Body mass (kg)	71.8	5.3
Maximum heart rate (BPM)	202.2	6.4

significantly in the 30 s leading up to the start and before the beginning of the uphill section, whereas heart rate was expected to decrease significantly in the 30 s leading up to entering the shooting range.

Methods

Participants

Ten highly trained male, national-level junior biathletes volunteered to participate in the study (see Table 1). All the biathletes were students at a Norwegian senior high school with a specialized sports program for biathlon. Before providing their written consent, the biathletes were fully informed about the nature of the study and that they could withdraw from the experiment at any time without giving an explanation. Because some of the participants were under 18 years of age at the time of testing, their parents gave a written consent before the biathletes entered the study. The study was reported to the Norwegian Center for Research Data (NSD).

Overall design

The present study was a quantitative experimental study performed during the biathlon competitive season. The study consisted of field tests outdoors in an approximately 2 km long standardized ski course, which was specifically designed for the study. The course consisted of a flat stadium section, an uphill section, and a downhill section, and it was designed with the intention to simulate the terrain of actual racecourses used in biathlon races set by the International Biathlon Union (2016a). The course also included a biathlon shooting range with electronic targets. An illustration of the course profile including elevation above sea level can be seen in Figure 1.

The participants skied 6–8 sets each consisting of five laps of the 2 km course. Three separate events along the course were operationalized as the 1) start event, 2) uphill event, and 3) shooting event. Each lap included all these three events, in their respective order. A subsequent break of approximately three minutes was included between each lap. ECG data from the participants were collected continuously throughout the test using portable ECG sensors at 4 Hz. In addition, GPS-position was tracked using a GPS watch at 1 Hz.

Instruments and materials

ECG data were collected using an Equivital LifeMonitor, EQ02 (Hidalgo, Cambridge, United Kingdom). The EQ02 device is a portable measuring system for human physiological and psychophysiological data. It consists of a Sensor Electronics Module (SEM) that records the data collected from the sensor belt. GPS position (latitude and

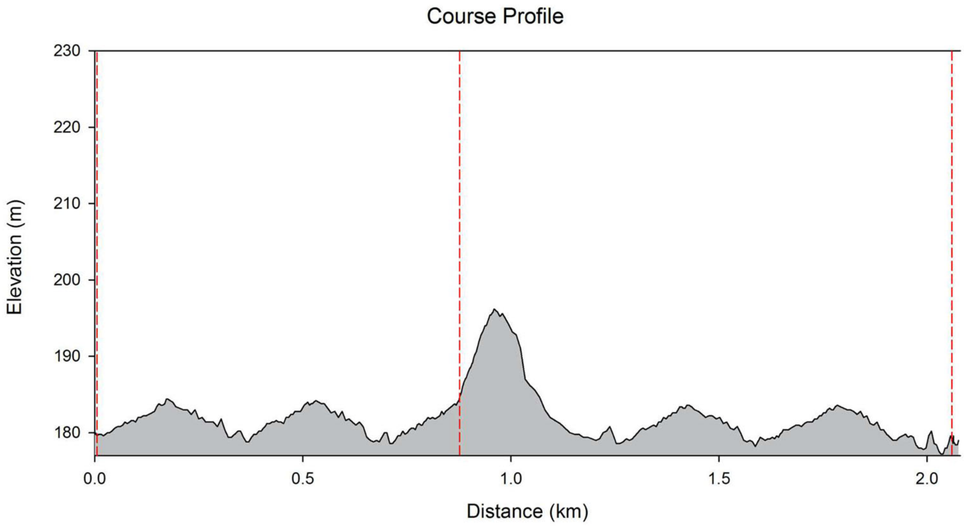

Figure 1. Illustration of the course profile with the relative elevation compared to sea level as a function of skiing distance in kilometers. The three vertical dotted lines illustrate from left to right the physical lines in the snow marking the start, the beginning of the uphill, and the entrance to the shooting range, respectively. Please note that the terrain was already rising slightly during the 100 m before the line in the snow indicating the beginning of the uphill.

longitude) and elevation (using a barometer) were recorded throughout the test using a GPS-watch, Garmin Forerunner 920XT (Garmin Ltd., Olathe, KS).

