Original Article

Validity and reliability of an incremental double poling protocol in cross-country skiers

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ABSTRACT

Govus, A., Marsland, F., Martin, D., & Chapman, D. (2015). Validity and reliability of an incremental double poling protocol in cross-country skiers. *J. Hum. Sport Exerc., 10*(3), pp.827-834. This study determined the validity and reliability of an incremental double poling protocol performed on a Concept II ski-ergometer and validated this against an existing treadmill ski-striding protocol. Ten well-trained male cross-country skiers (age: 19 ± 1.4 y; height: 182 ± 72 cm; body mass: 76.0 ± 10.8 kg, whole body VO_2Peak: 5.2 ± 1.0 $L.min^{-1}$; upper body VO_2Peak: 4.6 ± 1.0 $L.min^{-1}$; upper body:lower body ratio: 87.2 ± 5.6%) performed four VO_2Peak tests; one treadmill ski-striding test and three double poling ski-ergometer tests over five days. Test-retest reliability of the ski-ergometer protocol was determined for maximal oxygen consumption (VO_2peak). The ski-ergometer test showed excellent reliability for VO2Peak ($L.min^{-1}$) (coefficient of variation [CV] = 1.9%, 95% confidence limit [95% CL] [1.2, 4.7]; r = 1.00, [0.96, 1.00]) and UBPPeak (W) (CV = 1.4%, [0.9, 3.4]; r = 1.00, [0.97, 1.00]). Very strong correlations existed between the ski-ergometer and the ski-striding protocol for VO2Peak (r = 0.95, [0.76, 0.99]). The upper body ski-ergometer test provided valid and reliable measurements of ski-specific upper body aerobic power in well-trained male cross-country skiers. **Key words**: MAXIMAL OXYGEN CONSUMPTION, SKI-ERGOMETER, EXERCISE TESTING.

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INTRODUCTION

The double poling technique is an integral component of cross-country skiing events (Staib, Im, Caldwell., & Rundell, 2000; Stöggl, Lindinger, & Müller, 2006b) and is the sole technique employed in some sprint events (Stöggl & Holmberg, 2011). As both aerobic (Ingjer, 1991; Rusko, 1987) and upper body power (Alsobrook & Heil, 2009; Mahood, Kenefik, Kertzer., & Quinn, 2001; Nesser, Chen, Serfass., & Gaskill, 2004) correlate well with cross-country skiing performance, periodical assessment of these variables may indicate a skier's current performance capabilities.

The whole body nature of cross-country skiing makes it difficult to obtain an ecologically valid laboratory measurement of ski specific aerobic power. Although an incremental treadmill roller skiing test is arguably the most ecologically valid laboratory test of aerobic power in cross-country skiers, the need for a specialised treadmill prohibits its widespread use. Several upper body sprint and endurance tests using customised ski-ergometer protocols reportedly predict double poling performance on snow (Bortolan, Pellegrini, Finizia., & Schena, 2008; Carlsson et al., 2012; Gaskill, Serfass., & Rundell, 1999; Staib et al., 2000). However, these protocols often use a modified Concept II rowing ergometer to replicate the double poling technique (Holmberg & Nilsson, 2008; Alsobrook & Heil, 2009). To our knowledge, no studies to date have evaluated an incremental double poling protocol using the now commercially available Concept II upright ski-ergometer.

Thus, this study determined the test-retest reliability of an incremental double poling ski-ergometer protocol performed on a Concept II upright ski-ergometer, and validated this protocol against an existing treadmill ski-striding protocol.

METHODS

Participants

Ten well-trained male cross-country skiers [(mean ± s) age: 19 ± 1.4 y; height: 182.0 ± 7.2 cm; body mass: 76.0 ± 10.8 kg] were recruited from the Australian national cross-country skiing team. Before data collection, athletes were informed of the experimental procedures, the possible risks associated with participation, and written informed consent was obtained. The institution's Human Research Ethics Committee approved the study.

