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Research article

Metabolic Demand of Paralympic Alpine Skiing in Sit-Skiing Athletes

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Abstract
Paralympic Alpine Skiing comprises three main categories, namely Standing, Visually Impaired and Sitting, to one of which athletes get classified depending on their individual impairment of ability. An existing sport profile of alpine skiing for able-bodied athletes facilitates the physical preparation process of Standing and Visually Impaired athletes. However, very little is known about performance determinants as well as content and structure of the physical preparation of athletes with congenital or acquired spinal cord injury competing in the Sitting class. The objective of this study was to describe the metabolic demands of Paralympic Alpine Skiing Sitting class athletes using laboratory and field measurements. The study determined maximal oxygen uptake (VO_{2max}), maximum heart rate (HR_{max}) and maximal blood lactate concentration ($[La^-]$) as well as ventilatory thresholds in laboratory testing (n = 6) as well as on-snow in Slalom (SL) carried out in a ski dome, and Giant-Slalom (GS) on a natural slope. On-snow test variables are expressed normalized to laboratory maximum values ($\%VO_{2max}$, $\%HR_{max}$). For SL, values reached ~30% VO_{2max} and ~60% HR_{max} whereas GS values were slightly higher reaching ~50% VO_{2max} and ~75% HR_{max}. Lactate concentration remained close to baseline values for SL and was slightly higher at ~3 $mmol \cdot L^{-1}$ for GS. All athletes remained below their second ventilatory threshold and even skied for a long portion of runtime below their first ventilatory threshold. In general, measured metabolic values were lower than reported for able-bodied alpine skiers. However, despite the small and inhomogeneous sample covering all but one sit-skiing classes, strain of sit-skiing appears to be consistent throughout the five sit-skiing classes. Common measures of aerobic or anaerobic performance variables do not suggest further investigations in the field of metabolism for performance determinants in sit-skiing.

Key words: Paralympic winter sports, paraplegia, wheelchair exercise physiology.

Introduction

For decades, physiology of alpine skiing has been a topic of research with several publications (Andersen and Montgomery, 1988, Turnbull et al., 2009), primarily focussing on energy systems' contributions to the task of ski racing. As the sport has undergone equipment changes during the last decade, research has continued to provide a clear profile of current metabolic demands and parameters for elite alpine ski racers. This profile is reflected in classic measurable parameters during a skiing run like oxygen uptake (VO_2), heart rate (HR), to individual maxima normalized values expressed as percentage of maximum oxygen uptake and maximum heart rate ($\%VO_{2max}$, $\%HR_{max}$), and blood lactate concentration ($[La^-]$). Apparently, more recently reported values (von Duvillard et al., 2009) are lower than those from corresponding studies around the 80s (Karlsson et al., 1978; Veicsteinas et al., 1984). The extent of the different energy supplying systems' contribution to the respective alpine skiing disciplines is still topic of research (Vogt et al., 2005), focusing on the importance and weighting of aerobic and anaerobic capacities.

General Alpine skiing performance determinants have almost been entirely identified yet, but, despite longitudinal research (Impellizzeri et al., 2009), definite parameters with the potential to predict performance are lacking. Therefore, both aerobic and anaerobic fitness conditioning and its measurement are part of elite alpine skiers' training regimes (Gross et al., 2014).

In Paralympic Alpine Skiing, no information is available about metabolic parameters of an actual skiing load. According to IPC Classification Rules and Regulations Paralympic Alpine Skiing is subdivided into three competition classes: Standing class (e.g. upper or lower body limb loss, skiing with or without prosthetic or cerebral palsy), Visually Impaired class, and Sitting class (IPC, 2015). For the group of standing and visually impaired athletes, this lack of description of the race profile is mainly due to the simplistic assumption that findings on aerobic and anaerobic demands for able-bodied skiers accordingly apply for handicapped athletes. Obviously, for one leg standing athletes these assumptions are inappropriate, but no ski-specific research has presented for metabolic variances in this group to date and these athletes simply adopt a disability-specific modified training program.

