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The effects of new Edea and Graf figure skating boots and used Graf boots on the kinetics and kinematics of landing after simulated on-ice jumps

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Abstract: An increase in training intensity and the number of active participants and competitors in figure skating has been accompanied by an increasing frequency of injuries. The aim of this study was to investigate whether different brands of skates as well as the usage of the skates modify the kinetics and kinematics of the landing impact from a jump. New Graf Edmonton (NG), old used Graf Edmonton (OG) and new Edea Concerto (NE) skates were compared. Twelve participants completed six jump trials from 30 cm and 50 cm high boxes, respectively in all three skates and landed on a section of artificial ice placed on a laboratory floor. Landing kinematics (Oqus4 system, Qualisys, Sweden) and kinetics (force plate: Kistler, Switzerland; insoles: Pedar, Novel, Germany) were examined. Each participant acted as their own control for statistical comparison between the skates. The results confirmed that the kinetics and kinematics of the landing are affected by wearing different skates. During landing impacts in NG, participants had significantly greater dorsiflexion at initial contact (IC) and peak dorsiflexion of the ankle, peak flexion of the knee and also greater in-skate plantar forces (PF) than in NE, which may increase the risk of injury. In OG, participants had significantly greater peak flexion of knee and longer time from IC to first peak dorsiflexion (TP) of the ankle than in NG. The differences observed may be due to the different construction designs, such as height of the heel, used materials, and stiffness of the skates, which may affect injury occurrence.

Keywords: Figure skating boots; jump landing; landing impact; kinetics; kinematics

1. Introduction

In recent decades, the physical demands of figure skating have greatly increased. The progression in the complexity of elements that are performed by figure skaters and greater physical demands required to remain competitive may be the most noticeable changes. The intensity and volume of training required to remain competitive is constantly increasing. Early specialisation has also become common practice within figure skating. Bruening & Richards (2006) reported that solo figure skaters can perform up to 100 jumps a day in training. Considering the continued increase in training intensity, it is likely that the number of jumps performed per day has increased even more in contemporary solo figure skaters. The number and frequency of injuries in figure skaters have also increased (Bradley, 2006; Bruening & Richards, 2006; Porter, Young, Niedfeldt, & Gottschlich, 2007) in conjunction with an increase in the number of active participants and competitors.

Most injuries among young solo figure skaters are caused by the everyday wearing of the skates that expose the ankle and foot to pressure, leading to bruises and blisters, and also by training overload resulting in musculoskeletal injuries, (Campanelli, Piscitelli, Verardi, Maillard, & Sbarbati, 2015; Dubravčič-Simunjak, Pecina, Kuiipers, Moran, & Haspl, 2003; Dubravčič-Simunjak et al., 2008; Fortin & Roberts, 2003).

Figure skaters expose their body to repetitive traumas during take-offs and landings, which loads the ankles, knees, hips, and lower back of the skater (Porter et al., 2007; Weinhandl, Smith & Dugan, 2011). The absorption of relatively high forces during landing impacts acts on soft tissue and bones and may result in micro and macro damage to anatomical structures, which may ultimately lead to overuse injuries (Nash, 1988; Nigg & Bobbert, 1990; Zhang, Bates & Dufek, 2000). These loads may be exacerbated through increased jump heights, number of vertical rotations in the air and the
number of jumps performed (Grewal et al., 2016; Lockwood & Gervais, 1997; Ortega, Rodriguez Bies, & Berral De La Rosa, 2010; Porter et al., 2007; Weinhandl, Smith & Dugan, 2011; Yeow, Lee, & Goh, 2009).

