Does the Position of the Hinge in Cross-country Ski Bindings Affect Muscle Activation in Skating?

Conor M. Bolger[1], Øyvind Sandbakk[1], Gertjan Ettema[1] and Peter Federolf[1,2]
[1]*Center for Elite Sports Research, Department of Neuroscience, Norwegian University of Science and Technology, Trondheim, Norway*
[2]*Department of Physical Performance, Norwegian School of Sport Sciences, Oslo, Norway*

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Abstract: The objective of this study is to examine effect of changed hinge positioning in cross-country ski bindings on efficiency, kinematics and muscle activation patterns. Differences in muscle activation were investigated using a principle component analysis (PCA) due to the higher sensitivity of this method. Participants performed three tests utilizing varying hinge positions: front (toe attachment 0 cm), middle (4 cm behind toe), back (8 cm behind toe). The skiers performed 4 minutes at moderate intensity in G3 skating technique with all hinge positions. All tests were performed at 5% incline and 3.89 m/s. Conclusion: The greatest differences between skating and classical, and between genders were found on flat and uphill terrain, but were not associated with variations in heart rate. In all athletes, the hinge position affected ($F (2,87) > 5.71$, $p < 0.005$) the scores $\xi_{3,i}$ of the third eigenvector v_3 in which represented 7.0% of the entire variability of the dataset ($EV_3 = 0.0699$). The current pilot-study indicates differences in gross efficiency and kinematics, and revealed significant differences in muscle coordinative patterns with varying hinge positions.

1 INTRODUCTION

In cross-country ski skating the movement is performed in a zigzag fashion with the skis angled towards the average direction of travel and the corresponding leg push-off is performed perpendicular to the ski (Sandbakk et al., 2013). The ski boot is attached to the ski via a binding mechanism, normally creating a pivot location in front of the toe. Therefore a relatively soft boot that flexes is required to fully utilize plantar flexion. The leg push-off in ski skating is comparable to speed skating, but the klapskate introduced a more backward located mechanical hinge where a stiffer boot could rotate about. This innovative technology promotes plantar flexion and knee extension throughout the push-off phase (Houdijk et al., 2000).

Due to better mechanical efficiency the introduction of the klapskate resulted in a slight increase in total power output and an increase in speed skating velocities by 3-5% (de Koning et al., 2000). However, no differences in muscle activation patterns, neither in timing nor in amplitude, between the conventional skate and the klapskate could be identified using standard methods for analysing electromyogram (EMG) signals (Houdijk, 2000).

Although a previous study showed that the klapskate system might be more effective than this current system also in cross-country skiing (Stoggl et al., 2010), the effects of hinge positioning on such a system has never been examined. Therefore, the objective of this study is to examine effect of changed hinge positioning in cross-country ski bindings on efficiency, kinematics and muscle activation patterns. Differences in muscle activation were investigated using a principle component analysis (PCA) due to the higher sensitivity of this method (von Tscharner, 2002).

2 METHODS

2.1 Subjects

Three male Norwegian elite cross-country skiers participated in the study (26 ± 3 years, body height 182 ± 7 cm, body mass 74 ± 7 kg). The skiers participated at a national and international level and were familiar with roller skiing as part of their daily summer training.

M. Bolger C., Sandbakk Ø., Ettema G. and Federolf P..
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2.2 Instruments and Materials

Treadmill tests were performed on a 5x3 m motor driven treadmill (Forcelink B.V., Culemborg, the Netherlands). All skiers used a modified Madshus Nano Carbon skate boot (Madshus/K2, Biri, Norways) that was fit to a prototype binding designed specifically for this project, (IDT Sports, Lena, Norway). All skiers used the same pair of roller skis (IDT Skate, IDT Sports, Lena, Norway).

Ventilatory variables were assessed employing open-circuit indirect calorimetry with an Oxycon Pro apparatus (Jaeger GmbH, Hoechberg, Germany). The instruments were calibrated against ambient air and commercial gas with known concentrations (16.00 ± 0.04% O_2 and 5.00 ± 0.1% CO_2, Riessner-Gase GmbH and Co, Lichtenfels, Germany).

Movement kinematics were monitored via an Oqus (Qualisys AB, Gothenburg, Sweden) infrared camera-system with a 250Hz sample rate and where synchronized with EMG, sampled at 1500Hz. EMG-electrodes were attached to the skiers' dominant skiing-side leg on the bellies of m. semitendenosus, m. vastus medialis, m. vastus lateralis, m. rectus femoris, m. lateral gastrocnemius, and m. tibialis anterior. The placement of the electrodes followed the recommendations of the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM). The electrodes were bipolar, disposable pre-gelled Ag/AgCl surface electrodes (Noraxon USA, Inc., Scottsdale, AZ) with 20 mm inter-electrode distance.

2.3 Protocols and Procedures

Participants were prepped with retrorflective markers along with EMG electrodes and sensors prior to a 20-minute ski specific warm-up with the normal roller ski boots and bindings on the roller-ski treadmill. Participants performed three tests utilizing varying hinge positions: front (toe attachment 0 cm), middle (4 cm behind toe), back (8 cm behind toe). Skiers performed 4 min at moderate intensity in G3 skating technique with all hinge positions. All tests were performed at 5% incline and 3.89 m/s. Ventilatory variables where continuously monitored through the entire test. A 15-minute break was given between hinge tests to minimize sweating and fatigue.

A skate cycle was defined as one right and one left leg push-off. The beginning and end of each cycle was defined as ski lift-off of the left ski. Cycle rate was calculated as the number of cycles per second. Cycle length was the covered distance on the treadmill during one cycle, which was calculated as speed times cycle time.