The participants used their own skiing equipment while skiing, including standard competition ski's, poles, and boots. The participants also used their own standardized biathlon rifle for shooting, a .22-inch caliber rifle with a weight of approximately 3.5 kg. The rifle was carried on the back during skiing. All the equipment is in accordance with the rules set by the International Biathlon Union (2016a) . The shooting was performed in the standing position at the shooting range on an electronic target system (Megalink Electronic Biathlon 50 m, Vestby, Norway), with a shooting distance of 50 m which is in line with the IBU Event and Competition Rules (2016b).

Procedure

Upon arrival, the EQ02 Sensor Belt was placed on bare skin around the participants' torso with the strap positioned over the left shoulder. The SEM was connected to the belt through the port and placed in the pocket under the left arm, and it started logging ECG data immediately after it was connected to the sensor belt. Finally, the Garmin GPS-watch was placed on the participants' preferred wrist.

Participants used the skating technique, where skiers push and glide on alternating legs to create propulsion, and first completed a 15-minute standardized warm-up at low intensity where they familiarized themselves with the course. They also did one shooting bout of five shots in the standing position as part of the warm-up. Thereafter, the participants were instructed to prepare for the testing and remove their warm-up clothes.

During the test, participants skied 6–8 sets of 2 km, each consisting of 5 laps, in a predetermined ski course clearly marked with plastic custom v-boards. The ski course consisted of three separate events: (a) start event, (b) uphill event, and (c) shooting event. The start event was organized as a single start as utilized in the individual and sprint competitions in national and international biathlon races (International Biathlon Union, 2016a). During the start event, participants stood still with both feet completely behind a clearly marked start line. The experimenter showed the participant an iPad with a digital display count-down watch that started counting down 30 s before the start. The display visually presented the participants the remaining time before the start in seconds. In addition, the experimenter gave verbal forewarnings at 30 s, 15 s, and 10 s before start. The start command was given by the sound of three loud beeps of the watch. The participants crossed the line upon the starting command.

The participants then skied the course, which first consisted of two laps at the flat stadium section that served to bring their heart rate to a stable level, followed by an uphill section that corresponded to the start of the second event. The beginning of the uphill was marked with a clearly visible line in the snow (see Figure 1). The participants skied the uphill and a corresponding downhill and then they skied two additional flat laps before they entered the shooting range. The flat lap prior to the uphill served as a control in the analysis. The beginning of the shooting range was also marked with a line in the snow (see Figure 1) and corresponded to the start of the third event, the shooting event, where the participants did a shooting bout consisting of five shoots in the standing position at the shooting range, before they skied across a nearby finish line. The average duration of each set, including the shooting time, was approximately 6.5 minutes.

The participants were told by the experimenter to ski in a sub-maximal speed (85–90% of HR_{max}) during the test and to keep the skiing speed constant. The speed was also monitored by the experimenter by looking at the participants' lap times and heart rates. After they finished shooting, the participants took an active break of three minutes where they lowered their pulse by skiing at low intensities (60–70% of HR_{max}). This was done in order to reset the participants' heart rate to resting values before they started on the next lap. The whole procedure was repeated eight times for eight of the participants. Two of the participants only skied six and seven laps, respectively, because they were too tired to complete the total of eight laps and they wanted to save themselves for an upcoming competition. After the experiment, the participants were instructed to do a warm-down of chosen length, and after that the ECG measuring equipment was removed.

Data collection protocol

A timestamp method was used to synchronize ECG measurements of the participants' heart rate with the corresponding GPS-position in the course. Both the SEM and the GPS-watch use a satellite timestamp method to log data to the device, and prior to data collection, a timestamp synchronization test of the SEM and the GPS-watch was performed. The results of the synchronization test showed there was a delay of less than 0.5 seconds between the two devices, something that was considered an acceptable difference. Furthermore, prior to the test, the SEM and the GPS-watch were synchronized

Table 2. Average instantaneous heart rate (IHR) in beats per minute in the 30 s leading up to the biathlon events for the different participants. In parentheses, increase+/decrease- in IHR over the same period.