In contrast to the above-mentioned changes in figure skating in recent times, the design of the actual skates has undergone few changes over the same period (Bradley, 2006; Bruening & Richards, 2006). Contemporary skates limit the ability of the human body to deal with impact forces during jump landings due to the stiffness and the high heel of the skates. Several studies are in agreement indicating that a reduced ability of the human body to deal with impact forces may be at least partially attributed to the restriction of ankle motion and the high heel (Bruening & Richards, 2006; Dubravcic-Simunjak et al., 2003; Haguenauer, Legreneur & Monteil, 2006; King, 2000; King, Arnold & Smith, 1994; Porter et al., 2007; Saunders, Hanson, Koutakis, Chaudhari, & Devor, 2014). Restriction of ankle motion in skates is largely caused by the stiffness of the skates, but the stiffness of footwear is also important in order to secure the ankle joint against excessive motion (Böhm & Hösl, 2010; Campanelli et al., 2015; Cordova, Takahashi, Kress, Brucker, & Finch, 2010; Rowley & Richards, 2015), which is especially necessary during demanding jumps, spins, and steps on the ice. As the stiffness of a footwear decreases with extensive use (Böhm & Hösl, 2010), the risk of injury may increase since the ankle joint is less protected.

Several different manufacturers currently offer many models of figure skating boots on the market, which differ in stiffness, material use, and boot construction design such as heel height (Bradley, 2006; Campanelli et al., 2015). Different heel height and stiffness directly affect the rest of the kinematic chain where, for instance, restriction of ankle range of motion (ROM) limits the movement of the knee (Böhm & Hösl, 2010; Bruening & Richards, 2006; Cikajlo & Matjačić, 2007; Di Stefano, Padua, Brown, & Guskiewicz, 2008; Fong, Blackburn, Norcross, McGrath, & Padua, 2011; Macrum, Bell, Boling, Lewek, & Padua, 2012). During landing impacts, joints such as the ankle and knee are rapidly flexing in order to dissipate and absorb the impact force (DeVita & Skelly, 1992; Norcross et al., 2013; Yeow et al., 2009). If the ROM of the ankle and knee is limited, the landing has the characteristics of a stiff landing. During such landings, the acting impact vertical ground reaction force (VGRF) is greater, steeper, and acts for a shorter period of time compared to a soft landing, where greater ankle plantar flexion and ROM as well as knee ROM during the landing impact provides for a longer deceleration phase. This reduces the VGRF and loading rates, permitting a soft landing, which is a safer and more secure landing strategy (Dufek & Bates, 1990; Devita & Skelly, 1992; Zhang et al., 2000; Self & Paine, 2001; Distefano et al., 2008; Yeow et al., 2009; Fong et al., 2011; Norcross et al., 2013; Rowley & Richards, 2015). Increased landing stiffness increases the risk of injury. In addition, high VGRF during stiff landings and limited ankle and knee ROM could be associated with greater knee valgus displacement and increased risk of anterior cruciate ligament injury and patellar tendon injury (Fong et al., 2011; Macrum et al., 2012).

Different models of figure skates and blades may affect the biomechanics of a landing impact. The aim of this study was to examine the effects of different figure skates on the kinetics and kinematics of the landing impact. Stiffness of the skates decreases with extensive use and age, which may affect landing biomechanics. This study will, therefore, also compare new skates with old and used ones. Skates examined in this study were new Graf Edmonton Special Classic (NG), old used Graf Edmonton Special Classic (OG), and new Edea Concerto (NE). The OG skates had been used more or less daily for one year (approximately 500 hours) by an international level solo skater.

Insight into how different skates affect the landing biomechanics may provide important information assisting in the identification of weaknesses in current construction designs. Selection of appropriate skates may prevent some injuries and facilitate longer active competitive figure skating careers.

The hypotheses of this study were: (1) The in-skate plantar force (PF) acting on the human body during the landing impact is reduced in NE compared to NG. (2) The PF acting on the human body during the landing impact in OG is reduced compared to NG. (3) Peak plantar flexion and peak knee flexion is greater during the landing impact in used skates (OG) compared to new skates (NG).

2. Method

2.1. Participants

The inclusion criteria for participants to participate in this study were to be a national or international level either single or pair male skater with more than six years of competitive skating experience and to fit skates size 7 (UK men's size). The choice of participants created a homogeneous group of skaters, whose technique is stable so the landings performed were as standardized as possible between the attempts. Due to the participants’ experience, no learning effects were expected to confound the data collection.

