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The effects of the arm swing on biomechanical and physiological aspects of roller ski skating

Ann Magdalen Hegge [a,*], Gertjan Ettema [a], Jos J. de Koning [b], Asgeir Bakken Rognstad [a], Martin Hoset [a], Øyvind Sandbakk [a]

[a] Center for Elite Sports Research, Department of Neuroscience, Norwegian University of Science and Technology, Trondheim, Norway
[b] MOVE Research Institute Amsterdam, Faculty of Human Movement Sciences, VU University Amsterdam, The Netherlands

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ABSTRACT

This study analyzed the biomechanical and physiological effects of the arm swing in roller ski skating, and compared leg-skating (i.e. ski skating without poles) using a pronounced arm swing (SWING) with leg-skating using locked arms (LOCKED). Sixteen elite male cross-country skiers performed submaximal stages at 10, 15 and 20 km h^{-1} on a 2% inclined treadmill in the two techniques. SWING demonstrated higher peak push-off forces and a higher force impulse at all speeds, but a longer cycle length only at the highest speed (all $P < .05$), indicating a lower force effectiveness with SWING at the two lowest speeds. Additionally, the flexion–extension movement in the lower limbs was more pronounced for SWING. Oxygen uptake was higher for SWING at the two lowest speeds (both $P < .05$) without any differences in blood lactate. At the highest speed, oxygen uptake did not differ between SWING and LOCKED, but the RER, blood lactate and ventilation were lower with SWING (all $P < .05$). Taken together, these results demonstrate that utilizing the arm swing in roller ski skating increases the ski forces and aerobic energy cost at low and moderate speeds, whereas the greater forces at high speed lead to a longer cycle length and smaller anaerobic contribution.

* Corresponding author. Address: Center for Elite Sports Research, Smistadvegen 11, 7026 Trondheim, Norway. Tel.: +47 93421219; fax: +47 73591770.
E-mail address: ann.hegge@ntnu.no (A.M. Hegge).

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1. Introduction

Cross-country skiing is a whole body endurance exercise which involves coordinated timing of the upper and lower limbs. In ski skating, the skis are positioned at an angle to the forward direction and the leg push-offs are carried out perpendicular to the ski, which together with the poling movement propels the skier forward in a "zig-zag" motion (Smith, 1990). Additionally, a well-timed arm swing is thought to support the lower limb force production and to contribute to increased speed in cross-country skiing. Although, the arm swing has been discussed in classical skiing techniques (diagonal and kick double poling) (Gopfert, Holmberg, Stoggl, Muller, & Lindinger, 2013; Lindinger, Gopfert, Stoggl, Muller, & Holmberg, 2009), no study has investigated the effect of the arm swing in the skating technique. Among the skating techniques, the arm swing is especially pronounced in the G4 skating technique (also referred to as V2-alternate, open field or single dance).

It has been demonstrated that the arm swing enhances performance in other sports, such as vertical jumping and the long jump (Ashby & Heegaard, 2002; Hara, Shibayama, Takeshita, & Fukashiro, 2006; Harman, Rosenstein, Frykman, & Rosenstein, 1990; Lees, Vanrenterghem, & De Clercq, 2004; Luhtanen & Komi, 1979; Shetty & Etnyre, 1989). These improvements are mainly explained by higher ground reaction forces resulting in an increased take-off velocity of the body's center of mass. The role of the arm swing has also been studied in running where the arms increase the upward acceleration of the body's center of mass and reduce the anterior–posterior and medio-lateral ranges of motion, which helps the runner to maintain balance (Arellano & Kram, 2011; Hinrichs, Cavanagh, & Williams, 1987). Following these advantages, it has been reported that running at submaximal speeds with free motion of arms results in greater ground reaction forces, longer step lengths and a reduction in the energy cost compared to a suppressed arm swing (Arellano & Kram, 2011, 2012; Miller, Caldwell, Van Emmerik, Umberger, & Hamill, 2009). Whether the arm swing leads to an increased force application and thereby a longer cycle length and a reduced energy cost in ski skating is a question that has not yet been investigated.

The aim of this study was to examine the effects of the arm swing on biomechanical aspects and physiological responses during roller ski skating. It was hypothesized that the magnitude of ski force application would increase, cycle lengths would be longer and the energy cost would be reduced when the arm swing supports the leg work in roller ski skating.

2. Methods

2.1. Subjects

Sixteen male Norwegian elite cross-country skiers volunteered to participate in the study (age 24 ± 4 years, body height 180.3 ± 5.5 cm, body mass 74.4 ± 7.6 kg, VO_2 peak 71.5 ± 3.8 ml min^{-1} kg^{-1}). The skiers competed at national and international level, and were familiar with roller skiing as part of their daily summer training. The experimental procedures were approved by the Norwegian Regional Ethics Committee and the protocol and procedures were verbally explained to each subject prior to obtaining the written informed consent.

2.2. The experimental design

Experimentally, leg-skating (i.e. skating without poles) while imitating the G4 skating technique with an active backward and forward arm swing (SWING) was compared to leg-skating with locked arms (LOCKED), as illustrated in Fig. 1. The skiers performed submaximal tests at a low, moderate and high speed on a 2% inclined treadmill in both techniques. Cycle characteristics, ski forces, upper and lower limb kinematics as well as cardiorespiratory variables were assessed during the submaximal tests. The blood lactate concentration was taken directly after each stage.