The group of sitting athletes having acquired or congenital paralysis or lower limb loss use a sit-ski, and therefore, this kind of adaptation of training content is not feasible because of substantial differences in the nature of equipment used and the sitting posture during alpine skiing.

For other Paralympic sitting sports however, research has been conducted with various investigations focusing on endurance disciplines like wheelchair racing for paraplegic and tetraplegic athletes (Davis, 1993; Bhambhani, 2002; Shephard, 1988).

Individual location site and level of lesion determine the specific impairment of athletes' abilities. Accordingly, wheelchair ergometry performance of paraplegic cross-country skiers displayed clear differences for athletes with a lesion level resulting in tetraplegia (higher than the first thoracal vertebra (T1)), paraplegic athletes with a lesion level between T1 and T5, and athletes with a lesion level lower than T5.

The level of lesion is associated with the level of impairment of abilities which mainly impacts on locomo-

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tor and respiratory muscles' innervation and therefore on performance (Eriksson et al., 1988; Wells and Hooker, 1990).

Independent from lesion level (high or low) of paraplegic athletes, no significant differences in ventilatory or cardiorespiratory parameters were described (Bernard et al., 2000). In all parameters of cardiorespiratory fitness, e.g. aerobic capacity, a significant difference was only shown between tetraplegic and paraplegic athletes (Davis, 1993).

Accordingly, for Paralympic Alpine Skiing sitting athletes no restrictions in aerobic or anaerobic capacity are to be expected as complete tetraplegia is not represented among this class confirmed by results from the Italian National Paralympic Alpine Skiing Team members (Bernardi et al., 2012). Nevertheless, no information about metabolic and cardio-respiratory strain during the execution of Paralympic Alpine Skiing is available. Hence, implications for an optimal distribution of intensity in endurance training (Seiler and Kjerland, 2004) and related research in general on this topic are lacking. Therefore, the aim of the current study was to analyse parameters of VO_2, HR and lactate concentration $[La^-]$ for both laboratory and field measurements of Slalom (SL) and Giant Slalom (GS) competition like runs in order to identify metabolic strain in Paralympic Alpine Skiing sitting athletes for the purpose to derive sufficient information for sit-skier's physiological training preparation.

Methods

Experimental approach to the problem

The study included laboratory fitness testing, skiing in standardized conditions (ski dome) and on–snow field testing on a regular outdoor slope.

Measured variables were VO_2, HR and blood lactate concentration $[La^-]$ during exercise testing in the laboratory prior to the respective field testing sessions. Ventilatory thresholds (VT 1, VT 2) were determined for each athlete from the fitness testing data in order to relate skiing data to three zones: below the first ventilatory threshold (<VT 1), between the first and second threshold (VT 1- VT 2) and above the second ventilatory threshold (>VT 2).

During SL and GS runs cardiopulmonary data were collected, and $[La^-]$ samples were taken after each run. Relative workloads and the percentage of exposure to the threshold-zones were calculated based on the measured laboratory output values.

Participants

A total of six Sitting-class athletes, four male (31±5.9 years, 69 ± 10 kg, 1.76 ± 0.09 m) and two female (18.5 ± 0.7 years, 40 ± 0 kg, 1.34 ± 0.02 m), of the National Paralympic Team participated in the study. Four of the athletes participated in a pre-SL laboratory and in SL on-snow testing, five completed pre-GS laboratory tests and on-snow GS measurements. All athletes had a history of being part of the national team for at least three years and have competed on the International Paralympic Alpine Skiing World Cup circuit sanctioned by the International Paralympic Committee (IPC) for the same duration of time and were ranked among the Top 5 (female) and Top 10 (male), respectively, at the time of testing.

Every athlete was internationally classified by the IPC's sports classification panel. The process of classification according to IPC Alpine Skiing Classification Rules and Regulations (IPC, 2015) clusters athletes with similar injury or impairment patterns in so called LW (locomotor winter) 12-2 to LW 10-1 groups representing residual functional trunk musculature. In this context, LW 12-2 class athletes have the highest amount of functional trunk muscles as a consequence of the lowest levels of lesion, whereas on the opposite side of the spectrum LW 10-1 class athletes show the least amount of utilizable trunk muscles with sitting stability being considerably impaired.