Twelve present or recent (eight years since the most recent retirement of a participant, but still active in coaching on the ice) advanced male figure skaters (age 29 ± 15 years, mass: 62 ± 16 kg, height: 179 ± 12 cm,
years of competitive skating (12±6 years) living in
Sweden gave written consent to participate in this study. The study was approved by the Regional Ethics Review Board of Stockholm.

2.2. Skate properties

There are minor and major differences in mechanical and construction design properties between different brands of skates. Descriptive design data are presented in Table 1. See Figure 1 for illustration of the values in Table 1.

The material used for the individual parts of the skates:

2.2.1. NE skates

Outsole: fibreglass, nylon, plastic, thin soft layer of vibration absorbing material and hollow curved heel

Skate body: leather, plastic, fibreglass, microfiber, soft memory foam, metal hooks.

2.2.2. NG/OG skates

Outsole: leather midsole with tapered edge profile, self-reinforcing polypropylene (SRPP) surface, beechwood heel, shock-absorbing rubber.

Skate body: leather, laminated fabric, microfiber, soft foam, metal hooks.

Information concerning the boot construction design, technical parameters, and the materials used for the skates were obtained from the manufacturers or found on the manufacturer's websites. Furthermore, skates of the same model were cut in half and analysed by using micro weight scales and calipers.

The skates differed in stiffness. A lunge test was performed in skates before the mounting of the blades to assess the maximal dorsiflexion ROM. NG were stiffer with a greater limitation of ankle dorsiflexion compared to NE skates.

2.3. Experimental set-up

Landings from simulated figure skating jumps on a 10.44 m² artificial ice surface (Nordic Ice Consulting AB) were investigated. Three-dimensional kinematic data were sampled at a frequency of 250 Hz using a twelve-camera Qualisys motion capture system (Oqus 4, Qualisys AB, Gothenburg, Sweden). Diagram of laboratory set-up is presented in Figure 2. Sixty six passive reflective markers were placed on anatomical landmarks to examine the kinematics of the right lower extremity, right hip, and trunk.

Kinetic data were simultaneously collected by Kistler force plate (Kistler type 9281EA, Kistler AG, Winterthur, Switzerland: 2500 Hz) underneath the plastic ice surface and by an in-shoe pressure measuring system (Pedar-X, Novel GmbH, Munich, Germany: 200 Hz). The piece of plastic ice covering the force plate was cut to the exact dimensions of the force plate with an approximately 3 mm space to the adjoining ice surface to prevent dispersion of forces. The Pedar-X box and the Novel wireless unit and battery were attached to the participant’s hip and firmly secured by a wide belt.

2.4. Experimental protocol

Each participant completed six simulations of a figure skating jump from both a 30 cm high box (B1) and a 50 cm high box (B2) with each of the figure skate models and landed on the artificial ice surface. Each participant performed the jumps first from B1 and then from B2 with each type of skate. The order of skates for the
jumping trials was randomized. All boots were the same size (size 7 UK men's size) and identical blades (Jackson ultima Matrix Supreme light blade) were mounted on all boots. The participants wore nylon socks during the measurements.

The simulated figure skating jump consisted of a take-off from the box followed by a half vertical axis rotation (180°) and horizontal motion in the air before landing in a backward facing position with the right foot making first contact, which replicates the Waltz jump in figure skating. All participants were asked to practice the tasks during their warm-up in order to familiarize themselves with the experimental setup and protocol. The horizontal distance between the box and the concealed force plate, on which the participants were required to land, was individually chosen by each participant and remained the same between each of the tested skates. Participants were requested to minimize the vertical component of their take-off and not to lower their body’s centre of mass during take-off from the boxes and this was controlled visually for each trial.

**2.5. Data analysis**

The kinetic variables analysed were the maximal vertical ground reaction force at impact (VGRF), the maximal in-skate plantar force at impact (PF) and time from initial contact (IC) to PF (TPF). PF and VGRF were normalized to body weight. The data from the Pedar-X system were analysed for the complete foot, forefoot, midfoot, and rearfoot. Kinematic variables analysed were flexion at IC, first peak flexion, and the time from...
IC to first peak flexion (TP) of the right ankle, knee, and hip and of the trunk.

