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Original Article

The cardiovascular, cardiopulmonary and metabolic demands of a simulated snowboard cross competition – An exploratory case study

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Abstract
During a snowboard cross competition a successful athlete completes multiple time trials and race heats over the course of a day with varied recovery times. Understanding the demands of a snowboard cross competition can allow for potential performance limiting factors to be identified so that training, nutrition and/or ergogenic interventions can be developed to improve athletic performance. Unfortunately, as of yet, no studies have directly measured the cardiovascular, cardiopulmonary and/or metabolic demands of snowboard cross run or competition. Therefore, as an exploratory case study, we recruited two elite (ranked in the top 5 in the United States) youth (age 16-17 years old) snowboard cross athletes to participant in a case series to fill this knowledge gap. Prior to the study both athletes completed a treadmill based ventilatory threshold and aerobic power test to determine physiological capacity and bioenergetic cut puts. Two days later athletes then took part in a simulated snowboard cross competition that mimicked the 2017 male and female US nationals (2 course inspections, 2 time trials and 2-3 race heats) on an FIS certified course while wearing a portable metabolic cart and heart rate monitor. Averaged race values of oxygen consumption, respiratory exchange, ventilatory rate, breathing frequency, tidal volume and oxygen delivery per heartbeat were reported and referenced to treadmill tests. Comparisons were then made over the course of the competition and between the fastest and slowest runs for both athletes. Results indicate that 1) athletes primarily utilize anaerobic glycolysis at intensities between ventilatory thresholds 1 & 2, 2) oxidative metabolism was impaired due to restricted breathing frequency that may be a necessary component of snowboard cross technique, 3) athletes fully recovered between time trials but not race heats, and 4) athletes glycolytic demands are greater than those predicted by perceived exertion or heart rate data alone. These results suggest that snowboard athletes may benefit from supplemental endurance training similar to the physiological demands reported, strategies which can promote active recovery between race heats, and nutrition/supplementation strategies that can preserve glycogen availability throughout the competition. The present study also highlights the need for additional research related to the role that restricted breathing and dynamic core stability plays in snowboard cross performance and possible benefits of hypoxic and/or core strengthening programs.
Key Words: Snowboard, Boardercross, Carbohydrate, Recovery, Energy system

Introduction

Snowboard cross (SBX) is a relatively new Olympic sport, having been added to competition in 2006 Turin Olympic Games. In SBX, 4-6 athletes race down a predetermined course that includes a number of features such as large banked turns, sharp rolling hills and large jumps. Each competition course varies in the number and type of features present as well as overall length. However, all courses that can be used to determine national or world rankings must be certified by the International Ski Association (FIS) and take most athletes between 60-120 s to complete.

During competition, a SBX athlete will follow a predetermined schedule that can vary based on both the number of competitors at the event as well as their individual performance in time trials and previous race heats. Additionally, unpredictable changes are often made to the schedule resulting from on course injuries or the need for course maintenance. However, a typical FIS competition requires successful SBX athlete to perform 2 time trials as well as 3-4 race heats over several hours in a single day. The recovery time between runs can also vary with long breaks after time trials (1-2 hours) and shorter breaks between race heats (20-30 min). During these recovery times athletes often have to continue to exert themselves to traverse or descend the mountain to a lift as well as hike up to the starting position for their next run.

Unfortunately, there is presently no published research that directly measures the cardiovascular, cardiopulmonary and metabolic demands of a SBX competition. However, two studies have compared how cardiovascular fitness relates to SBX performance among elite athletes (Vernillo 2018). Firstly, Platzer *et al.* (2009) compared FIS ranking of 12 SBX athletes from the Austrian national team to a variety of exercise tests

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and found that of all of the tests performed the strongest relationship to FIS ranking was the maximal work rate during an incremental cycle test (r = 0.85). Expanding upon these results, Vernillo *et al.* (2016) using ten men from the Italian national SBX team, compared work rates and oxygen consumption at VO_2 maximum, ventilatory threshold 1 (VT-1: representing onset of blood lactate acid) and ventilatory threshold 2 (VT-2: representing lactic threshold) to average time trial time on a SBX course. In this study, Vernillo et al. (2016) found that oxygen consumption and heart rate at VT-1, VT-2 and VO_2 max were unrelated to performance. However, they also found that the work rates at each of these relative intensities (VT-1, VT-2 and VO_2 max) were strongly and positively related to performance (r = 0.90-0.93). Taken together, these results highlight the importance of cardiovascular fitness, however suggest that exercise economy (i.e. the work rate with a relevant physiological stress) is more important than physiological capacity (Bassett & Howley, 2000).