	Start	Uphill	Flat (control)	Shooting range
Participant 1	113 (+14)	167 (+3)	167 (+3)	167 (–5)
Participant 2	121 (+9)	193 (+3)	193 (+3)	190 (–4)
Participant 3	133 (+16)	180 (+3)	178 (+4)	180 (–3)
Participant 4	117 (+7)	179 (+3)	175 (+5)	178 (–6)
Participant 5	110 (+17)	175 (+2)	174 (+3)	171 (–8)
Participant 6	112 (+9)	166 (+3)	163 (+5)	165 (–5)
Participant 7	124 (+3)	179 (+2)	175 (+5)	176 (–8)
Participant 8	103 (+23)	–	–	–
Participant 9	137 (+14)	187 (+2)	187 (+3)	181 (–1)

with satellites to make sure the time had not been changed on the devices after the synchronization test was performed.

ECG data, as well as GPS position and elevation were logged during the entire duration of the test, and the recording was started before the start of the warm-up and stopped at the end of the warm-down. The times at the beginning of the start event, the uphill event, and the shooting event were manually noted by two experimenters who each were equipped with GPS-watches that were synchronized with the SEM and the GPS-watch worn by the participant. The experimenters also noted the start times, the lap times, the end times as well as the time used on the shooting range for each participant. The times noted by the experimenters were used to analyze heart rate with respect to the start event, uphill event, and shooting event.

The signal obtained by the ECG of the SEM was filtered using Matlab 8.5. A median filter with a window length of 5 s was first applied to remove outliers. A Butterworth low pass filter was then applied to remove high-frequency noise from the signal. The interbeat interval (IBI) measures obtained from the ECG were used to calculate an instantaneous heart rate (IHR). The IHR in beats per minute (BPM) is equal to 60/IBI when IBI is measured in seconds (Goldberger et al., 2017). The 30-second periods before the start, uphill, and shooting were analyzed. The mean IHRs (SD) over 5-second intervals were calculated for each lap for each participant. The participants' GPS-speed was determined using GPS-coordinates (latitude and longitude) measured by the GPS-watch, and the Haversine formula (Chopde & Nichat, 2013) was applied to compute GPS-distance from which skiing speed could easily be derived.

Data exclusion

One of the participants got confused and skied an extra flat lap, while another missed one flat lap. Participants were included in the analysis only if they had four or more accepted laps. For some of the participants, parts of the IHR data were noisy and contained too many outliers to be included in the analysis. Judgment whether the data were too noisy or not to be included in the analysis was done by visual inspection of heart rate values and heart rate graphs, based on information attained about exercise physiology and the ranges of normal heart rates in young adults during exercise (Goldberger et al., 2017). Specifically, one participant was excluded based on too much noise in the data, and another participant was excluded from the uphill and shooting