Representing the wide variation in lesions and limits our study group consisted of two LW 12-1, one LW 11, two LW 10-2 and one LW 10-1 classified athletes participating in the study.

The study was approved by the ethics committee of the local School of Medicine, and written informed consent was obtained from the athletes before commencing data collection.

Figure 1. Paralympic Alpine Skiing sitting athlete in field measurement situation equipped with mobile metabolic analyzer.

Procedures

An incremental step test was performed prior to the respective field testing session on a wall mounted handcycle ergometer with cranks operating in synchronous mode (Brachumera, Lode, The Netherlands). Initial workload for female athletes was set at 40 W and at 50 W for male athletes with a 10 W increment every 3 minutes for all athletes.

All gas exchange variables were measured with a metabolic analyser (Figure 1) applicable for stationary and mobile operation (Metamax, Cortex Biophysik, Germany) which according to manufacturer's manual provides a reliable operation temperature range from -10°C to +40°C. Additionally, HR (Polar S625, Finland) and blood lactate concentration $[La^-]$ (Biosen S Lab+, EKF Diagnostics, Germany) were measured. Each incremental test was performed to volitional exhaustion. All athletes reached a plateau in oxygen consumption and a respiratory exchange ratio (RER) > 1.10 during the last stage which was defined as maximum performance. VO_{2max} was defined as the highest 30 s mean value, and ventilatory thresholds VT 1 and VT 2 were determined (Wassermann et al., 1973) with VT 1 representing the threshold of transition from aerobic to aerobic-anaerobic metabolism and VT 2 the threshold of a continuous increase in lactate accumulation.

The same parameters as in the laboratory testing were measured on snow. Standardized skiing was carried out under controlled conditions in an indoor ski dome (Snowworld Landgraaf, The Netherlands) performing a 26-gate Slalom (SL) course on an icy water-injected slope. On-snow field testing was performed on a glacier in the Austrian Alps on an evenly set 30-gate Giant-slalom (GS) course on medium steep terrain and solid snow conditions. For on-snow testing, the same mobile metabolic analyser as in the lab was used. In addition to the standard calibration, the system was calibrated for temperature, altitude, relative humidity and barometric pressure. To prevent disturbances in air flow near the sensor, a windshield for the turbine body provided by the manufacturer was applied. The small, lightweight metabolic analyser was stored underneath the jacket not interfering with the athlete's mobility.

Capillary blood samples for $[La^-]$ determination were collected from the athlete's earlobe one minute after completion of the course with a mobile analyser from the same manufacturer as used in the laboratory tests (Lactate Scout, EKF diagnostics, Germany). Storing the hand-held analyser underneath the tester's jacket and close to the body until sample draw temperature was consistently above the temperature range of +5°C - +45°C for reliable operation.

A 5-s moving average was applied for breath-by-breath data of mobile gas exchange measures prior to further analysis. Athletes completed three GS and six SL runs in a race-like skiing manner.

In order to familiarize athletes with wearing a face mask during skiing, all athletes performed two warm up runs before data collection.

Statistical analyses

Descriptive statistics were compiled for laboratory data as well as SL and GS data for all participating athletes, expressed in relative workload of HR (%HR_{max}), VO_{2max} (%VO_{2max}) and $[La^-]$ during exercise.

Due to the small number of athletes, yet representing the country's population, as well as athlete differences in lesion level and different classifications accordingly, means and SDs were also calculated for each athlete separately.

For GS, run times were normalized at 100% and exposure to their individual threshold zones during three runs were calculated for each athlete.