Experimental approach

Participants performed four maximal oxygen consumption tests over five days. Testing consisted of one incremental ski-striding test, which was part of the group's normal monitoring procedure, and three incremental ski-ergometer tests (one familiarisation test and two maximal tests). The first day involved a ski-ergometer technique familiarisation session in the morning and an incremental treadmill ski-striding test to exhaustion in the evening. On day four and five, participants performed an incremental ski-ergometer test to exhaustion. Test time of day was standardised between sessions to minimise variation resulting from circadian rhythms.

Treadmill ski-striding test

The treadmill ski-striding test was performed on a custom-built motorised treadmill (AusTredDex, Preston, Victoria, Australia). Participants walked with rubber tipped ski poles for as long as possible using long strides, however, they were permitted to bound or run as the gradient or speed increased. Before commencing the test, participants performed a 5 min warm up at 6 $km.h^{-1}$ with a 1% gradient. Testing commenced at a speed of 6 km.h^{-1} with a 6% gradient, increasing by 0.5 km.h^{-1} and 2% gradient for each workload until volitional exhaustion. After an initial 4 min stage, each stage lasted 3 min 15 s separated by a 45 s stationary phase during which a capillary whole blood sample was obtained from the finger and analysed for blood lactate (BLa) concentration using a portable, automated blood lactate analyser (Lactate Pro, Arkray Inc., Kyoto, Japan). A further sample was also obtained 2 min after test completion. A custom built, automated dual Douglas bag collection system (Saunders, Pyne, Telford., & Hawley, 2004) collected expired gas volumes continuously throughout exercise. Peak oxygen consumption (VO_2Peak) was calculated by adding the two highest consecutive 30 s VO_2 values.

Upper body ski-ergometer test

Participants performed a discontinuous incremental test to exhaustion using a Concept II ski-ergometer (Concept II, Morrisville, VT, USA). To simulate the double poling technique, participants stood in an upright position and pulled down on a cord attached to a pulley system that drives an air friction-braked flywheel. One day before the incremental test, participants were familiarised with the ergometer, and given a set of standard instructions to ensure that double poling technique was consistent across each trial. Furthermore, an experienced coach observed all testing sessions and the test was terminated if the athlete was unable to maintain correct double poling technique.

The ski-ergometer was calibrated with a consistent drag factor of 50 W before each test. After a 10 min warm up at a self-selected poling cadence and intensity, the test started at 100 W for 2 min at a self-selected poling cadence. Thereafter, each workload increased by 20 W every 2 min separated by a 30 s stationary phase (2 min work: 30 s rest), during which time a capillary whole blood sample was obtained from the earlobe and analysed for blood lactate concentration using a portable blood lactate analyser. An additional sample was obtained from the earlobe 2 min post-exercise. We chose to sample blood from the earlobe since the arms were active throughout the test, although these two sampling sites have previously been shown to be well correlated with each other (Moran, Prichard, Ansley, & Howatson, 2012). To ensure athletes maintained the specified power output, they were provided with continuous visual feedback on their instantaneous power output (in watts) via a digital display mounted on the front of the ski-ergometer as well as average power output over the 2 min workload. Athletes were instructed to maintain their power output within 5 W of the specified workload, otherwise the test was terminated. Heart rate and oxygen consumption was recorded continuously throughout the test, and average power (W) and poling cadence (strokes.min^{-1}) for each 2 min workload were recorded from the automated display on the Concept II ski-ergometer during the final 10 s of each workload. Maximal oxygen consumption was calculated by adding the highest two consecutive 30 s values recorded for VO_2.

Gas analysis

Gas analysis was performed for the incremental ski-ergometer and ski-striding test as described by Saunders et al. (Saunders et al., 2004). Briefly, a custom designed open-circuit, indirect calorimetric system and associated in-house software monitored gas exchange during both the upper body and treadmill test. The automated system measured gas exchange every 30 s, permitting calculation of pulmonary ventilation (V_E), volume of expired oxygen (VO_2) and carbon dioxide (VCO_2), and respiratory exchange ratio. Participants breathed through a Hans Rudolph one-way valve with two openings, one allowing the inhalation of room air and the other directing expired air into respiratory tubing. Expired gas was collected in one of two 150 L aluminized mylar bags, with each bag receiving expirate for 30 s before being evacuated by a calibrated precision piston pump. Measures of piston displacement recorded from the pump enabled the system to automatically calculate the volume of gas collected during each 30 s period using Boyle's Law (where $P_1V_1 = P_2V_2$). A small volume of gas was sampled at the end of each 30 s epoch and passed through a desiccant column of anhydrous calcium chloride (Asia Pacific Specialty Chemicals Ltd, Sydney, Australia) before analysis by electronic O_2 and CO_2 analysers (Applied Electrochemistry, Ametek, Pittsburg, PA). These analysers were calibrated before each test with three gravimetrically weighed precision gas mixtures, with an acceptable calibration within ± 0.03% of the target value.