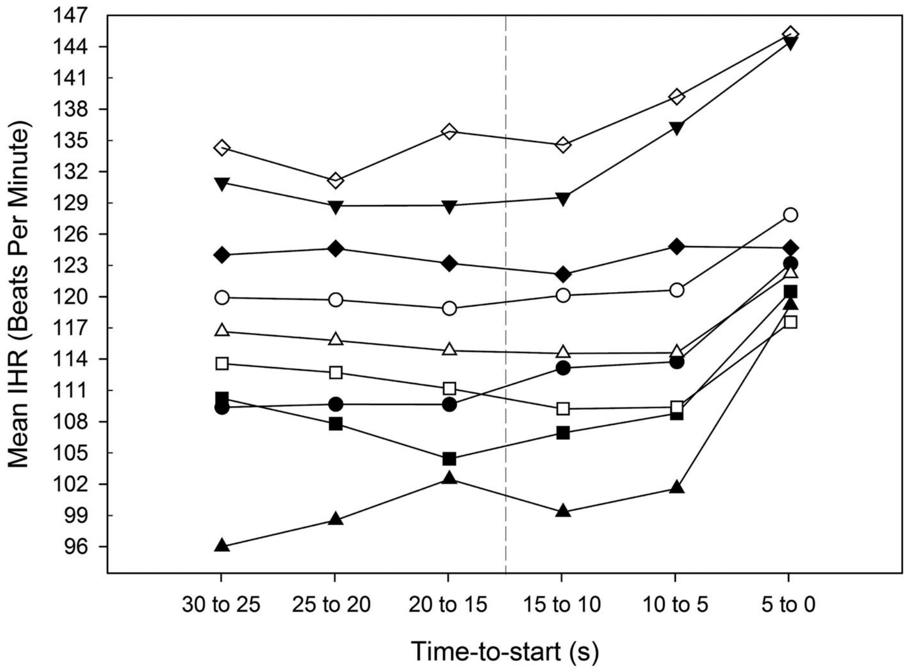

Figure 2. Graph showing the increase in mean instantaneous heart rate (IHR) as a function of the time-to-start at t = 0 during the countdown preceding the start. The included nine participants are represented by the black lines with different symbols. The dotted vertical line separates the first from the last 15 s of the 30 s countdown period to the start signal.

events for the same reason. The problem with these two participants was that they were too slim for the medium-sized sensor belt to fit tightly around their torso, causing noisy data.

Results

The use of prospective control of heart rate was investigated when it comes to the three biathlon events leading up to the start, the uphill (including a control condition), and before skiing into the shooting range. Table 2 shows the average IHR in beats per minute in the 30 s prior to the biathlon events for the different participants, as well as the overall increase and decrease in IHR over the same time period. The 30 s period prior to the start, uphill, and shooting was divided into six intervals each containing the mean IHR of a time period of 5 s.

The start event

The analysis of changes in mean IHR prior to the start revealed an increase in the mean IHR during the visual and auditory countdown leading up to the start signal, when the participants were waiting at the starting line. Overall, the increase in IHR was substantial as the mean IHR was 117 beats per minute (BPM) ($SD = 12$) at the beginning of the countdown and increased to 127 BPM ($SD = 10$) at the end of the

