HUMAN MOVEMENT
2015, vol. 16 (2), 83–87

PERFORMANCE DIAGNOSTIC IN CROSS-COUNTRY SKIING

doi: 10.1515/humo-2015-0030

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ABSTRACT
Purpose. Recreational cross-country skiers can benefit from a performance diagnostic when planning a training program. The aim of this study was to establish a simple test protocol to measure endurance capacity and provide training recommendations. **Methods.** The relationship between endurance performance and cross-country skiing technique was assessed using two tests. First, a lactate threshold test whereby running speed was determined on a treadmill at 4 mmol/l blood lactate concentration. Second, participants completed a variation of the Cooper test using skating technique on flat terrain to determine the distance covered in 12 min and maximum heart rate. **Results.** There was a correlative (r = 0.18 respectivelly R^2 = 0.43) relationship of between the distance covered in the Cooper test and treadmill running speed at 4 mmol/l blood lactate concentration. **Conclusions.** The two tests allow recreational athletes to rank themselves with regards to their endurance capacity within a population. The relationship between distance covered and maximum heart rate can indicate whether future training should focus on technical or physical improvement.

Key words: performance testing, cross-country skiing, technical skills

Introduction

Every human requires regular physical activity in order to lead a healthy life [1]. The modern lifestyle, with excessive food intake and insufficient exercise, has led to diseases such as obesity, sleeplessness, increased blood pressure, diabetes mellitus and metabolic disorders [2–4]. A high physical activity level has protective effects on health. Aerobic exercise, in particular, offers a number of health and performance benefits [2]. In some regions, such as in Switzerland, cross-country skiing presents an excellent opportunity to maximize these protective effects. Cross-country skiing requires considerable physical and muscular effort in which muscles of both the upper and lower extremities are involved. This type of activity changes the lactate threshold and increases maximum oxygen uptake (VO_2max) [1]. Technical and conditioning developments in cross-country skiing have placed increasing importance on the upper body compared with that of the lower body [5–8], where the propulsive power generated by the upper body is credited to account for 50% or more of total power [5]. This finding also highlights the importance of motor coordination between the upper and lower extremities. Cross-country skiing is particularly beneficial in stimulating the cardiopulmonary system and improving general endurance and in this way similar to long distance running, triathlon, cycling or rowing [9, 10]. However, the key feature of cross-country skiing is that it involves both upper and lower body motor performance that is intrinsically connected to the cardiopulmonary system. Depending on terrain, snow conditions (soft, frozen, packed or crusted) and technique (classic vs. skating), the different motor elements comprising cross-country skiing are combined to offer a multifaceted form of whole body training.

Many different types of performance diagnostics exist in cross-country skiing, with most focusing on endurance capacity. Different methods of varying complexity and robustness can be applied to estimate endurance capacity. These range from recording the time needed to achieve a certain distance (e.g. 3000 m run), to measuring heart rate or lactate concentration at different intensities on a treadmill, to determining maximum oxygen uptake (VO_2max). For professional athletes, endurance capacity is mainly assessed in laboratory settings by measuring blood lactate concentration or VO_2, where VO_2 is regarded as the gold standard by the literature. Many studies have used VO_2, resulting in high comparability of data sets [11]. However, research has shown that in trained as well as untrained runners and cyclists measurements of a fixed lactate threshold or an aerobic threshold correlate better with competitive performance in distances between 3 and 42 km than VO_2max [12–15]. It was also shown that performance at a specific lactate concentration or at a certain threshold (aerobic/anaerobic) correlated better with training effects than VO_2max [15–17].

Within lactate-specific diagnostics there also exist a number of methodologies, all of which aim to analyse endurance capacity by measuring lactate concentration

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as a response to a specific exercise [18–21]. Performance at 4 mmol/l is most easily measured and cited to be the most accurate, objective and valid measure of endurance capacity, yielding significant and close relationships (r = 0.85–0.97) with different endurance distances [4, 13, 22, 23]. Performance at 4 mmol/l, which is sometimes simplified and wrongly referred to as the anaerobic threshold, can differ widely between individuals with different endurance levels or between different sports [24]. Nevertheless, it is considered a robust method in repeatability measuring performance capacity due to its good reproducibility and its correlative strength with competitive performance [25].