Results

The incremental tests for athletes participating in the pre-SL laboratory testing (n = 4) returned a VO_{2max} of 33.1 ± 1.2 ml·kg^{-1}·min^{-1} (2.1 ± 0.5 L·min^{-1}), a HR_{max} of 195 ± 6 beats·min^{-1}, and a maximum $[La^-]$ of 11.8 ± 0.9 mmol·L^{-1}. Pre-GS laboratory testing revealed values for VO_{2max} of 44.5 ± 4.9 ml·kg^{-1}·min^{-1} (1.8 ± 0.2 L·min^{-1}) for female athletes (n = 2) and 35 ± 3.6 ml·kg^{-1}·min^{-1} (2.4 ± 0.2 L·min^{-1}) for male athletes (n = 3). HR_{max} reached 188 ± 22 beats·min^{-1} for female and 165 ± 35.9 beats·min^{-1} for male athletes and maximal values of $[La^-]$ of 7.9 ± 1.2 mmol·L^{-1} for female athletes and $[La^-]$ of 9.3 ± 2.5 mmol·L^{-1} for male athletes were observed. VT 1 and VT 2 values for female athletes were 0.96 ± 0.07 L·min^{-1} and 1.61 ± 0.13 L·min^{-1}, respectively. For male athletes a VT 1 of 1.13 ± 0.18 L·min^{-1} and a VT 2 of 1.88 ± 0.04 L·min^{-1} were observed.

Indoor ski-dome (SL, n = 4) and on-snow (GS, n = 5) measures are expressed as a percentage of VO_{2max} and HR_{max} for repeated runs of SL and GS presented in Table 1 for each athlete.

Overall, %VO_{2max} (25.8 ± 8.2), %HR_{max} (60.2 ± 8.0) and $[La^-]$ (0.8 ± 0.3 mmol·L^{-1}) during SL were lower compared to GS with 49.6 ± 4.7 %VO_{2max}, 73.3 ± 6.6 %HR_{max} and $[La^-]$ = 3.1 ± 1.5 mmol·L^{-1}, (Figure 2).

During three runs, all athletes remained below their VT 1 or between VT 1 and VT 2, except for 3% of one athlete's run (Second run PA 3), so no other athlete exceeded the individual VT 2 in GS (Figure 3).

Discussion

The purpose of this study was to describe the physiological demands of Paralympic Alpine Skiing sitting athletes in laboratory and field measurements and to prove the feasibility of on-snow testing in this population.

Athletes' laboratory incremental test values showed a wide range but were generally in accordance with previously published data for handicapped athletes of sports with intermittent characteristics such as wheelchair tennis or wheelchair basketball (Bernardi et al., 2010). Additionally, oxygen uptake values of 31.3 ± 6.6 ml·kg^{-1}·min^{-1} were reported for Italian Paralympic Alpine Skiing sitting athletes; and somewhat higher values at37.4 ± 1.08 ml·kg^{-1}·min^{-1} for athletes (n = 3) performing well in their sport (Bernardi et al., 2012). Accordingly, for

Table 1. Individual relative workload of Paralympic sit-skiers of six SL and three GS runs with corresponding pre-GS laboratory data of ventilatory thresholds. Data are means (±SD).

	Slalom (SL)			Giant Slalom (GS)			VT1			VT2		
	%VO_2max	%HRmax	[La-] mmol·l^{-1}	%VO_2max	%HRmax	[La-] mmol·l^{-1}	VO_2 l·min^{-1}	HF bpm	P W	VO_2 l·min^{-1}	HF bpm	P W
PA1	-	-	-	48 (4.6)	83.0 (8.3)	2.15 (.40)	.9	148	65	1.7	170	74
PA2	31.6 (3.6)	69.0 (8.0)	.83 (.21)	55 (3.9)	67.0 (11.1)	2.35 (.44)	1.0	163	63	1.5	190	86
PA3	33.2 (13.2)	52.0 (3.1)	.97 (.12)	53 (7.4)	74.0 (1.0)	2.63 (.44)	1.4	92	76	1.9	108	110
PA4	15.8 (4.4)	64.0 (4.3)	.89 (.13)	43 (3.7)	67.0 (3.8)	2.50 (.37)	.9	116	71	1.9	150	84
PA5	-	-	-	49 (1.7)	74.0 (12.3)	5.60 (1.10)	1.1	115	59	1.8	176	116
PA6	22.4 (3.2)	55.6 (1.6)	.79 (.72)	-	-	-	-	-	-	-	-	-