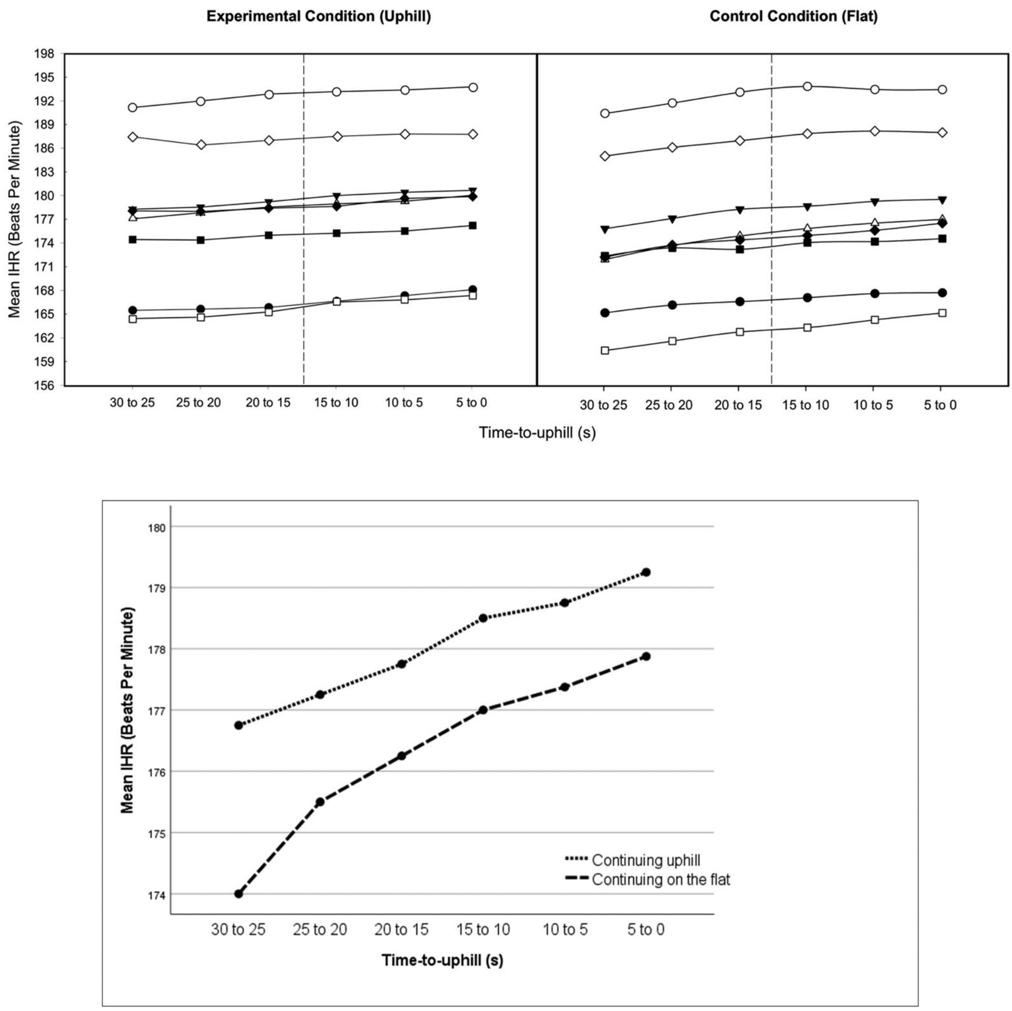

Figure 3. (Top) Graph showing the increase in mean instantaneous heart rate (IHR) as a function of the time-to-uphill at t = 0 as the participants were approaching the uphill and continued skiing up the hill in the experimental condition to the left, and as participants were skiing the same stretch but continued skiing the flat control lap to the right. The included eight participants are represented by the black lines with different symbols. The black dotted vertical lines separate the first from the last 15 s of the 30 s period leading up to the line in the snow indicating the start of the uphill. (Bottom) Graph showing that mean IHR increased steadily during the 30 s leading up to the line in the snow marking the beginning of the uphill. In addition, as participants were approaching the beginning of the uphill, IHR was consistently higher when they had to continue skiing up the hill as opposed to when they should veer off immediately after crossing the line and stay on the flat instead.

countdown. The mean IHR for the group increased notably by 10 BPM ($SD = 5$) during the final 15 s prior to the start.

Figure 2 shows the mean increase in IHR as a function of the time-to-start for nine participants as represented by the black lines. As can be seen in the Figure, the participants' mean IHR started increasing approximately 15 s before the start. The mean IHR increased especially during the last 5 s before the start. The increase was observed in all participants except for the participant represented by the black line with filled black diamonds, where the mean IHR remained approximately the same as in the previous interval. This participant showed, however, a relatively large increase in mean IHR during the preceding interval.

Repeated measures ANOVA was performed to test for differences in mean IHR between the six 5 s time intervals leading up to the start, i.e. from time-to-start at 30-25 s to time-to-start at 5-0 s. A main effect was found, showing that there was a significant increase in the mean IHR during the 30 s prior to the start, $F(5,40)=20.08$, $p < 0.001$.

Because of individual physiological differences, the between-subject variation in heart rate was relatively large, as the participants' IHR ranged between 96 BPM and 131 BPM at the beginning of the countdown, to 118 BPM and 145 BPM at the end of the countdown.

The uphill event

The changes in IHR when participants were approaching the uphill were analyzed with respect to a control condition to control for the effect of increased heart rate due to increased physiological workload when skiing uphill. The flat lap before the lap containing the uphill in each set that the participants skied, served as the control condition. In the experimental condition, the participants continued to ski the entire uphill after crossing the line that marked the start of the uphill. In the control condition, participants took a U-turn after crossing the line. Therefore, in contrast to the experimental condition, the control condition did not contain an uphill. The participants skied the same path leading up to the uphill in both conditions.

