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Comparison of skating kinetics and kinematics on ice and on a synthetic surface

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Abstract
The recent popularization and technological improvements of synthetic or artificial ice surfaces provide an attractive alternative to real ice in venues where the latter is impractical to install. Potentially, synthetic ice (SI) may be installed in controlled laboratory settings to permit detailed biomechanical analysis of skating manoeuvres. Unknown, however, is the extent to which skating on SI replicates skating on traditional ice (ICE). Hence, the purpose of this study was to compare kinetic and kinematic forward skating parameters between SI and ICE surfaces. With 11 male hockey players, a portable strain gauge system adhered to the outside of the skate blade holder was used to measure skate propulsive force synchronized with electrogoniometers for tracking dynamic knee and ankle movements during forward skating acceleration. In general, the kinetic and kinematic variables investigated in this study showed minimal differences between the two surfaces (P > 0.06), and no individual variable differences were identified between the two surfaces (P ≥ 0.1) with the exception of greater knee extension on SI than ICE (15.2° to 11.0°; P ≤ 0.05). Overall, SI surfaces permit comparable mechanics for on-ice forward skating, and thus offer the potential for valid analogous conditions for in-lab testing and training.

Keywords: Force measurement, kinematics, kinetics, ice hockey

Introduction
The game of ice hockey is a popular activity and a competitive sport, yet the specific mechanics of ice hockey skating remain for the most part obscure (Lafontaine, 2007). The paucity in quantitative skating studies may be in large part attributed to methodological limitations of conventional motion capture systems in ice environments that are unable to track skating skills which traverse large fields of view (Upjohn et al., 2008). Of the few studies reported, most have used video to analyze body kinematics during forward acceleration to identify key changes in gross body movement patterns that relate to performance (Marino, 1983). With respect to the skating start, de Koning et al. (1995) found substantial differences in the push-off technique of the second through eighth strides in elite-level speed skaters. In particular, their results showed little displacement of the skate during the second stride, signifying that the athlete was pushing off against a fixed point, similar to a running stride,
whereas during the eighth stride the skate was gliding during the push-off, creating more of a lateral push. Similar results have been found by Lafontaine (2007) when investigating the ice hockey start. These observations were also confirmed by Pearsall et al. (2001) when employing local joint dynamic electrogoniometers.

Upjohn et al. (2008) published the most recent study to use a non-traditional surface (i.e. skating treadmill) to evaluate the kinematics of skating. Using multiple video cameras to derive 3-D kinematics, they examined the body movement patterns which discriminate between high-calibre and low-calibre hockey players when skating at constant velocities. It was revealed that high-calibre skaters had a greater hip flexion at weight acceptance, greater knee extension and plantar flexion at the propulsion phase, and greater knee and ankle ranges of motion than their low-calibre counterparts. This study and others like it (Nobes et al., 2003; Lockwood and Frost, 2007) provide evidence that alternative surfaces like skating treadmills or artificial surfaces (SI) can be used to improve our understanding of skating biomechanics.

The cost of ice rental, transport of equipment and set-up of apparatus and the potential for malfunction of equipment in cold environments represent significant challenges to the efficient study of skating on ice. In addition, problems with the calibration of a large capture volume and difficulty in obtaining proper ambient lighting conditions using motion capture systems make it very difficult to obtain precise skating kinematics on ice (MacPherson et al., 2004). Thus, the use of an expanded synthetic ice (SI) surface could eliminate many of these problems and could provide an additional alternative to ice for the study of skating biomechanics. Several manufacturers produce SI surfaces, some of which consist of interconnected polyethylene panels. When these surfaces are covered with a silicone-based lubricant the friction of the artificial surface is diminished, creating ice-like glide properties. With sufficient scoring/scratching of the polymer surface it is also possible for skaters to simulate glide and push-off and all typical skating manoeuvres, skating with the same blades as those used for ice skating. Furthermore, the SI surface offers the possibility for use within a lab environment, making it possible to overcome some of the aforementioned difficulties associated with on-ice studies. However, comparative studies are needed to confirm whether SI surfaces produce a valid representation of ICE skating.

Thus, the purpose of this study was to compare forward skating mechanics between ICE and SI. Comparisons included the kinetic and kinematic-dependant measures (using force transducer strain gauges and electrogoniometry, respectively). It is anticipated that there will be no major differences with regard to skating kinetics and kinematics on the ICE surface or on the SI surface for forward skating tasks. Considering the inherent complications with studying skating on a frozen ice surface, it is anticipated that the controllable in-lab conditions afforded by the artificial ice surface will allow for successful capture of information on the gross movement patterns of ice hockey skating and other hockey-related skills.