A fixed lactate concentration of 4 mmol/l is used as it corresponds approximately to the mean maximal lactate steady state of recreational endurance athletes with heterogeneous endurance levels [20], although even under optimum test conditions lactate values can differ 2–3% due to technical and biological variability independent of training state [13, 26]. However, monitoring performance at a running speed involving a fixed 4 mmol/l lactate concentration seems inadequate given the technical complexity and demands of cross-country skiing even amongst recreational practitioners.

For this reason, a method including a direct technical element is suggested. This study aims to present a feasible and readily applicable test protocol for conducting endurance capacity diagnostics in recreational cross-country skiers. We suggest a 12-min cross-country skiing test similar to the Cooper test. In order to determine the relationship between endurance performance and cross-country skiing technique, we analysed running speed on a treadmill at a fixed 4 mmol/l blood lactate concentration and the distance covered during 12 min of cross-country skiing. It was postulated that the higher the running speed at the lactate threshold, the larger distance covered in the 12-min skiing test. By using the ratio of these two values, athletes will be able to rank themselves with regards to their endurance capacity.

Material and methods

The sample consisted of 14 healthy male (age 30 ± 7.3 years, weight 72.2 ± 4.8 kg, height 179 ± 6.3 cm) cross-country skiers recruited from recreational and competitive circles. Test procedures were explained and participants were advised to abstain from alcohol, be rested, and eat normally prior testing. Local ethical approval and participant informed consent was obtained. All participants completed a lactate threshold test in laboratory conditions and the 12-min cross-country skiing test outdoors 48 hours later. Due to the fact that the study focus was on performance in the 12-min test, the lactate threshold test was submaximal in nature.

The lactate threshold test was performed on a PPS Sport treadmill (Woodway, Germany) at 1405 m altitude in Andermatt, Switzerland. Heart rate was recorded with a V800 heart rate monitor (Polar, Finland). Lactate was measured from capillary blood drawn from the ear following the recommendations of Swiss Olympic for lactate threshold testing [21, 25] using a Lactate Pro meter (Arkray, Japan). Starting speed was 7.2 km/h, each stage lasted 3 min and rest intervals between stages were 30 s. Running speed was increased by 1.2 km/h per stage while the slope of the treadmill remained constant (1°). The running speed yielding a lactate concentration of 4 mmol/l was determined using linear interpolation between the stages that were closest to 4 mmol/l. If the participant was unable to complete a 3 min stage, the maximum speed was calculated by using the running time during that stage [27]. Heart rate, lactate concentration and perceived exertion using the Borg scale (on a 6–20 scale) were recorded [3].

The 12-min test was based on the Cooper test, developed by Dr. Kenneth H. Cooper and named in his honour. It is a standard tool for analysing general endurance capacity in large samples. In the original version, athletes run for 12 min and the maximum distance covered was measured. This was then used as an indicator of general endurance [9, 10, 28]. The test duration of 12 min requires participants to be able to correctly pace themselves in order not to produce too much lactate at the beginning (leading to high lactate loads and crossing the anaerobic threshold) but also not to run too slowly and thus not realise their full potential. The Cooper test is easy to apply with experienced runners and correlates with maximum oxygen uptake [10]. We translated the Cooper test for cross-country skiing by having the participants ski the maximum distance in 12 min using the skating technique. Participants were encouraged to push themselves in order to cover the largest distance possible. The test was performed between Ulrichen and Geschinen, Switzerland on a flat test track with less than 10 m elevation difference located at an altitude of about 1350 m (Figure 2), which needs to be taken into account when comparing the data [9, 10, 29]. The test was conducted in good weather conditions with clear visibility and ambient temperature of –5° C. The same equipment in the lactate threshold test was used to record maximum heart rate, capillary blood lactate concentration and perceived exertion using the Borg scale. GPS was used to measure the distance covered. All field measurements were performed according to guidelines developed by Harriss and Atkinson [30]. Data were analysed using SPSS (IBM, USA) and Excel (Microsoft, USA).