Statistical analysis
A Pearson product-moment correlation was used to compare VO_{2Peak}, between the two protocols (Hopkins, 2004). Data were first log-transformed then a linear regression analysis was performed using the log-transformed variables to calculate a Pearson product moment correlation coefficient (*r*). Correlation coefficients were interpreted using the following qualitative descriptors: trivial (< 0.1), weak (0.1-0.3), moderate (0.3-0.5), strong (0.5-0.7), very strong (0.7-0.9), near perfect (0.9-1.0), perfect (1.0) (Hopkins, 2000).

Test-retest reliability of the incremental ski-ergometer test was determined by calculating the coefficient of variation (CV%, where CV = (*s*/mean) x 100) and a Pearson product moment correlation coefficient for VO_{2Peak} and upper body peak power (UBP_{Peak}). Data were first log-transformed and typical error was calculated from the change score of the log-transformed variables. Thereafter, log-transformed variables were back transformed and CV% was calculated.

RESULTS

Although ten athletes were tested, four participants were eliminated from the sample due to equipment error and injury during testing. Hence, data from six athletes were used in the final analysis. The VO_{2Peak} response (n = 6) from the ski striding protocol was (mean ± s) 5.2 ± 1.0 $L.min^{-1}$ as compared to 4.6 ± 1.0 $L.min^{-1}$ in the ski-ergometer test. Maximal HR from the two test conditions were very similar (203 ± 9 $b.min^{-1}$ vs.197 ± 7 $b.min^{-1}$) between the ski striding and ski-ergometer test. Peak BLa concentration was slightly greater following the ski striding protocol (15.0 ± 3.1 $mmol.L^{-1}$) compared to the ski-ergometer protocol (12.3 ± 1.1 $mmol.L^{-1}$) (Table 1).

Table 1. Summary of measures for peak oxygen uptake (VO_{2Peak}), upper body power (UBP_{Peak}), peak heart rate (HR_{Peak}), peak blood lactate (BLa_{Peak}) and upper to lower body ratio (UB:LB) for the incremental ski-striding and ski-ergometer test respectively. Data are presented as mean and standard deviation (mean ± *s*).

	Ski-Striding	Ski-Ergometer	
		Test 1	Test 2
VO_{2Peak} ($L.min^{-1}$)	5.2 ± 1.0	4.6 ± 1.0	4.6 ± 1.0
VO_{2Peak} ($ml.kg^{-1}.min^{-1}$)	68.6 ± 5.4	60.0 ± 5.2	59.6 ± 5.8
HR_{Peak} ($beats.min^{-1}$)	203 ± 9	196 ± 8	193 ± 9
BLa_{Peak} ($mmol.L^{-1}$)	15.0 ± 3.1	12.3 ± 1.1	12.3 ± 1.1
UBP_{Peak} (W)		242 ± 58	241 ± 59
UBP_{Peak} ($W.kg^{-1}$)		3.1 ± 0.4	3.1 ± 0.4
UB:LB (%)			87.2 ± 5.6

Validity

The treadmill ski-striding test and upper body ski-ergometer test were very strongly correlated for VO_{2Peak} ($L.min^{-1}$) (r = 0.95, [0.76, 0.99]) (Figure 1). Peak BLa ($mmol.L^{-1}$) was weakly correlated between the two tests (r = 0.31, [-0.51, 0.83]).