Methods

Participants

Thirteen adult male hockey players were recruited to voluntarily participate in the study, although only 11 completed both protocols. Ten of the subjects were playing for the McGill University varsity hockey team, while one subject was a former ‘AAA’ level hockey player (7 forwards, 4 defensemen, 21.5 ± 1.9 years, 83.5 ± 4.3 kg). The subjects were skilled skaters, and were able to easily complete the required skating protocol. A power analysis was
performed using a freely available sample size calculator (Dupont and Plummer, 1997) to estimate the required sample size to obtain a power value of 0.85 or greater at an alpha level of 0.05. Using a detectible difference of 2 degrees, based on literature ± 2° error of the elgon, and a predicted standard deviation of 2° (pilot data with one McGill varsity hockey player and one QMJHL hockey player), 10 subjects was deemed necessary for an adequate kinematic evaluation. Thus, we recruited more than 10 subjects anticipating some subject mortality and/or problems with lost data in testing sessions.

The subjects were recruited by verbal communication, and completed an informed consent document prior to participation in the study. The study was approved by the McGill University Research Ethics Board.

Experimental protocol

Ice surfaces. Testing composed of two parts: an in-lab collection session on a SI surface (Viking Ice®) and an ICE data collection session within an ice arena. The in-lab testing occurred on a specially constructed SI surface in the McGill University Biomechanics Laboratory (Figure 1), while the ICE testing took place at a McGill ice rink. Dimensions of the SI surface were 12.9 m in length by 5.9 m in width. The SI surface was installed over top of a concrete floor, and was levelled using common construction techniques. The reported surface friction of the SI surface used in the current study is $\mu = 0.27$, (Viking Ice, 2009) while the coefficient of friction of ice is reported to be in the order of $\mu = 0.003$ to 0.007 (Kobayashi, 1973; Jobse et al., 1990; de Koning, 1992; Nobes et al., 2003).

Subject preparation

During testing the subjects wore a pair of appropriately sized ice hockey skates (model Nike-Bauer Supreme One95). The right skate was instrumented with force transducer strain gauges. The force measurement system utilized in the study is described in detail by Stidwill et al. (2009). Each instrumented hockey skate had 3 half-active Wheatstone bridges composed of 350Ω, 0.125” long strain gauges provided with an excitation voltage of 2V ± 2% (5 gauges attached to skate) connected to a 13 bit analog to digital converter.

Figure 1. Depiction of synthetic skating surface for experiments in laboratory. The surface was sprayed with a silicone substance to reduce friction prior to the beginning of testing sessions.
(DataLOG model P3X8, Biometrics Ltd., Gwent, UK). Each gauge was located at strategic locations on the blade holder so as to capture the amount of vertical and medial-lateral strain produced on the blade holder (Figure 2). Each subject also carried a hockey stick to mimic game situation skating patterns as closely as possible. Kinetic information was captured at a frequency of 100 Hz.

The subjects were also fitted with 2-D electrogoniometers about the ankle and knee of the right leg. The first electrogoniometer was placed along the Achilles tendon of the right ankle, while the second electrogoniometer was positioned on the lateral aspect of the right knee, situated so that the centroid of the instrument was aligned with articulation point of the knee. The left leg was not instrumented as symmetry of the bimodal movement pattern was assumed. The electrogoniometers allowed for successful capture of the subjects’ lower body joint kinematics. A Biometrics Ltd. DataLOG was used to record the data (100 Hz) from the electrogoniometers. Once the subject was properly fitted with the electrogoniometers, the signals were set to zero with respect to the subject’s neutral standing position while barefoot. All data collected were normalized to this ‘zeroed’ neutral standing position. The logger was placed in a small backpack worn by each subject during testing.

**Tasks**

The subjects were asked to perform five maximum effort skating starts on both surfaces (SI and ICE). The SI surface was treated with a thin film of a silicone-based lubricant, while the ice rink surface was resurfaced with a Zamboni™ prior to each testing session to create optimal and consistent ice conditions.

Each trial consisted of the subject beginning from a standing position, starting with a front start, and accelerating as quickly as possible up to maximum velocity. A front start is a typical hockey skill in which the athlete begins facing their intended direction of travel. The athletes began by initially pushing with their right leg, and swinging their left leg. Each trial consisted of a minimum of three full push-offs of the right leg.

Figure 2. Strain gauge placement on skate. Gauges were placed on each side of the rear post, middle and front posts areas of the skate blade holder to capture forces exerted on the skate.
The subjects were instructed to skate as fast as possible for a distance of approximately 13 m, and were given ample recovery time between trials to avoid fatigue (approximately 1 minute) (Beachle and Earle, 2000). Crash mats were placed at the end of the runway for the in-lab testing condition to increase subject safety.

