Human Movement Science 55 (2017) 100–107

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Full Length Article

The role of speed and incline in the spontaneous choice of technique in classical roller-skiing

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ARTICLE INFO

Keywords:
Cross-country skiing
Phase transitions
Coordination

ABSTRACT

Cross-country skiers change technique depending on terrain (incline) and effort (work rate; speed at a particular incline or resistance). The literature is not unequivocal about the influence of incline or speed on the choice of technique, i.e., which of these act as a 'control parameter'. Identifying task related control parameters for spontaneous technique shifts assists elucidating which mechanisms are active for triggering technique transitions. The aim of this study was to investigate whether speed or incline acted as such control parameter for technique shifts during classic style roller skiing. In this study, we kept the exercise intensity constant while changing two potential control parameters (speed and incline). Thus, any effect of work rate was excluded.

Eight male competitive cross-country skiers performed roller skiing on a treadmill while incline was altered from 3 to 11% and back to 3% each minute by 1% and speed changed accordingly to obtain a constant work rate. This protocol was performed at three submaximal work rates (170, 200, and 230 W) to obtain various combinations of speed and incline.

The athletes were free to choose their technique (double poling, double poling with kick and diagonal stride), which was identified using continuous phase analysis on the motion of the skis. Physiological response (heart rate, oxygen uptake) was recorded continuously.

The incline seemed to affect choice of technique shift more than speed: the ANOVA for repeated measures on all work rates showed no significant effect of incline ($p > 0.2$) and an effect for speed ($p < 0.001$). No effect of protocol order (increasing versus decreasing incline) was found for transitions. The physiological response was lowest for conditions of steep incline-low speed and was affected by protocol order. Cycle rate was affected by incline only in the double poling technique.

Possible mechanisms related to the triggering of technique transitions are discussed.

1. Introduction

Cross-country ski training and competition is typically performed in varied terrain where skiers use different techniques, both in freestyle (skating) and classical style, primarily depending on that terrain. The different techniques are considered as a gear system to adapt to changes in speed and incline (e.g., Nilsson, Tveit, & Eikrehagen, 2004), possibly in a similar way as different gait forms (running vs walking) are preferred depending primarily on speed. Parameters that trigger transitions in gait in general are well investigated. Metabolic rate (Alexander, 1989; Hoyt & Taylor, 1981; Mercier et al., 1994), mechanical stress (Farley & Taylor, 1991;

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http://dx.doi.org/10.1016/j.humov.2017.08.004
Received 26 April 2017; Received in revised form 7 August 2017; Accepted 8 August 2017
Available online 12 August 2017
0167-9457/

Hreljac, 1995; Neptune & Sasaki, 2005) and subjective feeling of comfort (Daniels & Newell, 2003; Prilutsky & Gregor, 2001; Thorstensson & Roberthson, 1987) have been proposed as parameters that, when reaching critical values, trigger transitions.

In cross-country skiing in the classic style, the main techniques applied are diagonal stride (DIA), double poling with a kick (DK) and double poling (DP). DIA follows a diagonal coordinated pattern as known from walking and running, where arms and legs move contralateral (Pellegrini et al., 2013). The DIA technique is primarily used in moderate to steep uphill slopes, where the high propulsive phase ratio (the relation between propulsive phase and recovery phase) provides advantages (Dahl, Sandbakk, Danielsen, & Ettema, 2017; Pellegrini et al., 2013). DP is a symmetrical and synchronous movement of both arms, where the propulsive forces are exerted only through the poles. The propulsion is supported by considerable trunk flexion (Holmberg, Lindinger, Stoggl, Eitzlmair, & Muller, 2005). The lower limbs contribute in the production of propulsive forces by elevating center-of-mass by extending ankle- and knee joints, resulting in an increase of potential energy (Dahl et al., 2017; Danielsen, Sandbakk, Holmberg, & Ettema, 2015; Holmberg, Lindinger, Stoggl, Bjorklund, & Muller, 2006). DP is most frequently used in slight uphill, slight downhill and flat terrain, but in recent years also in steeper uphill terrain when the friction is low and the snow is hard-packed and allows for effective poling. In DK, the upper body movement is quite similar to the movement in DP. In addition to the propulsive force from the poles, DK is supported by propulsion from either a left or right leg kick, inserted between the double poling actions to enhance the propulsive phase. DK is a combination of DIA and DP and is commonly used slightly uphill or if snow conditions cause high resistance in flat terrain (Smith, 2003). The inserted leg kick has the same characteristics as the lower limb movement in DIA (Lindinger, Gopfert, Stoggl, Muller, & Holmberg, 2009). DK has a large propulsive phase of about 52% of a cycle, including leg- and pole push offs. This is considerably higher than that of DP at similar speeds, with a propulsive phase of 30–38% of a cycle (Göpfert, Holmberg, Stöggl, Müller, & Lindinger, 2012), but lower than DIA with a phase of about 80% at high speed (Dahl et al., 2017). In addition to the large amount of propulsive phases, DK shows the lowest cycle rate among the sub-techniques in classical cross-country skiing.