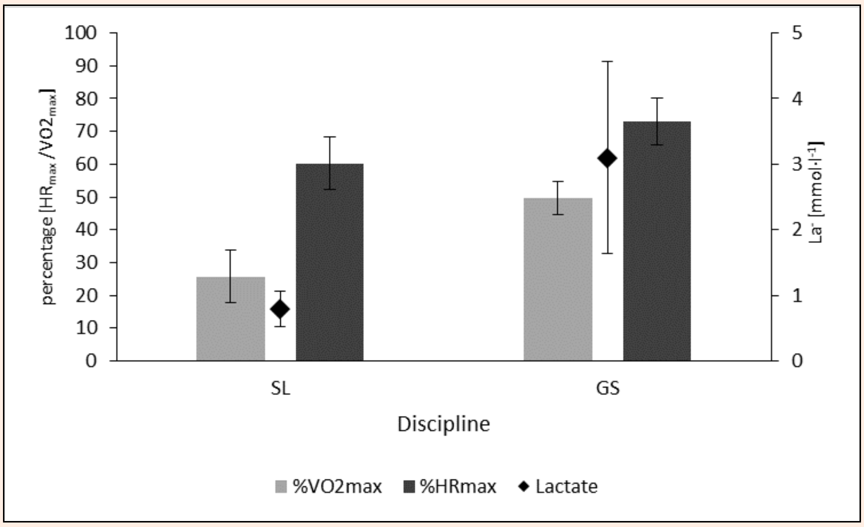

Figure 2. Mean ± SD values of all Paralympic athletes for the disciplines of Slalom (SL, six runs) and Giant Slalom (GS, three runs). Values are expressed as percentage of maximum heart rate (%HRmax, black bars), maximum oxygen consumption (%VO_{2max}, grey bars) and absolute lactate values ([La-] in mmol·L^{-1}).

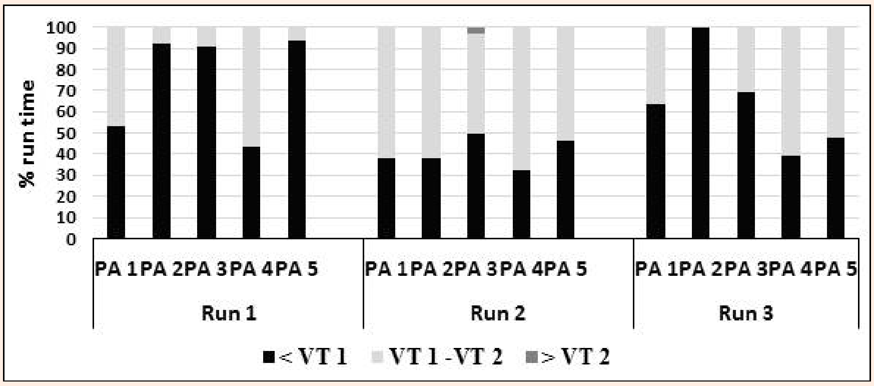

Figure 3. Athletes' exposure to their individual threshold zones in each of three Giant Slalom runs.

our athletes a comparable fitness level and a general ability to perform well in the discipline of alpine skiing could be assumed prior to field measurements.

Interestingly, despite the small sample size and inhomogeneity in athletes' lesion levels, metabolic strain was comparable within a single discipline, however, differed between SL and GS, findings that were additionally affirmed by results of a previous pilot study (Goll et al., 2012).

In relation to able-bodied skiers, all measured physiological variables during SL and GS sit-skiing remained below the reported values for alpine-skiing (Turnbull et al., 2009).