Unfortunately, the aforementioned studies do not provide a context as to the actual physiological stresses of competition. Such information is of great importance because it can allow for coaches and athletes to focus on-snow and off-snow training to develop the relevant energy systems for competition as well as help coaches to identify factors that may limit performance in their athletes (Arruza et al., 2005). Additionally, as it has been observed that injury rate increases later in the competition day (Steenstrup et al., 2011) and that a single snowboard run can result in significant fatigue (Vernillo et al., 2017) understanding the cumulative effects is of great importance. For these reasons, as a case study, the cardiovascular, cardiopulmonary and metabolic demands of two elite (top 5 – nationally), junior (U16) American SBX athletes were observed while performing a simulated SBX competition on an FIS certified racecourse in order to create a physiological profile of the demands of a SBX competition.

Materials & Methods

Participants

One male (age 17) and one female (age 16) elite youth SBX athlete gave their informed consent with parental permission to take part in this study, which was approved by the institutional review board at the University of Rhode Island. Both athletes had been enrolled in Carrabessett Valley's Snowboard Academy (Carrabessett, Maine USA) for at least two years, where they trained on at their host mountain (Sugarloaf Mountain) 4-6 days per week during the winter. At the time of testing both athletes were ranked in the top five in their age category by FIS points.

Study Design

The present study used a case study design in which both athletes took part in two subsequent days of testing. On the first day, athletes completed a maximal graded incremental treadmill test that was used to determine physiological capacity [Ventilatory threshold-1 (VT-1), ventilatory threshold 2 (VT-2), & maximal oxygen consumption (VO_2 Max)]. Then on the second day, athletes completed a simulated SBX competition, which followed the competition schedule of the medaling athletes in the 2017 US nationals (see Table 1), in which the cardiovascular, cardiopulmonary and metabolic demands of competition were assessed.

Graded Treadmill Test

Participant completed a graded treadmill test on an off day of training and after a two hour fast. Prior to the test athletes completed a standardized dynamic warm-up consisting of 10 of each of the following stretches deep squats, walking forward lunges, knee hugs, quad pulls and toy soldiers before being outfitted with a portable metabolic cart (Oxycon Mobile, Cosmed, USA) and heart rate monitor (polar, USA) and given 5 min of passive recovery. The graded exercise test consisted of a 5 min warm-up stage with 3 min at 3.5 mph and 2 min at 5 mph immediately before the first stage. Each stage of the test was 2 min in duration and the test ended when the athlete could no longer maintain the pace of the treadmill. The speed at the first stage was 7.0 mph, which increased by 0.5 mph after each stage. If the athletes reached 9.5 mph and the incline of the treadmill was then raised by 0.5° per stage for the remaining stages. In the final 30 s of each stage the rate of perceived exertion was measured using the 6-20 Borg scale and blood lactate was measured via finger stick (Lactate Plus, Nova Biomedical, USA). To be considered a successful test the follow had to occur; respiratory exchange ratio (RER) > 1.1, heart rate within 10 bpm of age predicted max, and lactate above 8.0 mmol/L (Svedahl & MacIntosh, 2003). The greatest relative oxygen consumption throughout the test was recorded as VO_2 Max, and inflection points of RER data during the test were used to determine VT-1 and VT-2 respectively using the metabolic cart's associated software.

Simulated Competition

The day following the graded treadmill test participants performed simulated SBX competition, which followed the competition schedule of the medaling US male and female youth athletes of their respective age groups. Testing took place in March 2018 on a racecourse at the athletes' host mountain (Sugarloaf Mountain) that was used for an FIS competition two weeks prior to testing. Athletes were instructed to follow their normal routine, which included eating and drinking schedules, warm-up routine and use of down time in order to best replicate the competition (Sporer et al., 2012). Both athletes were required to report at the start of the course at 9:00 am and were given 1 hour to complete 1-2 slow to moderate speed course inspection runs. The course was then closed off to the athletes before their first time trial at 10:57 am. Both athletes were then given 2 time trials before completing 3 (female) or 4 (male) simulated race heats. Before each time trial and race heat temperature and wind-speed were recorded from the race start using a WBGT (Kestrel 5400, Kestrel USA) and participants were asked to report the snow conditions.