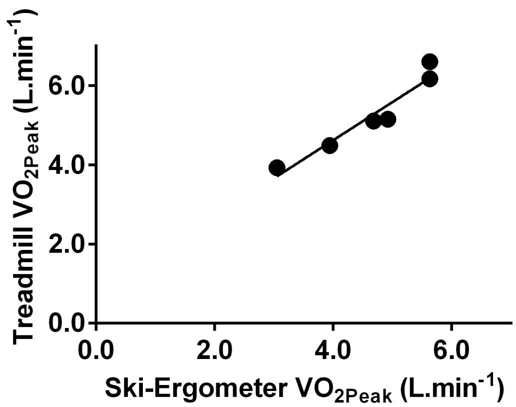

Figure 1. Linear regression analysis of the relationship between the incremental ski-striding test and upper body ski-ergometer test for VO_{2Peak}.

Reliability

The two upper body ski-ergometer tests were very strongly correlated for VO_{2Peak} ($L.min^{-1}$) (r = 1.00, [0.96, 1.00]) and UBP_{Peak} (W), (r = 1.00, [0.97, 1.00]) (Figure 2) and showed a low coefficient of variation for VO_{2Peak} ($L.min^{-1}$) (CV = 1.9%, [1.2, 4.7]) and UBPPeak (W) (CV = 1.4%, [0.9, 3.4]). A strong relationship existed for BLa_{Peak} between the two upper body tests (r = 0.57, [-0.45, 0.94], CV = 11.7%, [7.2, 31.3]).

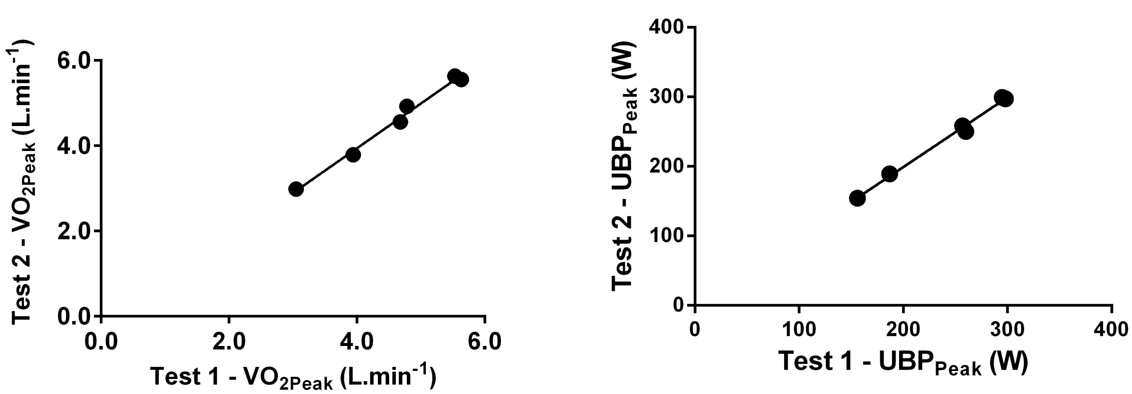

Figure 2. Linear regression analysis of the relationship between the two upper body ski-ergometer tests for a) VO_{2Peak} b) UBP_{Peak}.

DISCUSSION

Despite the importance of the upper body musculature in successful double poling performance (Bojsen-Møller et al., 2010; Holmberg, Lindinger, Stöggl, Eitzlmair, & Müller, 2005; Lindinger, Holmberg, Müller, & Rapp, 2009; Losnegard et al., 2011), many upper body ski-ergometer tests reported in the literature are custom built and not commercially available. To our knowledge, the Concept II ski-ergometer has not previously been validated against any pre-existing laboratory or roller skiing protocols. We report that an incremental double poling protocol on a Concept II ski-ergometer has excellent test-retest reliability for maximal oxygen consumption in male cross-country skiers. Furthermore, we validated this test against a pre-existing treadmill ski-striding protocol (Figure 1).