Results

Table 1 shows the results from the lactate threshold test. Mean running speed was 16.32 km/h at 4 mmol/l blood lactate concentration. This classified the participants as endurance trained. Heart rate at 4 mmol/l blood lactate was relatively high (176 bpm), explained by the fact that the sample included relatively well-trained ath-

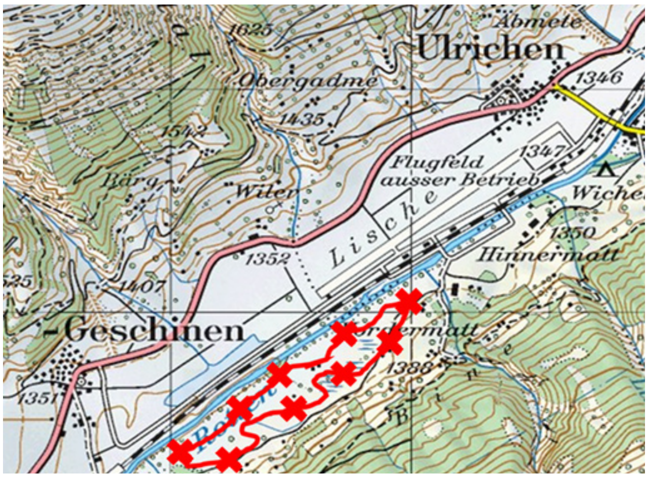

Figure 1. The track (marked by x-line) used in the Cooper 12-min skating

Table 1. Results of lactate threshold test at 4 mmol/l capillary lactate

	M ± *SD*
Speed at threshold (m/h)	16.32 ± 1.82
Heart rate at 4 mmol/lactate (bpm)	176 ± 10
Borg rating	18 ± 1.7

Table 2. Results of 12-min skating test

	M ± *SD*
Distance (m)	4061 ± 821
Maximum heart rate (bpm)	177 ± 16.1
Lactate concentration (mmol/l)	6.1 ± 2.4
Borg rating	17.4 ± 1.5

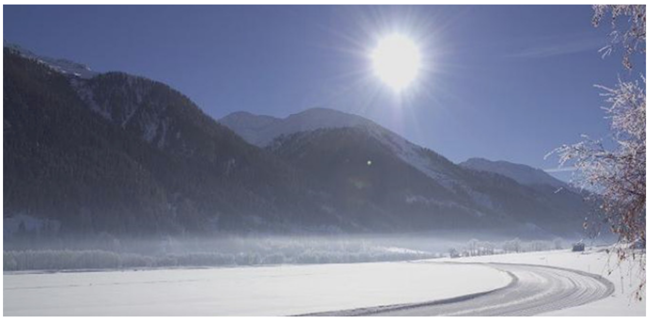

Figure 2. The flat test track

letes [10]. Mean Borg rating was 18, which can be considered slightly high when compared with actual heart rate. This could be due to the fact that some participants were very well trained, thus having an anaerobic threshold below 4 mmol/l and therefore running with a relatively high lactate load.

Table 2 below shows the results from the 12-min skating field test. The mean distance completed was 4061 m. This indicates a mean speed above 3 min/km and is slightly faster than that observed in the classic Cooper running test, where athletes measured on a treadmill at 4 mmol/l blood lactate concentration would probably achieve 500 m less [10]. The mean heart rate of 177 bpm was higher than when running at 4 mmol/l in the lactate threshold test. This was to be expected as the participants were encouraged and motivated for maximum performance and appears to be justified due to the high lactate concentration (6.1 mmol/l). The Borg rating had a mean value of 17.4 and is within expected boundaries. When multiplied by 10 this results in a predicted heart rate of 174 bpm, which is relatively close to the measured value.

Figure 3 illustrates the importance of the technical component in cross-country skiing. For a level speed of 16 km/h at a fixed threshold of 4 mmol/l blood lactate concentration the participants can cover distances between 3300 and 5300 m.