As the schedule was taken from the previous year's US national championships it can be noted that the differing recovery times and number of race heats between genders was due to a lower number of participating female athletes and that in the male competition there was a longer than normal anticipated between the final race heats (22 min vs ~17 min) due to course maintenance before the final heat.

Metabolic Cart Measures

During the time trials and race heats cardiovascular, cardiopulmonary and metabolic measures were taken with a portable metabolic cart, finger stick lactate and heart rate monitor (see Figure I). During and after each run oxygen consumption (VO_2), carbon dioxide exhalation (CO_2), respiratory exchange ratio (RER), minute ventilation (VE), breathing frequency (BF), tidal volume of exhalation (TV_{ex}), heart rate (HR) and oxygen delivered per heart beat (O_2/HR) were recorded and compared between each athlete's fastest and slowest runs. Levels of O_2 consumption were reported and referenced to physiological intensities (VT-1, VT-2 and VO_2 max) observed during treadmill tests (Svedahl & MacIntosh, 2003).

Figure I: A depiction of experimental set-up.

Results

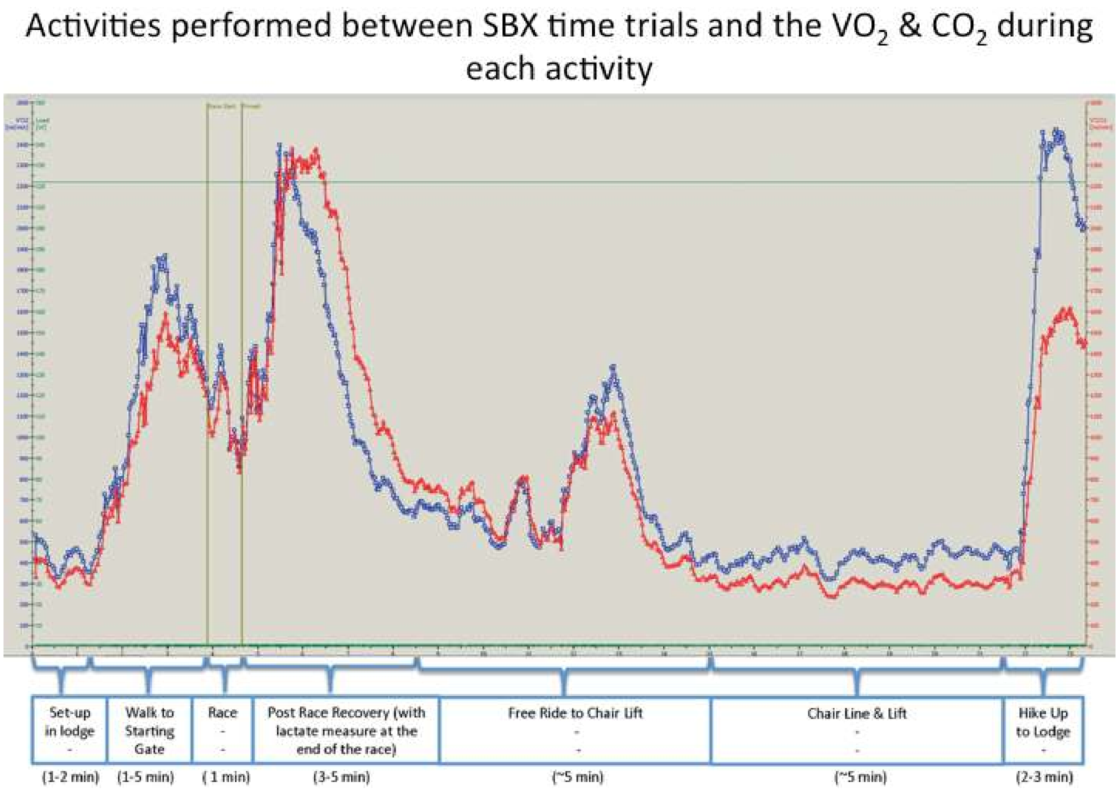
The male youth athlete had a VO_2 max of 55.6 ml/kg/min and VT-1 and VT-2 occurred at 69% and 84% of VO_2 max while the female youth athlete had a VO_2 max of 49.6 ml/kg/mL and VT-1 and VT-2 occurred at 53% and 92% of VO_2 max. These values are comparable to those reported for the Italian men's SBX team (Vernillo et al. 2016) who had an average VO_2 max of 51.2 ml/kg/mL and VT-1 and VT-2 occurred at 72% and 86% of VO_2 max, which the exception of the female youth athlete's VT-1 which occurred at a lower intensity than the values previously reported.