Work rate was calculated, in accordance with Sandbakk et al. (Asan Grasaas et al., 2014), as the sum of power against gravity $P_g = m \cdot g \cdot \sin\alpha \cdot v$ and friction $P_f = m \cdot g \cdot \cos\alpha \cdot \mu \cdot v$ where m is the body mass of the skier, g the gravitational acceleration, α the angle of treadmill incline, v the speed of the treadmill belt, μ the frictional coefficient (.026). The aerobic metabolic rate was calculated as the product of VO_2 and the oxygen energetic equivalent using the associated respiratory exchange ratio and standard conversion tables. Gross efficiency was calculated as the external work rate performed by the entire body divided by the aerobic metabolic rate, presented as a percentage.

The EMG analysis was conducted with custom-written Matlab™ (The MathWorks Inc., Natwick, MA) codes and included the following steps: For each trial, 30 stride cycles were determined using the acceleration signal with the ski takeoff serving as trigger points. A wavelet transformation (von Tscharner, 2000) yielded the intensity of the EMG signal. This intensity was resampled such that 501 data points represented each cycle and normalized to unit intensity per cycle. The normalized waveforms of the 6 muscles were then concatenated into a 3506-dimensional vector. All vectors from the 3 subjects skating with 3 different hinge positions formed a 270 x 3501 matrix which was submitted to a principal component analysis (PCA). The PCA yielded (a) eigenvectors $\mathbf{v_k}$ that quantified correlated deviations from the mean waveform, (b) eigenvalues EV_k quantifying how much of the variability was represented by each eigenvector, (c) scores $\xi_{k,i}$ that quantified how much the deviations of each cycle i from the mean waveform was represented by the eigenvectors $\mathbf{v_k}$. The scores $\xi_{k,i}$ were analyzed to determine if the hinge position caused correlated deviations from the mean multi-muscle EMG waveform. Due to the small number of participants, the statistical analysis was only conducted to determine intra-subject effects of the hinge position, i.e. for each subject a 1-way ANOVA was calculated and Student T-tests were used for the post-hoc comparison between hinge positions.

3 RESULTS

The mean cycle lengths for the front, middle and back hinge positions were 8.0 m, 8.0 m, and 7.8 m respectively, with corresponding cycle rates of

0.49s, 0.48s, and 0.50s. Gross efficiency for the front, middle, and back hinge positions were 16.1%, 16.6% and 15. 9% respectively.

In all athletes, the hinge position affected ($F_{(2,87)} > 5.71$, $p < 0.005$) the scores $\xi_{3,i}$ of the third eigenvector $\mathbf{v_3}$ (Figure 1). This eigenvector represented 7.0% of the entire variability of the dataset ($EV_3 = 0.0699$). A visual representation of how $\mathbf{v_3}$ changed the muscle activation pattern is displayed in Figure 2.

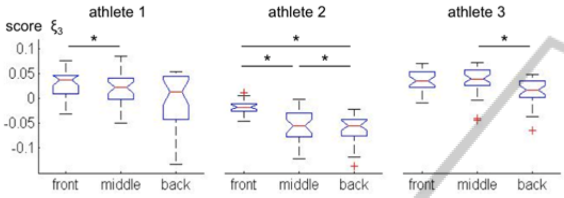

Figure 1: Boxplots representing the distribution of the scores ξ_3 obtained for the 30 skating cycles analysed for each condition. The asterisk * indicates significance in the post-hoc test.

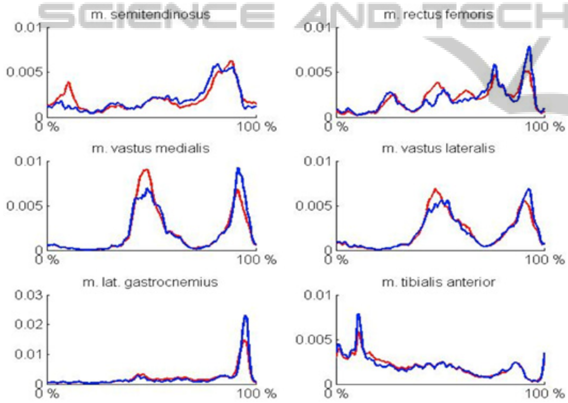

Figure 2: Mean muscle activation pattern of the 6 muscles plus the deviation from the mean represented by $\mathbf{v_3}$: the blue curve indicates the back hinge position, the red line the front hinge position. The skating cycle is represented from ski take-off (0%) to the following ski take-off (100%).

4 DISCUSSION

The current pilot-study indicates trends in gross efficiency and kinematics, and revealed significant differences in muscle coordinative patterns with varying hinge positions. Although differences in efficiency and kinematics were expected due to previous literature on the effects of the klapskate, the effect on EMG patterns has not been shown before. The employment of PCA to determine hinge position differences is a novel approach that investigated correlated deviations from the mean multi-muscle EMG waveform and could validly reveal small changes in muscle activation.

The EMG waveforms seen in Figure 2 represent the skate push-off for the front and back hinge position. With the back hinge position the gastrocnemius activation indicates an increased plantar flexion during the push-off phase and the tibialis anterior activation indicates a counter dorsiflexion movement during the swing phase. This suggest increased hip and knee extension within the skate push-off proposing that the skiers' hips are held in an anterior position as the knee extends dorsolateral to the movement direction, which may have resulted in the shorter cycle length and decreased mechanical efficiency. Conversely, increased activity in the vastus lateralis, vastus medialis and rectus femoris during the ski-plant phase with the front hinge position may suggest decreased stability of the system and increased muscle recruitment required to balance.

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