Subjects were asked to perform a 10 to 15 minute self-selected on-ice skating warm-up routine prior to the beginning of the in-lab and on-ice testing sessions to become familiar with skating on the SI surface, with the equipment set-up. This warm-up was conducted at a low intensity. Following these warm-ups, the subjects were asked to perform the skating protocol at 50% intensity two or three times to become familiar with the testing procedure.

Statistical analysis

Analysis of kinetic variables included maximum total force in Newtons expressed as % of body weight (N/% body weight) and determined by the summation of vertical and mediolateral force components, maximum vertical force (N/% body weight), maximum mediolateral force (N/% body weight), impulse (Ns), and contact time (ms). Kinematic variables analyzed included maximum and minimum knee flexion-extension and ankle dorsiplantarflexion amplitudes (degrees), knee flexion-extension and ankle dorsiplantarflexion amplitude at the point of maximum force production (degrees), as well as knee and ankle maximum angular velocities during push-off (degrees). A two-way MANOVA was used to compare all kinetic and kinematic variables across three skating strides by the two skating surfaces. A univariate $F$-test was performed on each of the dependent variables to interpret the results of the MANOVA (George, 2006). Statistical significance was set at $\alpha = 0.05$.

Stride time (ms) was analysed independently from the MANOVA. Given that not all subjects were able to finish the recovery phase of their third stride during the in-lab scenario, it was not possible to compare the third stride on both surfaces with all other variables via the combined MANOVA. Thus, a two-way ANOVA was performed on stride time for the first two strides across surface conditions. All statistical analyses were performed using SPSS (v.17, Chicago, IL, USA).

Results

In general, the kinetic and kinematic measures were the same for both surfaces ($P > 0.06$). On inspection of the data, similar force and joint angles profiles with respect to time were demonstrated on ICE and SI. During skating acceleration comparable transitions in force-time profiles from the first to third stride were also observed.

Table I. Average kinetic measures ($s$) values across surface conditions averaged across all subjects ($N = 11$), trials, and strides.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Total force (N)</th>
<th>Vertical force (N)</th>
<th>Medial-lateral force (N)</th>
<th>Contact time (ms)</th>
<th>Impulse (Ns)</th>
<th>Stride time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE</td>
<td>163.7 (28.6)</td>
<td>141.8 (28.8)</td>
<td>24 (16.6)</td>
<td>354 (47)</td>
<td>203.6 (48.4)</td>
<td>585 (56)</td>
</tr>
<tr>
<td>SI</td>
<td>160.5 (33.3)</td>
<td>134.1 (31.1)</td>
<td>30 (18.4)</td>
<td>358 (56)</td>
<td>203.1 (60.2)</td>
<td>581 (72)</td>
</tr>
</tbody>
</table>

Group means and standard deviations ($s$).
Kinetics

The analysis showed that none of the kinetic variables were significantly different across skating surfaces (Table I). Total force production was found to be similar between ICE and SI surfaces (163 N/%BW vs. 160 N/%BW; $P = 0.67$). Similarly, average peak vertical forces were found to be equivalent in both conditions (141 N/%BW vs. 134 N/%BW; $P = 0.31$). Average peak medial-lateral forces were found to be slightly higher on SI as compared with ICE approaching but not reaching significance (30 N/%BW vs. 24 N/%BW; $P = 0.11$). Similarly, contact time and impulse were the same on the two surfaces ($P = 0.61; P = 0.93$), as were stride times also similar ($P = 0.75$).

Kinematics

Kinematics were evaluated simultaneously with force measures. Similar knee flexion-extension and ankle plantar-dorsiflexion stride patterns were observed.

Knee kinematics

Though like knee flexion-extension stride profiles were observed, analysis of curve parameters (Table II) identified one difference in knee excursion. Specifically, mean maximum knee extension amplitude was found to be significantly different between conditions, with greater extension occurring during skating on SI than ICE (11° vs. 15.2°; $P = 0.05$). Mean knee angles at maximum flexion and at the point of maximum force production were equivalent between ICE and SI ($P = 0.11; P = 0.14$). Similar mean maximum knee extension velocities during push-off across surface conditions were observed ($P = 0.89$).

Ankle kinematics

Due to technical problems with the electrogoniometers at the ankle, data for only four subjects on both surfaces was recorded for kinematics. Kinematic parameters (Table III) were found to be similar when surface conditions were compared ($P = 0.66; P = 0.26; P = 0.20; P = 0.19$).