Snow conditions were unchanged throughout both testing sessions with athletes reporting conditions as "hard-packed". Temperature remained relatively stable ranging from -4.0˚ to -1.8˚ C for the male and -9.3˚ to -7.7˚ C for the female athlete. Wind speed was minimal during the male's competition (range 0.0 – 1.5 mph) but dropped from 12 mph during the first time trial to 3.8 mph during the final race heat for the female athlete indicating a potential confounding variable. No measurable precipitation occurred during data collection.

A graph showing the typical oxygen consumption demands of a SBX run from approaching the gate to start the run, until approaching the gate for a subsequent run are presented is presented in Figure II. During the run, oxygen consumption (VO_2) was marginally elevated from resting values prior to the start of the run. During the run itself oxygen consumption ranged between 23-38% of VO_2 max for the male participant and 29-42% of VO_2 max for the female participant with faster runs being characterized by relatively stable O_2 consumption and slower runs being characterized by an rapid increase in O_2 consumption (see Figure III).

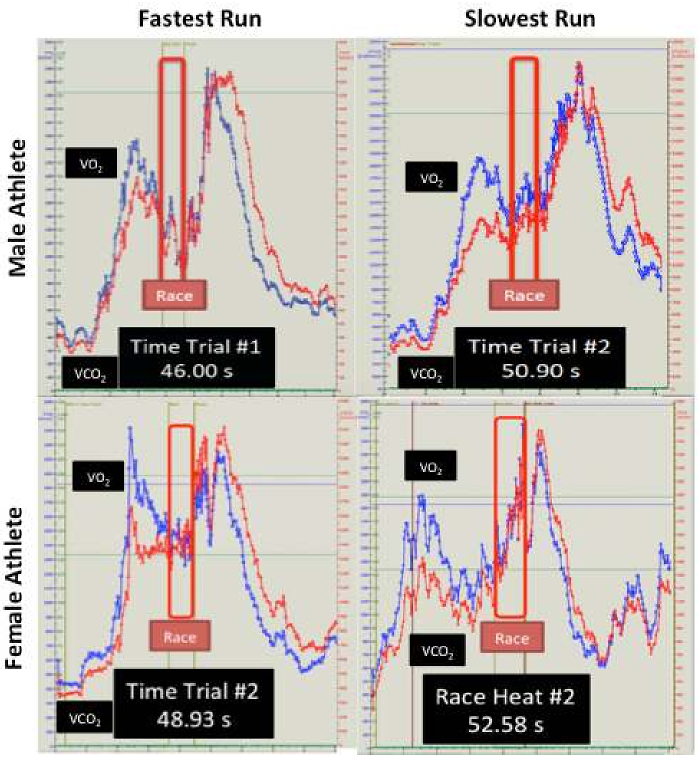
During the run RER ranged between 0.87-1.01 for the male athlete and 0.87-0.97 in the female athlete indicating increased reliance on anaerobic metabolism from rest (see Figure IV). After the time trials athletes able to reach stable VO_2 and RER values similar to baseline between 3 and 7 minutes, however in race heats athletes often experienced incomplete recovery before being required to prepare for their next race heat.

Figure II: Example of VO_2 and CO_2 demands during a snowboard cross run. Details of each activity performed between race heats as well as the expected time spent performing each task is provided. Data presented is between the male athlete's first two time trials.



Activities performed between SBX time trials and the VO_2 & CO_2 during each activity

Figure III: Comparison of the VO_2 (blue) and CO_2 (red) demands between each athlete's fastest and slowest runs.



Similar to VO_2, VE was elevated prior to the run and decreased from this elevated rate during the run (see Figure IV). During the race, BF drastically fell from pre-race values in all runs for both athletes while VT_{ex} remained relatively stable indicating the drop in VE was due to a decreased number of breaths during the race and not from shallower breaths (see Figure V).

Figure IV: Comparison of the minute ventilation (VE) between each athlete's fastest and slowest runs.