During the uphill condition where participants continued to ski the uphill after crossing the line, a gradual increase in IHR was observed during the 30 s period before the participants reached the line indicating the start of the uphill. The range in IHR was between 164 and 191 BPM when participants were 30-25 s away from the uphill and it increased in all participants on average by 2.6 BPM when participants were 5-0 s from the starting point of the uphill.

Figure 3 (top) shows the mean increase in IHR as a function of time-to-uphill for eight participants as represented by the black lines for the experimental condition to the left, and for the control condition to the right. As can be seen, there was a small gradual increase in mean IHR for all the participants when approaching the beginning of the uphill for both the uphill condition and the flat condition.

Repeated measures ANOVA on the six 5 s time intervals leading up to the beginning of the hill for when participants continued to ski up the hill and for when they veered off to ski a control round on the flat, revealed significant main effects on IHR for time-to-uphill, $F(5,35)=89.00$, $p < 0.001$, and for terrain (continuing uphill or on the flat), $F(1,7)=8.4$, $p < 0.025$. Figure 3 (bottom) illustrates these effects graphically, indicating that IHR increased slightly but significantly as participants approached the line in the snow marking the beginning of the uphill, and that IHR was consistently higher when participants approached the hill to ski up it as opposed to when they took a U-turn before the beginning of the uphill and continued with a flat control round instead.

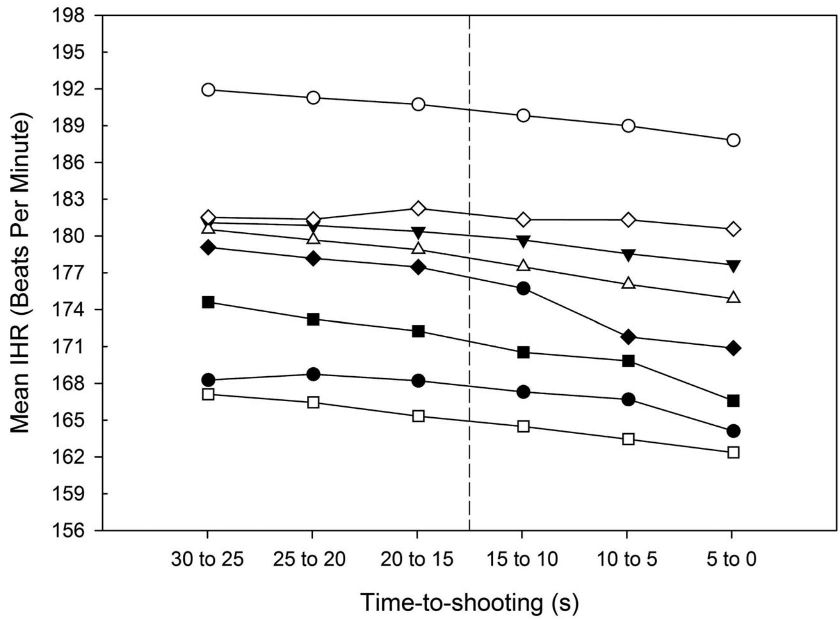

Figure 4. Graph showing the decrease in mean instantaneous heart rate (IHR) as a function of the time-to-shooting at $t = 0$ when participants were approaching the shooting range. The included eight participants are represented by the black lines with different symbols. The dotted vertical line separates the first from the last 15 s of the 30 s period leading up to shooting.

The shooting event

The shooting event was analyzed in an equivalent way to the start event. A decrease in the mean IHR at the group level was observed during the final 30 s when participants were approaching the shooting range. The mean IHR was 178 BPM ($SD = 8$) 30-25 seconds before the shooting and decreased gradually by 5 BPM to 173 BPM ($SD = 9$) 5-0 seconds before the beginning of the shooting.