Discussion

The purpose of this study was to compare forward skating mechanics between SI and ICE. Comparison included kinetic and kinematic dependent measures (using force transducer strain gauges and electrogoniometry). Overall, the results of the present study demonstrated that skating mechanics on these two surfaces were not different in terms of both gross

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Table II. Averaged knee kinematic variables across surface conditions across all subjects ($N = 11$), trials, and strides.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Knee extension (deg)</th>
<th>Knee flexion (deg)</th>
<th>Knee flexion @ maximum force (deg)</th>
<th>Knee angular velocity (deg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE</td>
<td>15.2* (3.9)</td>
<td>86.9 (8.6)</td>
<td>39.1 (6.5)</td>
<td>334.4 (58.1)</td>
</tr>
<tr>
<td>SI</td>
<td>11.0* (7.1)</td>
<td>81 (18.9)</td>
<td>35.5 (11.8)</td>
<td>336.9 (85.3)</td>
</tr>
</tbody>
</table>

Group means and standard deviations (s).

*Indicates significant difference at $\alpha \leq 0.05$ for the F-test.
movement pattern and skate force production. For the most part, similar knee and ankle movement patterns were observed on ICE and SI. Although not statistically significant, a more pronounced squatting stance (i.e. greater knee flexion and ankle dorsi-flexion) was evident during mid-glide followed by greater limb extension (i.e. greater knee extension and ankle plantar flexion) at push-off as executed on ICE in contrast to SI surface. These joint movements culminated in slightly though not significantly greater ranges in motion (58 to 108). Measures of stride ground contact times and knee joint extension speeds did not differ significantly between the two surfaces.

Subjects extended their knees by an average of four degrees greater on the SI compared to the ICE surface. From a qualitative inspection of the videos of each subject’s trials, some visually distinct differences in knee extension in approximately half of the subjects were noted when skating on the two surfaces.

It was initially anticipated that differences in dependent measures, if they did occur, would be primarily attributed to disparity in surface coefficients of friction. Ice’s coefficient of friction when skating has been reported to vary between a \( \mu \) of 0.003 and 0.007 (Kobayashi, 1973; Jobse et al., 1990; de Koning, 1992; Nobes et al., 2003), while the reported coefficient of friction of the synthetic surface used in this study is around 0.27 (Viking Ice, 2009). Undoubtedly, differences in friction would pose problems for athletes if they were forced to skate on such a surface during game like conditions. In the context of a brief skill comparison, the artificial surface seems appropriate for short duration skill execution and seems to compare favourably to a real ice surface. Thus, given that force production and stride times were similar on both surfaces, and the very brief nature of the skill examined in the present study, differences in surface friction cannot be the only explanation for the slight kinematic difference noted. Notwithstanding, the increased friction on SI would result in quicker deceleration and thus require quicker recovery from stride to stride resulting in reduced limb excursions from stride to stride. It is also possible that skaters anticipated the need to adjust their posture due to the shorter distance on the SI surface. That is, the SI skate surface distance of 13 m required a more rapid deceleration, whereas the ICE surface rink forward acceleration and skating was unrestricted for up to 60 m. Whatever the mechanism, the slight differences in kinematics suggest that during the former test condition, subject’s posture was more upright (i.e. less flexed knees and less dorsi-flexed ankle) during skating in anticipation of the need to maintain balance while decelerating from stride to stride.

Notwithstanding the above issue, the skating kinetics of each respective stride were not different between SI and ICE conditions and both vertical and medial-lateral force patterns were near identical in magnitude and shape. Typically, the first three strides of the acceleration phase involve pushing against a fixed point with little to no gliding (de Koning, 1995; Lafontaine, 2007). This was evident from the unimodal impulse patterns recorded on both surfaces.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Ankle plantar flexion (deg)</th>
<th>Ankle dorsi-flexion (deg)</th>
<th>Ankle flexion at maximum force (deg)</th>
<th>Ankle angular velocity (deg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE</td>
<td>-12.9 (6.5)</td>
<td>18.6 (6.1)</td>
<td>17.4 (7.7)</td>
<td>353.1 (38.8)</td>
</tr>
<tr>
<td>SI</td>
<td>-11.8 (4.5)</td>
<td>15.1 (7.2)</td>
<td>11.4 (12.2)</td>
<td>277.9 (174.0)</td>
</tr>
</tbody>
</table>

Table III. Ankle kinematic variables across surface conditions averaged across subjects with complete ankle data (\( N = 4 \)), trials, and strides. Group means and standard deviations (s).
Conclusion

Through kinetic and kinematic analyses, the present study of forward skating has shown that the SI surface can provide an analogous environment to true ice with this task condition, resulting in skating mechanics that were not different. Future comparative studies of other skating skills are warranted, particularly agility skills requiring substantial carving into the surface and quick changes of direction. In summary, SI surfaces may provide a feasible means of bringing the game skills into a laboratory environment. More research is required on other skills to determine if skill execution on SI is realistic and transferable to the game ice conditions.

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References