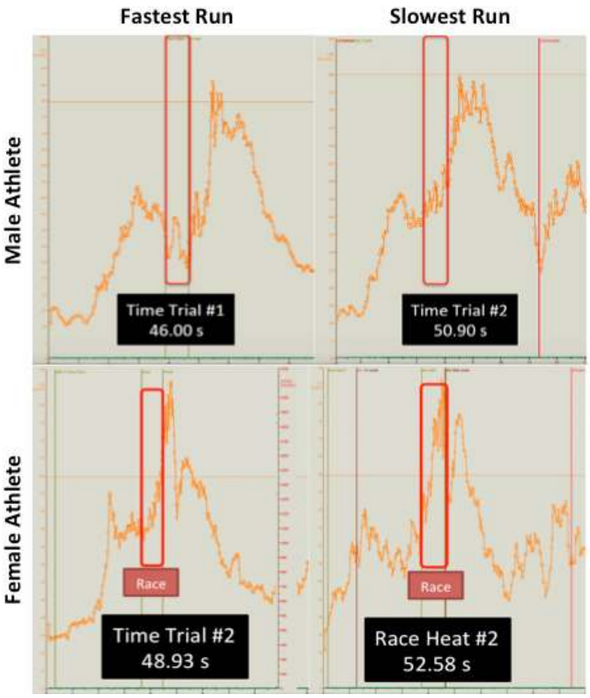
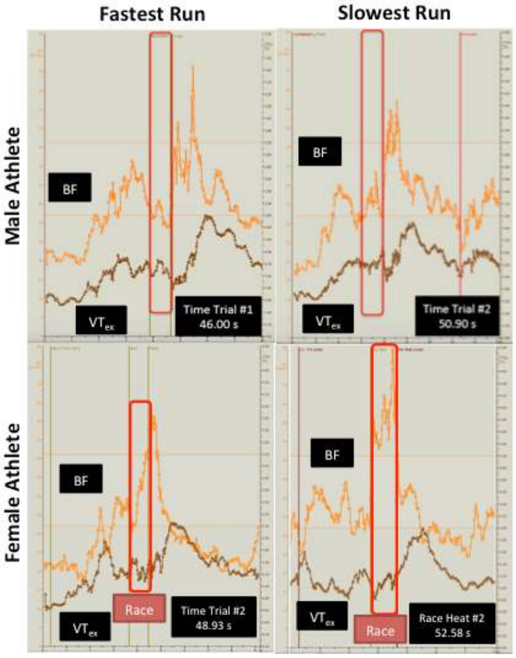
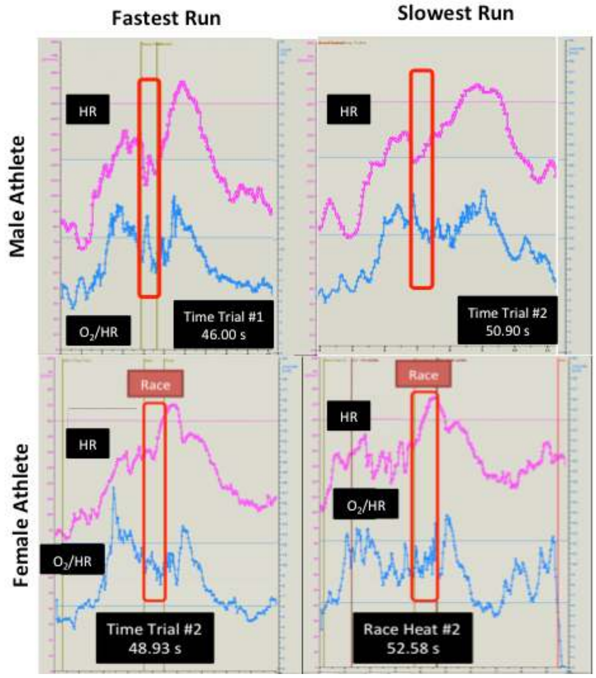


Figure V: Comparison of the breathing frequency (orange) and exhalation tidal volume (brown) between each athlete's fastest and slowest runs.



During the race HR ranged from 107-126 (52-62% of age predicted max HR) in the male athlete and 107-126 (52-59% of age predicted max HR) in the female athlete. During the race estimated O_2/HR decreased from pre-race values indicating a negative physiological aspect of decreased oxygen consumption (see Figure VI).

Figure VI: Comparison of heart rate (prink) and O_2 delivery per heart rate (blue) between each athlete's fastest and slowest runs.



Discussion

The primary purpose of the present study was to ascertain the cardiovascular, cardiopulmonary and metabolic demands of a SBX competition. A secondary purpose of the study was to compare each athlete's fastest and slowest runs in order to provide context as what differentiates successful and unsuccessful runs. This knowledge can be used so that performance limiting factors to be identified so that training, nutrition and/or ergogenic interventions can be enacted to improve athletic performance.

