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ORIGINAL ARTICLE

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Plantar pressure distribution in ice skates while gliding and standing compared to barefoot and trainer conditions

Authors' Contribution:
A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection

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Abstract

Background: *The aim of this study was to identify whether there are differences between plantar pressure distributions experienced whilst wearing ice skates during ice-gliding, compared to standing whilst barefoot, wearing trainers and wearing ice skates. The results of this study aim to provide a greater understanding of the distribution of the pressure through the ice skate to the human musculoskeletal system.*

Material/Methods: *Nine female participants were recruited for this study (age 36.6 years ± 15.3, mass 63.7kg ± 7.4 height 1.63m ± 4.1). Pressure applied to the plantar surface of the feet was recorded at 50Hz using an F-Scan sensor. Data was collected for 5 seconds while participants performed an ice glide in their own ice skates. Standing data was collected over the same period of time while participants stood still on a carpeted surface wearing their own ice skates, their own trainers and cotton socks without shoes. For each condition 10 trials of data were collected.*

Results: *The results reported similar peak pressure distributions under the plantar region of the foot for standing and ice gliding while wearing ice skates. Furthermore, the results identified a shift of peak pressure values to the forefoot and midfoot regions whilst wearing ice skates compared to trainers.*

Conclusions: *This research suggests information on plantar pressures during ice gliding may be obtained from standing data in future research and that ice skates may expose the wearer to an increased risk of plantar pressure related injuries in the forefoot/midfoot regions of the feet.*

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Introduction

Ice skating is a popular Olympic sport with disciplines including figure skating, speed skating, synchronized skating and ice hockey. In recent years figure skating has seen an increase in the incidence of injuries [1]. Injuries are most common in less experienced skaters [2]. Traumatic acute injuries have been reported as the most common injuries prevalent in both experienced and less experienced skaters [2, 3]. However, previous research has reported that overuse injuries are common amongst elite junior skaters [4]. Furthermore, stress fractures and related injuries in the lower extremities of skaters occur predominantly in the feet [5]. Excessive localised pressure between the plantar surface of the foot and the insole of the footwear has been linked to overuse injuries in the foot [6, 7, 8, 9].

Variations in footwear and orthotic conditions have been found to influence the magnitude of peak pressures applied to specific regions of the plantar surface [7, 10, 11, 12]. Previously, plantar pressure distribution patterns have been reported in ice skates, with and without orthotics, during jumping movements [13]. However, no actual values of pressure were reported in this research or in similar research measuring force distribution during figure skating jumps [14].

There appears to be a paucity of research investigating pressure distribution and magnitudes experienced at the plantar surface of the foot while gliding in ice skates. There is a clear need to investigate the magnitudes of peak pressures experienced in ice skates compared to other footwear. As such, the aim of this study was to investigate plantar pressure distribution in ice skates during gliding, and to compare these results to standing in no footwear, in trainers and in ice skates. The results of this study aim to provide footwear designers and manufacturers with a greater understanding of the distribution of pressure through the ice skate to the human musculoskeletal system, allowing design considerations where necessary.

Material and methods

Participants

Nine female participants were recruited for this study (age 36.6 years ± 15.3, mass 63.7kg ± 7.4 height 1.63m ± 4.1). The skaters were taken from a sample of a skating club that had members participating in youth as well as veteran figure skating hence the large age range. Participants were competitively involved in figure ice-skating at various levels and trained a minimum of three times per week. All were injury free at the time of data collection and completed an informed consent form. Ethical approval for this project was obtained from the University ethics committee and each participant provided written consent, in accordance with the declaration of Helsinki.

Procedure

An in-shoe plantar pressure measurement system (F-scan, Tekscan Inc, USA) was used to record pressure data across the plantar surface of the participant's feet at 50Hz. The sensors were calibrated to the manufacturer's guidelines. To record plantar pressure distribution in standing barefoot conditions, the in-shoe sensor was inserted into the socks of each participant and positioned under the plantar surface of each foot. The same type of cotton socks were used for each participant to reduce the influence of different sock texture on plantar pressure [15]. The participants were then instructed to stand as still as possible on a carpeted surface, their hands positioned freely by their side while focusing on a point in the distance. Five seconds of data was recorded for each trial with ten trials recorded in total. This procedure was repeated while participants wore trainers and ice skates with the F-scan sensors inserted inside the sock as before. The ice glide was recorded for five seconds for each trial along a four metre ice runway; each participant was instructed to push off one metre before the runway and only started slowing down at the end of the runway with their hands again positioned freely by their side (Fig. 1).