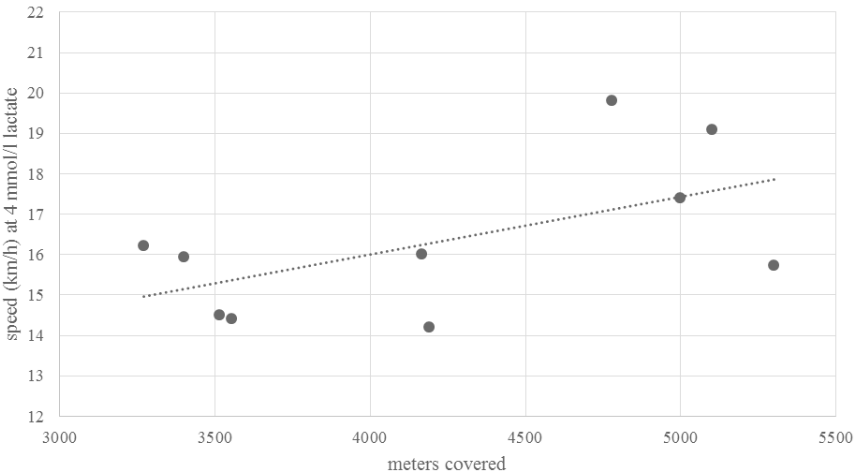

Figure 3. Relationship between distance covered (x axis) and running speed [speed (km/h) = 10.3 + 0.00143 * distance (meters)] on treadmill at 4 mmol/l (y axis); correlative relationship at $r = 0.43$ ($R^2 = 0.18$) ($p < 0.01$)

Discussion and conclusions

In regards to the sample, the results showed relatively large intra-individual differences in terms of endurance capacity and technical skill. At a speed of 16 km/h (corresponding to a blood lactate concentration of 4 mmol/l), the distance covered by the participants differed by more than 2000 m. This indicates that in the sampled population pure physical (i.e. cardiopulmonary) condition was more a qualification than a reason for rendering a good cross-country skier.

This study aimed to develop a readily applicable diagnostic test protocol to measure endurance capacity in recreational cross-country skiers. The introduced test protocol allows cross-country skiers to rank themselves within a test population and analyse their physical capacity in regards to their technical skills. This relatively easy testing protocol could be especially useful for young athletes, such as those in a regional training group who have not yet developed their own standards regarding performance. The diagnostic outcomes can also serve to provide training recommendations. For example, skiers who achieved a relatively high speed at 4 mmol/l lactate in the lactate threshold test, but only a relatively short distance in the 12-min skating test, should focus more on improving technical skills. In contrast, athletes who achieved greater distances in the skating test (indicating good technical proficiency) with lower speeds in the lactate threshold test could strongly benefit from physical training during the summer and autumn seasons.

It must be pointed out that the cardiopulmonary system, via heart rate, is the limiting factor for endurance capacity and has therefore the highest predicative validity for assessing cross-country skiing capacity in athletes [10]. Based on maximum heart rate, recreational practitioners of the endurance level assessed in this study should exercise three to four times per week depending on time restrictions by running or cycling. Threshold training, i.e. exercising near the aerobic/anaerobic threshold, would be particularly suitable for this endurance level and also for future cross-country training at higher altitudes [13, 31–34]. The fear that running or cycling may only train the lower extremities is not a principal concern at this level. Among recreational athletes, specific upper body training is of less importance than general endurance capacity, which needs to improve through any available forms of aerobic training (strengthening the cardiovascular and cardiopulmonary systems). This would later help improve upper body performance. At the same time, the necessary muscular adaption of the upper extremities can be achieved within a relatively short time through a training programme specifically tailored to cross-country skiing as skeletal muscle is extremely adaptable. It was shown in untrained individuals that only six weeks of intensive endurance training can increase VO_2max by 15% and volume density of capillaries and mitochondria in stressed skeletal muscles by up to 30% [35, 36].

For recreational athletes with limited available time, running and threshold training provide an efficient training option. Training gains achieved over the summer and autumn would be beneficial when cross-country skiing in winter. However, in order to maintain technical proficiency, roller skiing appears to be a suitable modality as it also trains balance, allowing for improved coordination of the upper and lower body.

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Paper recived by the Editor: April 21, 2015
Paper accepted for publication: June 24, 2015

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