Of note is that during each run, while VO_2 was marginally elevated prior to the start of the run (~40-50% of VO_2 max), during the run VO_2 substantially dropped (23-42% of VO_2 max). These results suggest aerobic capacity is not a limiting factor of performance, which supports the previous observation that VO_2 max is not related to SBX performance (Vernillo et al., 2016).

While aerobic capacity was not a limiting factor of performance aerobic metabolism was hindered by a decrease in VE and BF from pre-race values, which also resulted in decreased O_2/HR an indicator of effective oxygen delivery to active muscle (Casey & Joyner, 2011). Both athletes experienced restricted breathing during the run likely due to high force isometric contractions performed in a flexed trunk position (Hackett & Chow, 2013). To provide further evidence a typical valsalva response was observed where oxygen delivery per heart beat dropped causing heart rate to rapidly increase and then rapidly drop (Hackett & Chow, 2013). Additionally, when comparing the fastest and slowest runs for both athletes, when breathing rate increased during the run the athletes performance suffered. Speculatively, these results may indicate that restricted breathing may result from successful SBX technique or that uncontrolled breathing during the run results in decreased performance (Looga, 2005).

During each run the athlete's RER ranged from 0.87 – 1.01 indicating that the primary energy system utilized during the run was anaerobic glycolysis. In further support, each run resulted in an increase in blood lactate as measured by a finger stick measurement immediately after the race. As absolute lactate values are highly variable between individuals these measures hold more value when related to ranges below VT-1, between VT-1 and VT-2, and above VT-2 are more meaningful to practitioners. In the present study it was observed that in all successful runs lactate values fell between VT-1 and VT-2. These results indicate that during a snowboard run there is a high reliance on anaerobic glycolysis that is at an intensity that is below VT-2 or the point to which the ability of the muscle to buffer muscle acidity is not exceeded. Therefore, the results from the present study suggest that metabolic acidosis is an unlikely limiting factor of performance (Xu & Roberts, 1999). In contrast, the work capacity of VT-1 may be a limiting factor of performance (Myers & Ashley, 1997; Xu & Roberts, 1999), an observation also observed in elite adult SBX athletes. It is also important to note that because of the importance of glycolytic metabolism to performance athletes and the long duration of competition it is important that athletes take part in feeding strategies that prevent glycogen depletion during later race heats (Coyle et al., 1983).

After the race RER exceeded 1.2 in both individuals in all runs, indicating hyperventilation and continued reliance on anaerobic metabolism during recovery. Similarly, after the race VO_2, minute ventilation, breathing rate and heart rate all sharply increased and remained elevated above pre-race values for 3-5 minutes. During this recovery period VO_2 reached up to 70% of VO_2 max and heart rate rapidly increased up to 86% age predicted heart rate maximum. During this time, the athletes also hyperventilated as indicated by a respiratory exchange ratio (RER) greater than 1.2. These results indicate significant post-exercise oxygen consumption (EPOC) and that the energy demands during the run were not met using aerobic metabolism. Therefore, athletes may benefit from training, techniques, or ergogenic aids which can improve the rate recovery immediately post run so that athletes are prepared for subsequent runs (Verma et al., 1979).

This study has several important limitations necessary to be accounted when interpreting. Firstly, because of the case study design application of this information should be cautioned (Lobo et al., 2017), especially when translated to adult, in preparation for competitions with differing schedules, or with athletes with differing levels of cardiovascular fitness (White & Johnson, 1991). It should also be noted, that while both athletes should similar trends in many variables when comparing fastest and slowest runs, both athletes trained at the same facility and have been coached by the same coaches, thus differences may exist between athletes given different tactical or technical approaches to competition (Arruza et al., 2005). It is important to note that the race heats did not have other competitors in the field, thus athletes always took optimal lines and they did not benefit from tactical approaches such as drafting (Fuss 2018 & Wu 2006). Finally, it should be noted that the mountain at which testing occurred has a maximum altitude of 1291 m, and that competitions at higher altitudes would affect both oxygen availability and drag resistance (Chapman et al., 2009).

Conclusions

In conclusion, the nature of SBX competition creates several unique physiological challenges such as multiple runs throughout the day with varied recovery time and an athletic position that may restrict breathing. Understanding these challenges can allow coaches and athletes to identify factors which may limit performance, optimally design both on-snow and off-snow training programs to match the cardiovascular and cardiopulmonary demands of competition and implement fueling and recovery strategies that allow for optimal performance to be maintained.

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Conflicts of Interest Statement

We declare there are no conflicts of interest related to this study.

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