As with the other conditions, ten trials of gliding data were recorded for each participant. This number of trials with a nine-participant study of this type conformed to statistical guidelines previously recommended [16].

The plantar region of the foot was divided into nine anatomical areas: Area 1 = Hallux, 2 = Toes, 3 = 1st Metatarsal Head (1MTH), 4 = 2nd and 3rd Metatarsal Head (2&3MTH), 5 = 4th and 5th

Metatarsal Head (4&5MTH), 6 = Medial Arch (MA), 7 = Lateral arch (LA), 8 = Medial Calcaneus (MC) and 9 = Lateral Calcaneus (LC). Pressure and force data were reported for each area (Fig. 2).

Fig. 1. A participant wearing the F-scan in shoe pressure system with cuffs attached about the lower shanks

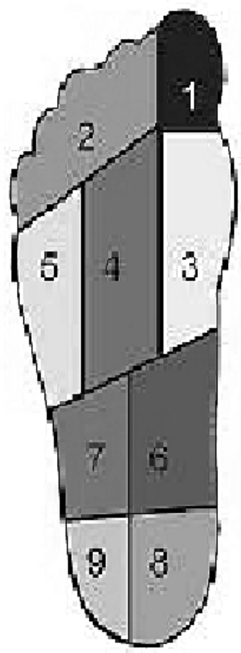

Fig. 2. Nine areas of the foot

ANOVAs were performed to compare participants' mean peak pressure and peak force in each of the areas of the plantar surface shown in Figure 2. Post hoc analysis using a Bonferonni test to control for type I error was used to identify significant differences at the p<0.05 level. All statistical procedures were quantified using SPSS 17.0 (SPSS Inc., Chicago, IL, USA).

Results

Peak pressures

Peak pressure values for posterior (MC and LC) and forefoot (2&3MTH and 4&5MTH) areas were significantly higher ($p < 0.05$) in the standing barefoot condition compared to the standing trainer condition (Table 1). However, significant ($p < 0.05$) increases in peak pressure values in the trainer condition were identified in the midfoot areas (MA and LA).

The ice skate standing and glide conditions presented significantly ($p > 0.05$) higher peak pressures under the hallux when compared to barefoot and trainer conditions. A significant increase ($p > 0.05$) was also found under the toes and 1MTH for the ice skate standing and gliding compared to barefoot and trainer conditions.

Ice skate glide and standing conditions also reported significant increases in peak pressures under the MA and significant decreases in peak pressures under the LC when compared to barefoot standing. In general, mean barefoot posterior pressures (MC and LC) values were consistently greater ($p > 0.05$) than the three shod conditions. Conversely, the LA, and MA, report a significant ($p < 0.05$) increase for the three conditions compared to barefoot.

Tab. 1. Peak pressure values (kPa) for the plantar surfaces areas (n = 9) in the footwear conditions (n = 4)

Areas	Barefoot standing		Trainers standing		Ice skates standing		Ice skates gliding	
	mean	SD	mean	SD	mean	SD	mean	SD
Hallux	27.94	16.46	32.16	16.70	61.61*¥	22.78	53.96*¥	23.29
Toes	24.54	21.31	40.21	17.11	50.79*¥	18.69	36.74*¥	21.22
1MTH	63.11	35.30	60.72	28.58	119.46*¥	49.01	87.92*¥	40.47
2&3MTH	79.00¥	29.78	48.54	27.87	72.06	23.12	60.96	16.69
4&5MTH	75.86¥	31.80	48.22	18.02	66.94	18.97	58.90	18.17
MA	6.30	10.88	41.16*	20.78	44.99*	32.66	32.49*	29.39
LA	45.33	28.36	71.61*	37.16	76.56*	58.10	60.03*	19.16
MC	191.88*¥,¤	40.43	111.12	27.50	155.05	86.52	160.58	111.61
LC	174.37*¥¤	54.25	96.28	23.33	83.71	36.60	97.78	37.24

* = significantly ($p < 0.05$) greater than barefoot standing, ¥ = significantly ($p < 0.05$) greater than trainers standing, ¤ = significantly ($p < 0.05$) greater than ice skate standing, # = significantly ($p < 0.05$) greater than ice skate gliding.

Peak force

The plantar area under the 2&3MTH and the 4&5MTH reported a significant ($p < 0.05$) increase in peak force for barefoot conditions compared to trainers. The ice skate conditions produced significant ($p < 0.05$) increases in peak forces applied to the area under the hallux and toes (Tab. 2) compared to barefoot and trainer conditions. Ice skate standing conditions also reported significantly ($p < 0.05$) higher peak forces than in trainer standing under the 2&3MTH. Significantly ($p < 0.05$) higher peak force values were also identified under the MA in trainers, ice skate standing and gliding, compared to the barefoot condition. Furthermore, the trainer condition significantly ($p < 0.05$) reduced peak force applied to the MC and LC plantar region compared to barefoot standing. Additionally, ice skate standing and gliding also significantly ($p < 0.05$) reduced peak forces applied to the LC compared to barefoot conditions.