Figure 4 shows the main decrease in IHR (average decrease in IHR over 6–8 sets per participant) as a function of the time-to-shooting for eight participants as represented by the black lines. The Figure shows a gradual decrease in mean IHR among most of the participants from 30 to 15 s before the shooting, and a more pronounced decrease in mean IHR during the last 15 s leading up to the shooting. The between-subject variation ranged from 167 BPM to 192 BPM at 30-25 s before the shooting, to between 162 BPM and 188 BPM at 5-0 s before the shooting.

Repeated measures ANOVA was performed to test for differences in mean decrease in IHR between the six 5 s time intervals leading up to the shooting, i.e. from time-to-shooting at 30-25 s to time-to-shooting at 5-0 s. A significant main effect was found, showing that there was a significant gradual decrease in mean IHR during the 30 s leading up to the shooting, $F(5,35)=24.09$, $p < 0.001$.

As biathletes must decelerate when getting close to and be able to stop at the shooting range, a small and expected decrease in skiing speed as measured by GPS was observed when participants were approaching the shooting range. However, from time-to-shooting at 30 to 10 s, skiing speed was maintained at above 20 km/h and an average decrease in speed of only 0.7 m/s (2.5 km/h) was observed for the whole sample of participants as the average speed decreased from 6.5 to 5.8 m/s.

Discussion

The present study investigated whether directional preparatory control of heart rate occurred during three central aspects of a biathlon competition, namely during the 30 s leading up to the start, before skiing up a hill, and before entering the shooting range, to find evidence of prospective control.

The results of the start event revealed a significant increase in mean IHR in the preparation period for action, during the 30 s countdown before the start signal. The mean IHR at the group level increased notably starting approximately 15 s before the start signal and was most remarkable in the last 5 s before the start. In fact, the participants' heart rate increased by more than 10 BPM during the last 15 s prior to the start. It takes approximately 1 s to increase the heart rate by 25% at the onset of exercise (Coote & Bothams, 2001), depending on the contraction force and type of muscle. In the present study, an increase in IHR by approximately 8% was observed even before the onset of exercise. This suggests that a considerable part of the increase in heart rate that is observed at the onset of exercise may in fact happen prospectively.

The increase in mean IHR that happened even before movement onset, serves as evidence that mechanisms other than peripheral physiological mechanisms, likely prospective control, may contribute to increases in heart rate during movement anticipation. Research on preparation of movement supports this idea. Heart rate and pulmonary ventilation were found to increase during the mental imagery of locomotion, and these increases were proportional to imagined walking speed (Decety et al., 1991). The fact that autonomic activation happened even before the onset of movement and thus goes beyond metabolic demands, supports the idea of a commonality between preparation for action based on perceptual information and actual performance of action. This is in line with the notion that movements must be guided prospectively in order to make sure energy resources are sufficient and readily available prior to when the action takes place, based on that animals and humans have limited energy available to make movements (Lee, 2005).

The results of the uphill event showed a significant increase in mean IHR when participants were approaching the starting point of the uphill, and the same absolute increase was not observed in the flat control lap where the participants were skiing the same path leading up to the starting point of the uphill but turned around before the uphill started. The mean increase in IHR was quite small, however, as it increased by 2.6 BPM over the last 30 s before the start of the uphill.

The reason that the increase in IHR was quite small for the uphill event compared to the starting event is likely due to natural physiological responses during exercise. As stated in the Introduction, there is an increase in heart rate during exercise because of decreased cardiac vagal tone (Coote, 2010). During prolonged exercise, the heart rate increases proportionally with the workload as a result of increased sympathetic activity. In competitions, biathletes usually ski at a relatively high intensity over long periods of time (Gallicchio et al., 2016). It is therefore difficult to separate the changes in heart rate due to peripheral physiological effects that are present under physical activity from effects that may be a result of, for example, prospective control. Furthermore, a ceiling effect is usually observed under physical activity, which involves that at high intensity levels heart rate can only increase so much as it approaches HR_{max}. During rest or at low intensity, however, heart rate is kept at low levels (Secher, 2007). This means that the range over which heart rate can increase is higher at rest, and the heart rate therefore increases relatively more at the onset of exercise compared to when in activity.