One reason for lower metabolic strain may be that the duration of our SL course, due to limited slope length in ski-dome conditions, was shorter (~30s) compared to able-bodied SL (~50s). As lactate concentration is related to intensity and duration the shorter duration of the SL runs in our study may explain at least in part the low lactate values found. For oxygen uptake according to an able-bodied skiing study with a run-time of ~45 s (Vogt et al., 2005), values of up to 90% VO_{2max} can be expected. However, even when performing longer run times of approximately 55 s in our GS testing section of the study, all measured values remained clearly below values of 90% VO_{2max} and were at most comparable or even lower than those reported during a 60-70s GS run for able-bodied skiers (von Duvillard et al., 2009, Spirk et al., 2012). The fact that athletes can only use a small muscle mass, usually upper body muscles as well as some trunk muscles utilized in combination during sit-skiing may explain at least in in part our results. Also, performance limiting factors like reported for alpine skiing (Ferguson, 2009) have not been investigated for sit-skiers yet, specifically, potential effects of equipment (sit-ski suspension) on sit-skiing strain and athletes' muscle fibre recruitment have not been considered. Focussing on the low lactate values, it appears that external forces occurring during SL and GS turns are absorbed to a large degree by the suspension unit of the sit-ski, which in turn reduces the actual load on the athlete substantially. In that case, back and abdominal muscles would be used for maintaining balance but may not be required to produce the same amount of high eccentric forces previously reported for standing ski racers (Tesch, 1994). This difference in force production may, at least in part, explain why metabolic strain is lower in sit-skiing than in standing athletes. Additionally, the notion also matches lactate responses of the sit-skiers. As anaerobic contribution to whole body metabolism was clearly lower in sit-skiers, it is suggested that high lactate concentration in standing athletes mainly stems from the demand on large lower limb muscle groups, which obviously are not being used by sit-skiers.

Heart rate values expressed as $\%HR_{max}$ observed in disciplines like wheelchair tennis, wheelchair basketball, or wheelchair fencing are in accordance with those observed in our study; however, the submaximal character of those sports is more likely to be ascribed to athlete's self-pacing (Bernardi et al., 2010) rather than to short duration or low load like in the case of sit-skiing. However, compared to able-bodied alpine ski racing where athletes are reported to reach their individual HR_{max} (Veicsteinas et al., 1984), Paralympic Alpine Skiing sitting athletes showed HR values that remain on a sub-maximal level suggesting that aerobic performance or rather generally endurance capacities, plays a smaller role for sit-skiers compared to standing or able-bodied alpine skiers. The values of time normalized runs, representing the athletes' exposure to their individual ventilatory threshold zones additionally support the interpretation of the low lactate values as low anaerobic demands and complete the picture of moderate strain on sit-skiing athletes even under repeated race-like situations.

Conclusion

Based on the results of the study and concerning the physical conditioning process, it appears that neither aerobic nor anaerobic performances are crucial factors for success in Paralympic sit-skiing. Thus, aerobic training as well as general physical conditioning aiming to increase maximal oxygen uptake appears to have a secondary role compared to the specific sit-ski technique. Nevertheless it might be useful to screen athletes for medical diagnostic purposes and for a fitness state sufficient to deal with the conditions associated with their sport such as high altitude, cold, on-snow training volume and travel to ensure optimal recovery and/or stamina to endure a rigorous daily schedule. With respect to reported values in the literature (Bernardi et al., 2012, Goosey-Tolfrey and Leicht, 2013) and values observed in this study, a VO_{2max} comparable to wheelchair sports with an intermittent load structure appears to be sufficient.

The same applies for anaerobic performance, which is also no crucial factor of sit-skiing performance.

Additionally, with regard to the process of establishing evidence-based classification (Tweedy and Vanlandewijck, 2011) and for future research, effort should be put in increasing sample size, which currently is the biggest limiting factor, however not uncommon in Paralympic research. International research projects could be a promising option to increase participant numbers.

Investigations on external forces, strength, and motor control demands during sit-skiing could complete the profile of the sport and help gaining additional information for an optimized physical conditioning program for sit-skiing.

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Key points

- Metabolic demand and strain of Paralympic sit-skiing is different to able-bodied skiing.
- Measured parameters of VO2max and [La-] are lower in sit-skiers compared to able-bodies skiers.
- Equipment used for sit-skiing is suggested to absorb external forces to some degree, thereby lowering the strain.
- Implications for training focus (e.g. skiing higher volumes with a focus on technique) and the physical conditioning process (aerobic/ anaerobic capacity are suggested to be no performance determinants) may be derived.

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