The reliability for our reported ski-ergometer protocol was comparable to a 6 min 'all out' upper body ski-ergometer test for absolute VO2Peak reported previously (Holmberg & Nilsson, 2008; Wisloff & Helgerud, 1998). Although two previous papers have reported the test-retest reliability peak upper body power for a 60 s 'all out' test (Alsobrook & Heil, 2009; Holmberg & Nilsson, 2008) to our knowledge, these authors did not report the reliability of upper body power at VO2Peak. Further research is required to establish the reliability of our protocol in female skiers considering the reported differences in the relative contribution of the upper body musculature and poling characteristics between female and male skiers during double poling (Sandbakk, Ettema, & Holmberg, 2014; Sandbakk, Ettema, Leirdal, & Holmberg, 2012). It will also be necessary to identify whether there are differences in muscle activity patterns (Holmberg et al., 2005; Stöggl, Lindinger, & Müller, 2006a) and technical changes between ski-ergometer and snow double poling with a validation of this protocol against double poling performance on snow.

The higher HRPeak and VO2Peak recorded for the ski-striding test suggests oxygen delivery and lactate oxidation was greater in this protocol compared with the ski-ergometer protocol. Effective lactate oxidation by skeletal muscle during exercise depends on a high rate of oxygen delivery, extraction and the activation of a large muscle mass (Calbet et al., 2007; Saltin, Rådegran, Koskolou, & Roach, 2002). Thus, the recruitment of a smaller muscle mass in the upper body ski-ergometer may also explain why peak lactate concentrations were lower in this test. Although the upper body is the predominant source of power during double poling technique (Lindinger, Holmberg et al., 2009; Stöggl et al., 2006a), it also involves meaningful joint movements at the hip, knee and ankle as well as muscle activation in the trunk, hip flexors, triceps surae and shoulder extensor muscles (Bojsen-Møller et al., 2010; Holmberg et al., 2005). Therefore, the double poling technique is not solely an upper body movement and meaningful activation of the leg and trunk muscles, in addition to the arm muscles could conceivably assist blood lactate clearance during the ski-ergometer test (Holmberg, Lindinger, Stöggl, Björklund, & Müller, 2006). Thus, given the lactate differences between these two maximal exercise protocols, we recommend establishing lactate thresholds that are specific to upper body ski-ergometry training and/or on snow double poling since these thresholds are likely to be more specific to upper body exercise than those established during whole body, ski-striding protocols.

The upper body VO2Peak achieved during the ski-ergometer test was 87.2 ± 5.6% of that achieved during incremental ski-striding. This is comparable to the mean upper to lower body ratio of 89.4 to 95.7% reported in elite Danish (Mygind, Larsson, & Klausen, 1991), American male cross-country skiers (86% and 87.4 ± 7.4%) (Staib et al., 2000) and Swedish elite skiers (90-95%) (Sharkey & Heidel, 1981). Thus, we believe using the double-poling ski-ergometer protocol evaluated in the current study in conjunction with a treadmill ski-striding protocol provides a more holistic evaluation of whole body aerobic power and snow skiing performance than either test performed in isolation.

PRACTICAL APPLICATIONS

To improve the reported protocol, we recommend including an 'open-ended' final workload (i.e. double-pole all out until exhaustion) which in our opinion would provide a more accurate measure of upper body power corresponding with VO2Peak. Furthermore, we observed that the average poling cadence during low intensity workloads ranged from 30-40 strokes.min-1 where athletes would achieve the prescribed power output by 'sitting', i.e. using their body mass and gravity to provide greater downward propulsion. In comparison, the poling cadence was lower than employed during double poling on snow at a similar intensity (Lindinger, Stöggl, Müller, & Holmberg, 2009). To address this issue, we recommend setting a minimum poling cadence of 40 strokes.min-1 and ensuring that all participants are thoroughly familiarised with the upper body ski-ergometer test and given feedback on whether they are using good "skiing technique".

As the Concept II double poling ski-ergometer is commercially available, there is potential for coaches to develop skiers' upper body aerobic or anaerobic power by incorporating double-pole ski-ergometer training as a regular part of an athlete's training programme and this protocol could be used periodically to measure upper body training adaptations. Furthermore, when used in conjunction with a ski-striding protocol, in our opinion this protocol provides a holistic assessment of whole body ski-specific fitness.

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