In-skate force and pressure data were processed in the Pedar-X Online program. Data from the force plates and motion capture system were processed in Visual3D v5 Professional software (C-Motion Inc. Germantown, MD, USA) following digitization and export using the Qualisys Track Manager (QTM; Qualisys AB, Gothenburg, Sweden). Raw kinematic data were normalized to height and body weight and low-pass filtered using a digital fourth-order zero-lag Butterworth filter with a cut-off frequency of 7 Hz. The definition of analysed angles is illustrated in Figure 3.

The highest and the lowest values for all kinetic and kinematic values, obtained during the six trials, were discarded. All averaged values for kinetic and kinematic variables were statistically compared between the figure skates using IBM SPSS Statistics software (version 24, Armonk, NY: IBM Corp.). Values are expressed as mean ± standard deviation (SD) with p-values. Following testing for normality with the Shapiro–Wilks test, either a non-parametric Wilcoxon test or a paired samples T-test was used to test for significant differences. The level of significance was set at p ≤ 0.05.

Due to technical difficulties, data for all trials were not available for all participants. The number of participants whose trials were included in the specific experimental conditions is presented in Table 2.

3. Results

Kinetic results are presented in Table 3 and Figure 4. Kinematic results are presented in Table 4. The means for different parameters presented for specific skates in different comparisons, e.g. NE vs. NG and NG vs. OG differ slightly as different trials are included in different comparisons.

3.1. Kinetic results

A significantly greater PF underneath the whole foot was seen in NG compared to NE skates, for B1 (NG 2.28 ± 0.38 and NE 1.95 ± 0.27 N* BW; p = 0.005) and for B2 (NG 3.01 ± 0.69 and NE 2.69 ± 0.59 N* BW; p = 0.001), and this was also the case for the rearfoot for B2 (NG 1.57 ± 0.76 and NE 1.30 ± 0.57 N* BW; p = 0.037). In the NG skates, TPF was significantly longer for B2 (NG 0.05 ± 0.01 and NE 0.04 ± 0.01 s; p = 0.031) and this was also the case for the midfoot during the landings for B2 (NG 0.04 ± 0.01 and NE 0.03 ± 0.01 s; p = 0.046).

A significantly greater PF acted on the midfoot in NG compared to OG skates during landings for B2 (NG 0.27 ± 0.16 and OG 0.14 ± 0.11 N* BW; p = 0.001). TPF for the midfoot in the NG skates was significantly longer than in the OG skates for B1 (NG 0.05 ± 0.01 and OG 0.03 ± 0.01 s; p = 0.006) and for B2 (NG 0.04 ± 0.01 and OG 0.03 ± 0.01 s; p = 0.025) as well as for the rearfoot for B1 (NG 0.05 ± 0.06 and OG 0.03 ± 0.01 s; p = 0.011), and for B2 (NG 0.04 ± 0.02 and OG 0.02 ± 0.004 s; p = 0.021).

No further kinetic variables showed significant differences between the skates. In general, the force magnitude increased when landing from B2 compared to landing from B1 and the TPF tended to decrease when landing from B2 compared to landing from B1.

3.2. Kinematic results

A significantly greater IC ankle dorsiflexion was seen in NG compared to NE skates during landings for B1 (NG 224 ± 5.10 and NE 218 ± 4.73°; p = 0.004) and for B2 (NG 224 ± 5.03 and NE 217 ± 4.54°; p = 0.001), and this was also the case for the peak dorsiflexion for B1 (NG 258 ± 7.08 and NE 253 ± 5.14°; p = 0.001) and for B2 (NG 261 ± 6.54 and NE 255 ± 4.91°; p = 0.001) as well as for the greater IC knee flexion for B1 (NG 210 ± 5.25 and NE 208 ± 4.75°; p = 0.015) and for B2 (NG 209 ± 4.05 and NE 207 ± 4.23°; p = 0.013).