A flat control condition was included in the uphill event in the present study, to control for the peripheral physiological effects discussed above. The results of the uphill event showed a significant increase in mean IHR over the time intervals leading up to the beginning of the uphill. However, IHR was consistently higher when biathletes continued to ski up the hill as opposed to when they took a U-turn and continued to ski a flat control round instead. It is therefore reasonable to assume biathletes were prospectively increasing their heart rate when preparing for the uphill to meet upcoming physiological demands. This means both peripheral factors and prospective control play an important role when it comes to preparing the body to climb an uphill.

As expected, a decrease in mean IHR during the 30 s period prior to the shooting was found. More specifically, a gradual decrease in mean IHR was observed from 30 to 15 s before the shooting, and a more pronounced decrease in mean IHR was observed during the last 15 s leading up to the shooting. The mean IHR decreased by 2.69 BPM during the last 15 s. A small decrease in skiing speed of an average of 0.7 m/s (2.5 km/h) was detected over the last 30-10 s when the participants were approaching the shooting range. However, the speed was kept above 20 km/h over this time period, and the change in speed is thus considered small enough to assume the decrease in mean IHR was caused by prospective control and not by reduced physiological workload because the biathletes were decelerating into the shooting range. Today, most coaches advise their biathletes to maintain skiing speed when approaching the shooting range, rather than merely sliding or "freewheeling" into the shooting range in an attempt to lower their heart rate and catch their breath.

The increase in mean IHR as observed during the start and uphill events, as well as the decrease in mean IHR observed in the shooting event, may be a result of the use of visual prospective control. Evidence for visually based prospective control comes from a study done on long-jumpers (Lee et al., 1982). This study investigated how gait is regulated during the run-up in long jumping and found that in the final phase of the run-up when long-jumpers where approaching the takeoff board, they used external visual information rather than an internal motor program to adjust their final steps. This was done so that their steps would fit the time to arrive at the upcoming takeoff board. The visual guidance of steps thus seemed to be based on how far in time they were from the board, the time-to-contact with the board.

Time-to-contact is a feasible information source for long-jumpers, and is based on a single optical parameter termed tau, which is the inverse of the rate of expansion of the image of the board on the retina (Lee et al., 1982). Similarly, time-to-start, time-to-uphill, and time-to-shooting may be important sources of information for biathletes. In the present study, perceptual information about the time remaining to the start-, uphill-, and shooting events was readily available to the participants. Visual and verbal forewarnings were given prior to the start, the beginning of the uphill was indicated by a line drawn in the snow, and the beginning of the shooting range could also be clearly seen. These cues may have provided participants with important information about what was going to be required of them soon, and they could thus control their heart rate prospectively to prepare the body for the events and accompanying physiological demands they were about to face. Moreover, biathlon is a dynamic sport with a fast-changing environment. It would therefore be advantageous for biathletes to use prospective time-to-contact information to accommodate their action system optimally to the changing environmental and physiological demands. In fact, in future research we plan to investigate whether biathletes who show better prospective control of heart rate and/or breathing rate also perform better in competitions.

In conclusion, the findings of the present study provide evidence that preparatory heart rate responses are prospectively controlled during biathlon events. We showed empirically that biathletes are able to increase their heart rate prior to the start and when approaching uphill terrain, while they decrease their heart rate prior to the shooting during simulated biathlon events. The use of prospective control of heart rate in this context may be important for preparing the body for forthcoming physical effort and other challenges that lie ahead. Preparatory heart rate responses of the kind measured in our study that are clearly dependent on the correct pick-up of predictive perceptual information (Van der Meer & Van der Weel, 2020), may be important for expert performance in a number of different sports, as well as in other fields where regulation of heart rate is the key to success (e.g., brain surgery, performing arts).

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Declaration of interest statement

The authors have declared that no conflict of interest exits.

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