Although the conditions under which particular techniques are preferred are reasonably well known, most studies that target this issue were not designed to identify, independently of workload, the task related control parameter, i.e., slope or speed, for the transition of technique. For example, Cignetti, Schena, Zanone, and Rouard (2009) investigated transitions in classical cross-country skiing by letting the skiers ski "as naturally as possible" while roller-skiing on a treadmill where speed was constant (10 km h^{-1}) and the incline increased by 1° every 30 s, from 0° to 7°. Cignetti et al. (2009) suggested that increasing incline caused a technique transition by a loss of stability. Pellegrini et al. (2013) used the same test setup as Cignetti et al. (2009), but in addition varied speed at a constant incline. In addition, they tried to identify the main trigger parameters regarding technique transition in classical cross-country skiing. The results from this study suggested two different primary parameters. They hypothesized that there is a limited force a skier would like to exert through the poles and approaching this limit triggers a transition to another technique where less of the propulsive forces are exerted through the poles. The other suggested parameter was leg thrust time, i.e., the time where the ski stands still during a leg stride. The thrust time was suggested to have a lower limit (0.1 s), which, if approached, would trigger a technique transition allowing longer thrust time. This corresponds to Nilsson et al. (2004) observations, where 0.15 s was the shortest leg thrust time. Although these studies provide valuable information about the control parameter(s) that may play central roles in shifts of technique, they are not (and cannot be) conclusive about whether incline and/or speed is the key control parameter that determines technique shifts in varying terrain. Therefore, it was our aim to explore this issue further by a protocol that changed both incline and speed simultaneously to keep workload unaltered. By performing this protocol at different workloads, i.e., studying different combinations of incline and speed, we attempted to determine which of these two parameters, if any, could be regarded as the control parameter for technique shifts. We recorded motion of skis and poles to identify the different techniques and changes thereof, and cycle rate was determined to shed light on possible mechanisms behind technique shifts. Furthermore, we recorded the physiological response continuously to investigate if metabolic demand was altered throughout this protocol.

2. Methods

2.1. Participants

Eight male national level competitive cross-country skiers (age 22.4 ± 1.7 years, body height 183.7 ± 4.4 cm, body mass 80.3 ± 7.7 kg, and $\dot{V}O_{2max}$ 73.9 ± 6.4 ml kg^{-1} min^{-1}) volunteered to participate in this study. All procedures were explained verbally to each skier and written informed consent was obtained and signed. All participants were informed that could withdraw at any time without giving any reason. The study was registered, and approved by Norwegian Social Science Data Services. The study was conducted in accordance with the Declaration of Helsinki.

2.2. Experimental design

All participants completed three sessions of warm-up and a test protocol at constant work rate. The warm up was performed on the treadmill and consisted of a 5-min self-paced familiarization period before a standardized 12-min warm-up at varying speed and incline during which techniques could be employed. The test sequences (Fig. 1A) were done at three different submaximal aerobic work rates (target: 170, 200, and 230 Watts) in randomized order and were executed on three different days. First, 11 min of constant work rate where incline increased by 1% each minute from 3 to 11% incline, and speed simultaneously decreased accordingly to obtain the same and constant external workload ('upward' protocol). The first incline-speed combination was maintained 3 min rather than one to give the athlete time to obtain steady state physiological conditions. Each shift of incline and speed took about 2 s