A significantly greater peak knee flexion (OG 253 ± 8.08 and NG 252 ± 8.80°; p = 0.036) and longer ankle dorsiflexion TP (OG 0.13 ± 0.02 and NG 0.12 ± 0.02 s; p = 0.005) were seen for the landings from B2 in OG compared to NG skates.

Table 2. Trials included in the analysis.

<table>
<thead>
<tr>
<th></th>
<th>New Graf vs. Old Graf</th>
<th>New Graf vs. New Edea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force plate</td>
<td>B 1</td>
<td>11 Subjects</td>
</tr>
<tr>
<td></td>
<td>B 2</td>
<td>11 Subjects</td>
</tr>
<tr>
<td>Pedal Insole</td>
<td>B 1</td>
<td>10 Subjects</td>
</tr>
<tr>
<td></td>
<td>B 2</td>
<td>9 Subjects</td>
</tr>
<tr>
<td>Qualisys</td>
<td>B 1</td>
<td>11 Subjects</td>
</tr>
<tr>
<td></td>
<td>B 2</td>
<td>11 Subjects</td>
</tr>
</tbody>
</table>

B1 = 30 cm high box; B2 = 50 cm high box.

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No further significant differences in kinematic variables were seen between the skates. In general, the peak flexion angles showed slight, non-significant increases when landing from B2 compared to from B1.

### 4. Discussion

The aim of the current investigation was to examine whether different brands of figure skates as well as the age of the skates affected the kinetic and kinematic properties of the landing impact from a simulated figure skating jump on the right lower extremity. Significant kinetic and kinematic differences between the examined figure skating boots were seen. PF in NE skates were lower than in NG skates, which supported the hypothesis. The second research hypothesis was, however, rejected since the PF in OG was not significantly different compared to NG. The third research hypothesis was also rejected since the peak ankle flexion in OG was not significantly different compared to NG. To the authors’ knowledge, this represents the first study comparing biomechanical differences of the landing impact from a jump in skates with different characteristics and may provide useful information regarding the construction design of skates in relation to the landing biomechanics.

Significantly different maximal impact PF acted inside the skate during the landings in NG compared to...
The results showed significantly greater plantar flexion of the foot at IC, smaller peak dorsiflexion of the foot after IC and smaller IC flexion of the knee compared to the NG skates. This may suggest that the anterior-posterior flexibility of the upper and the skate construction may assist in decelerating the skater’s mass by permitting greater plantar flexion and, therefore, decreasing impact forces. This is consistent with the results of this study where greater boot upper flexibility in the NE skates permitted greater ankle ROM compared to the NG and OG skates, despite the fact that the padding in NE skates is greater.

The only kinematic differences between NG and OG skates were in the degree of peak knee flexion from the higher box, while the ankle ROM was the same in NG and OG skates.

A possible cause of the lower PF inside the NE skate compared to other skates may have been the significantly greater plantar flexion and knee extension in the NE skates facilitating a greater ROM after landing and, therefore, a more gradual deceleration of body segments. This explanation is in agreement with Bruening & Richards (2006) and Rowley & Richards (2015), who observed similar landing patterns in participants where VGRF was reduced. Another possible explanation is that the landing impacts in NG and OG skates, with greater knee flexion at IC, appeared to provoke stiffer landing strategies because the remaining available knee ROM was limited (Gribble & Robinson, 2009; Van der Worp, De Poel, Diercks, Van den Akker-Scheek, & Zwerver, 2014). The greater knee flexion at IC in NG and OG skates may be caused by the greater stiffness of these skates, which restrict plantar flexion of the foot at IC. According to DiStefano et al. (2008), Yeow et al. (2009), Fong et al. (2011) and Macrum et al. (2012), the ability of the lower extremity to dissipate energy may be reduced by a limited ROM of the knee, which would explain the greater PF in NG and OG skates.

During landing impacts from B2, the TPF in NG skates was longer than in NE skates, which may be caused by the lower heel height of the NG skates. The increased TPF did not decrease the PF inside the NG skate compared to NE skates. According to Lockwood, Gervais & McCreary (2006), Porter et al. (2007), Gribble & Robinson (2009) and Van Der Worp et al. (2014), the longer TPF may also indicate a safer landing.

