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Effect of fatigue on double pole kinematics in sprint cross-country skiing

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The aim of the present study was to examine the effect of fatigue (physiological, mechanical, and muscular parameters) induced by a sprint simulation on kinematic parameters (cycle, phases, and joints angles) of the double pole technique. Eight elite skiers were tested for knee extensor strength and upper body power both before and after a three-bout simulation of sprint racing. They were video analyzed during the final part of the test track of bouts 1 and 3 using a digital camera. Results showed that skiers were in a fatigue state (decrease of the knee extensors voluntary force (−10.4 ± 10.4%) and upper body power output (−11.1 ± 8.7%) at the end of the sprint. During bout 3, the final spurt and cycle velocities decreased significantly (−7.5 ± 12.3%; −13.2 ± 9.5%; both $p < .05$). Angular patterns were only slightly modified between bouts 1 and 3 with trunk, hip, and pole angles being significantly greater for the third bout. The decrease of hip and trunk flexion and the lower inclination of the pole during the poling phase suggested a reduced effectiveness of the force application which could lead to a decrease in the cycle velocity.

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1. Introduction

For many years, the official distance for individual cross-country races ranged from 5 to 50 km. Over the last decade, new very short races have been established: the sprints (<2 km). During a sprint, each skier runs the qualification bout and the 30 fastest racers qualify for the quarter-final, subsequent trials leading to the semi-final and the final race. As a consequence, the eight fastest skiers perform four high-intensity bouts, separated by progressively shorter rest periods (usually less than 15 min between the semi-final and the final). Each bout has a short duration (2–4 min) in comparison to conventional long distance races.

In the classical style, the final fraction (spurt) of each bout, usually performed using the double poling technique, is often the more determinant portion of the track. Many studies have investigated the kinematics of the double poling technique in long distance races (Bilodeau, Rundell, Roy, & Boulay, 1996; Smith, Fewster, & Braudt, 1996), in maximal velocity tests (Hoffman, Clifford, & Bender, 1995; Stöggl, Lindinger, & Müller, 2006a, 2006b), and in submaximal velocity tests (Holmberg, Lindinger, Stöggl, Eitzlmair, & Müller, 2005; Millet, Hoffman, Candau, Buckwalter, & Clifford, 1998; Millet, Hoffman, Candau, & Clifford, 1998). Although Bilodeau et al. (1996) observed no significant relation between cycle velocity (CV), cycle rate (CR), and cycle length (CL) during a 50 km race, several studies reported a significant correlation between the CV and CL in double poling (Smith, 1992). Moreover, Millet and colleagues (i.e., Millet, Hoffman, Candau, Buckwalter et al., 1998; Millet et al., 1998) showed that the speed increase was achieved by increasing the CR and pole force associated with short poling and gliding durations. Concerning the angular pattern in double poling, Holmberg et al. (2005) showed that the entire body works as a chain of segments and that muscles engage in sequential order starting with trunk and hip flexors, followed by shoulder extensors and the elbow extensor triceps brachii. Moreover, Smith et al. (1996) and Holmberg et al. (2005) highlighted that faster skiers began the poling phase with the poles in a more vertical position and with their trunk in a more vertical position compared to slower skiers. They also demonstrated that the faster skiers had a smaller minimum elbow, hip, and knee angle, a higher pole force during shorter poling phase duration.

Fatigue has been defined as an acute impairment of performance (Enoka & Stuart, 1992), or as a disability to maintain a level of strength (De Luca, 1984), or as a temporary decrease in work capacity (Asmussen, 1993). Fatigue in elementary movements has often been studied, whereas fatigue of complex movements in a natural environment has not been the subject of much investigation (Millet, Martin, Maffiuletti, & Martin, 2003). Few studies have analyzed the fatigue induced by a cross-country skiing race. Forsberg, Tesch, and Karlsson (1979), Viitasalo, Komi, Jacobs, and Karlsson (1982), and Millet et al. (2003) observed a significant decrease in the strength of the knee extensor muscles after long distance races. A physiological fatigue was also suggested by the observation of high blood lactate concentrations after a long distance cross-country skiing race (Mognoni, Rossi, Gastaldelli, Canclini, & Cotelli, 2001; van Hall et al., 2003). The above mentioned studies were carried out only on long distance races. For the sprint, a recent study of Stöggl et al. (2006) analyzed a simulated competition in classical cross-country skiing on a treadmill. Results indicated that the fastest skiers produced longer cycle lengths at equal cycle rate in all classical techniques. In addition, performance in classical sprint depended on speed abilities, technique use, fatigue resistance, and anaerobic capacity. Analysis of peak lactate, oxygen uptake, and tidal volume during the sprint simulation indicated the onset of fatigue.

Along these lines, the aim of this study was to determine if a simulation of sprint leads to a fatigue state on the upper and lower body in order to investigate the effect of the fatigue on kinematic parameters (cycle, phases, and joints angles) of the double poling technique during the final spurt. Thus, it would be possible to determine the reason of a possible performance decrease. We hypothesized that the sprint induced a state of fatigue characterized by a reduced upper limb strength capacity which could result in decreased propulsion and cycle length because of the substantial involvement of the upper limb in propulsion. We also expected a decrease in elbow extension because of the link between local fatigue differences and local kinematic changes. However, because previous studies showed that in double poling the entire body works as a kinetic chain of segments and muscles, we hypothesized also that the upper limb fatigue would modify trunk motion.