Tab. 2. Peak force values (N) for the plantar surfaces areas (n = 9) in the footwear conditions (n = 4).

Areas	Barefoot standing		Trainers standing		Ice skates standing		Ice skates gliding	
	mean	SD	mean	SD	mean	SD	mean	SD
Hallux	2.20	1.80	2.53	1.64	5.79*¥	2.63	5.41*¥	2.43
Toes	1.73	1.76	2.77	1.11	6.23*¥	6.47	3.57*¥	2.31
1MTH	6.21	3.65	5.91	2.90	12.16	5.09	13.30	18.39
2&3MTH	7.72¥	3.24	4.62	2.98	7.15¥	2.49	5.89	1.85
4&5MTH	7.42¥	3.29	4.67	1.80	6.57¥	2.14	5.53	1.97
MA	0.26	0.46	3.57*	2.33	3.43*	1.99	2.25*	2.48
LA	4.27	2.99	6.34	2.64	6.80	2.88	5.04	2.05
MC	19.40¥	4.18	10.75	3.81	14.06	6.10	14.88	10.50
LC	17.19¥¤#	5.25	9.20	3.11	8.48	3.23	9.15	4.05

* = significantly ($p \leq 0.05$) greater than barefoot standing, ¥ = significantly ($p \leq 0.05$) greater than trainers standing, ¤ = significantly ($p \leq 0.05$) greater than ice skate standing, # = significantly ($p \leq 0.05$) greater than ice skate gliding.

Discussion

The aim of the current investigation was to determine whether there are differences in plantar pressure distribution experienced whilst wearing ice skates during ice-gliding, compared to standing whilst barefoot, wearing trainers and wearing ice skates. This study represents the first known examination of the pressure that is applied to the plantar surface during skating.

The results indicate that no significant differences in peak pressures and forces ($P > 0.05$) were observed at any of the nine anatomical areas between ice skate standing in comparison to ice gliding. As such with respect to plantar pressure distribution and magnitude it may be acceptable to consider ice skate standing to be similar to that of gliding.

During barefoot standing peak pressures in the forefoot were found to be greatest in the second and third metatarsal head region, which agrees with previous investigations [17, 18]. Whilst wearing trainers the peak pressures recorded were redistributed, reducing the pressure on this anatomical area. However, no such reduction could be identified ($P > 0.05$) in either of the ice skate conditions. In other areas of the forefoot (hallux, toes and 1MTH) significant increases ($P < 0.05$) in both peak pressures and forces were observed in the ice skate conditions compared to both the barefoot and trainer conditions.

The heel raise on the ice skate compared to barefoot standing reproduces similar findings to assessments on heeled shoes, namely reduction in heel pressures [19, 20]. This is demonstrated by the observed decreases in peak pressure and force under the calcaneum in the ice skate and trainer conditions compared to barefoot. However, no significant differences ($P < 0.05$) were observed under the calcaneum between the trainer and ice skate conditions, although results suggest a trend towards an increase in force and peak pressure under the MC. Furthermore, the ice skate did not reduce midfoot pressures compared to the trainers, as was reported in the high heeled footwear research.

These results suggest there is a shift of peak pressure values to the forefoot and midfoot regions whilst wearing ice skates during standing and ice gliding. These findings are concerning as increased localised pressures have been shown to be potential areas for common foot problems [6, 7, 8, 9, 21]. As such it appears that ice skating may expose the human body to an increased risk of injury to the midfoot and forefoot regions. It should, however, be mentioned that the reduction in peak pressures under the heel during skating may be of some benefit. However, overall this research appears to show that the trainer conditions protect the foot from such injuries more effectively. Ice skaters with a history of foot injuries linked to loading specific sites of the foot may be able to reduce these risks through the use of a suitable shoe insert to redistribute pressure at the plantar region of the foot [12].

Further research is required to investigate differences between human locomotion on ice and over ground, to understand more about the injury potential in more dynamic movements. Future studies are also required in areas such as insole variations, the need for orthotics and blade position if we are to further understand injury risks in an ice skating population.

Conclusions

The findings of this research suggest that assessment of pressure distribution at the plantar surface of the foot during ice gliding may be measured during normal standing in the same footwear. This would allow for more practical and consistent data to be collected for assessment of injury potential.

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