### Table 4. Comparison of kinematic variables between skates.

<table>
<thead>
<tr>
<th></th>
<th>New Graf</th>
<th>Old Graf</th>
<th>p</th>
<th>New Graf</th>
<th>New Edea</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B1</td>
<td>B1</td>
<td></td>
<td>B1</td>
<td>B1</td>
<td></td>
</tr>
<tr>
<td>Ankle</td>
<td>IC flexion (°)</td>
<td>224 ± 5.34</td>
<td>225 ± 3.61</td>
<td>&gt;0.05</td>
<td>224 ± 5.10</td>
<td>218 ± 4.73</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>224 ± 5.27</td>
<td>224 ± 3.39</td>
<td>&gt;0.05</td>
<td>224 ± 5.03</td>
<td>217 ± 4.54</td>
</tr>
<tr>
<td></td>
<td>Peak flexion (°)</td>
<td>258 ± 7.19</td>
<td>260 ± 5.00</td>
<td>&gt;0.05</td>
<td>258 ± 7.08</td>
<td>253 ± 5.14</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>262 ± 6.48</td>
<td>263 ± 5.25</td>
<td>&gt;0.05</td>
<td>261 ± 6.54</td>
<td>255 ± 4.91</td>
</tr>
<tr>
<td></td>
<td>TP (s)</td>
<td>B1</td>
<td>0.14 ± 0.06</td>
<td>0.13 ± 0.02</td>
<td>&gt;0.05</td>
<td>0.13 ± 0.06</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>0.12 ± 0.02</td>
<td>0.13 ± 0.02</td>
<td>&gt;0.05</td>
<td>0.12 ± 0.02</td>
<td>0.12 ± 0.02</td>
</tr>
<tr>
<td>Knee</td>
<td>IC flexion (°)</td>
<td>210 ± 5.40</td>
<td>212 ± 5.31</td>
<td>&gt;0.05</td>
<td>210 ± 5.25</td>
<td>208 ± 4.75</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>209 ± 3.98</td>
<td>210 ± 5.22</td>
<td>&gt;0.05</td>
<td>209 ± 4.05</td>
<td>207 ± 4.23</td>
</tr>
<tr>
<td></td>
<td>Peak flexion (°)</td>
<td>247 ± 9.33</td>
<td>249 ± 7.85</td>
<td>&gt;0.05</td>
<td>245 ± 9.66</td>
<td>246 ± 8.99</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>252 ± 8.80</td>
<td>253 ± 8.08</td>
<td>&gt;0.05</td>
<td>251 ± 9.38</td>
<td>251 ± 9.66</td>
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<tr>
<td></td>
<td>TP (s)</td>
<td>B1</td>
<td>0.22 ± 0.11</td>
<td>0.19 ± 0.06</td>
<td>&gt;0.05</td>
<td>0.21 ± 0.11</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>0.21 ± 0.09</td>
<td>0.21 ± 0.06</td>
<td>&gt;0.05</td>
<td>0.20 ± 0.09</td>
<td>0.19 ± 0.07</td>
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<tr>
<td>Hip</td>
<td>IC flexion (°)</td>
<td>212 ± 7.84</td>
<td>215 ± 6.93</td>
<td>&gt;0.05</td>
<td>212 ± 7.51</td>
<td>212 ± 8.03</td>
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<td></td>
<td>B2</td>
<td>211 ± 7.43</td>
<td>213 ± 5.69</td>
<td>&gt;0.05</td>
<td>211 ± 7.21</td>
<td>211 ± 7.57</td>
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<td></td>
<td>Peak flexion (°)</td>
<td>256 ± 10.59</td>
<td>254 ± 9.95</td>
<td>&gt;0.05</td>
<td>256 ± 10.29</td>
<td>255 ± 10.73</td>
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<tr>
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<td>B2</td>
<td>261 ± 10.82</td>
<td>261 ± 11.94</td>
<td>&gt;0.05</td>
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<td>TP (s)</td>
<td>B1</td>
<td>0.48 ± 0.13</td>
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<td>B2</td>
<td>0.39 ± 0.09</td>
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<td>&gt;0.05</td>
<td>0.40 ± 0.08</td>
<td>0.42 ± 0.10</td>
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<td>Trunk</td>
<td>IC flexion (°)</td>
<td>210 ± 4.90</td>
<td>210 ± 7.62</td>
<td>&gt;0.05</td>
<td>210 ± 4.70</td>
<td>211 ± 6.74</td>
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<tr>
<td></td>
<td>B2</td>
<td>211 ± 5.16</td>
<td>211 ± 5.97</td>
<td>&gt;0.05</td>
<td>211 ± 4.92</td>
<td>212 ± 5.43</td>
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<tr>
<td></td>
<td>Peak flexion (°)</td>
<td>256 ± 9.60</td>
<td>252 ± 10.73</td>
<td>&gt;0.05</td>
<td>256 ± 9.15</td>
<td>255 ± 8.89</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>262 ± 9.60</td>
<td>259 ± 11.32</td>
<td>&gt;0.05</td>
<td>261 ± 9.37</td>
<td>258 ± 9.59</td>
</tr>
<tr>
<td></td>
<td>TP (s)</td>
<td>B1</td>
<td>0.36 ± 0.11</td>
<td>0.34 ± 0.07</td>
<td>&gt;0.05</td>
<td>0.38 ± 0.12</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>0.34 ± 0.04</td>
<td>0.35 ± 0.08</td>
<td>&gt;0.05</td>
<td>0.35 ± 0.05</td>
<td>0.37 ± 0.07</td>
</tr>
</tbody>
</table>

Values are expressed as mean±SD with p-values. Significant differences are indicated with *. Significance level was set at p > 0.05. B1 = 30 cm high box; B2 = 50 cm high box; IC: initial contact; TP: time from initial contact to first peak flexion.
strategy improving the landing stability and, therefore, protecting from potential injury.

The presented kinetic and kinematic results suggest that ankle flexion and ROM may play a more important role in reducing the PF during the landing impact than the knee. This assumption is supported by other studies (Zhang, Bates & Dufek, 2000; Yeow, Lee & Goh, 2011), where the ankle was a major contributor to energy dissipation in the sagittal plane during single leg stiff landings, where greater force of short duration is produced, compared to the knee.

The different flexion angles of the ankle during the landing impacts may be explained by the different heel heights and stiffnesses between the skates. The NE has a 1.1 cm higher heel compared to the NG and OG skates. Even though the padding in NE skates is greater, the stiffness of the skates is lower allowing greater flexibility of the foot compared to NG and OG skates. Furthermore, the construction design and material of the skates may contribute to dispersion of the forces since the force acting inside the NG skates was significantly greater than in NE skates, but the force acting between the skates and the force plate underneath the plastic ice surface was not significantly different.

The tests were conducted in a laboratory setting, which facilitated controlled conditions for all tested skates and participants. The number of potential participants for this study was limited due to the inclusion criteria.

The sampling frequency of the plantar pressure system was set at its maximal 200 Hz, which was considerably less than the sampling frequency chosen for the force plate (2500 Hz). A sampling rate of 200 Hz has been recommended for accurate measurement of plantar pressures and forces while jogging (Urry, 1999). Although this indicates that the system is appropriate for dynamic activities, the landings investigated in this study will have had greater loading rates than seen during jogging. The limited sampling rate is, therefore, a limitation of the study.

5. Conclusions

Differences in landing impact forces are important due to the large volume of landings performed and the associated repetitive loading experienced by figure skaters. This study showed that different skates significantly affected the kinetic and kinematic properties of the landing impact. Impact forces were lower in NE skates compared to NG skates and no differences between NG and OG skates were detected, suggesting that NE skates potentially prevent injurious forces to the human body during landing impacts. The choice of skates may be important to maintain and increase the high level performance of individual figure skaters and to prolong their amateur and professional skating careers.

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Disclosure statement

No potential conflict of interest was reported by the authors.

References


