PLANTAR PRESSURE CHARACTERISTICS OF SKELETON ATHLETES DURING THE PUSH START ON A DRY-LAND TRAINING SURFACE

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The purpose of this study was to characterise plantar pressure maps through the push start of top-level skeleton athletes. The push start is a vital component in skeleton to achieve success, and therefore, a focus on the performance characteristics of the push start could help to reduce the run time and increase the athlete's initial velocity. Five international skeleton athletes each performed 3-5 push starts on a dry-land push track with wireless pressure insoles. Key differences in 2-d plantar pressure patterns were identified with a confidence interval of $\alpha<0.05$ using statistical parametric mapping. This displayed a higher pressure-concentration on the medial edge of the outside foot through the full start and an anterior shift in the pressure-concentration during the acceleration phase. These results could be used for understanding start mechanics and to help support equipment choice.

KEYWORDS: skeleton, push start, SPM, plantar pressure map, pressure insole.

INTRODUCTION: Skeleton is a sport in the Winter Olympics where athletes compete to descend an ice track with the shortest overall time on a sled in a prone, headfirst position. The run begins with a push start, timed from 15m to 65m, with the athlete sprinting on ice to get up to speed before loading onto the sled. The close margins of competitions highlights the importance of the push start as shown by its high correlation to finishing times (Zanoletti, La Torre, Merati, Rampinini, & Impellizzeri, 2006). Therefore, attempts at developing a further understanding of key performance indicators to the push start is a large area of research in skeleton (Colyer, Stokes, Bilzon, Holdcroft, & Salo, 2018).
In a sport of such small margins, understanding every aspect of the performance can be essential and can be the difference between winning and losing. The push start in skeleton is the only part of the run where the athletes can input energy into their descent. Being a winter sport, access to natural ice tracks to refine driving skills is not available year-round, therefore maximising this stage in the race is key to their performance. Therefore, gaining an understanding on the foot contacts through the 15-20 step sprint can provide a crucial insight into the athlete's technique, a basis for transferring performance from summer training onto the ice season, and can be used to inform optimal equipment choice to support performance. Similar plantar pressure studies have been conducted to evaluate shoe construction and running surfaces (Shorten, 2009; Tessutti, Trombini-Souza, Ribeiro, Nunes, & Sacco, 2010) and in sports like basketball and football (Hennig, 2014). These insights can be used to improve athlete and equipment performance by gaining insight to loading patterns and potentially reduce injury risk (Chow, Chen, & Wang, 2018).
This study will investigate characteristic patterns in the plantar pressure of skeleton athletes in their push start to determine potential areas for performance indicators in the footfall events of the push start. The major areas of interest include differences between the inside and outside foot and the different phases of the push.

METHODS: Five top level skeleton athletes participated in this study, two females and three males, whose experience ranged all levels of international competition. Their mean age, mass, and height was 29.0 ± 4.2 years, 67.5 ± 3.5 kg, and 173.0 ± 7.1 cm for the females, and 27.0

± 2.6 years, 82.3 ± 6.8 kg, and 178.7 ± 7.5 cm for the males. The data collection sessions were performed over the course of two days in the beginning of the summer training period on dry-land push track. After completing a standard competition warm-up for a training session on the start track, each athlete performed 3-5 maximal effort push starts while wearing the Medilogic pressure insoles in their own skeleton brush spikes. All athletes pushed from the left side of the sled and loaded onto the sled with their left foot making the final ground contact. Each start consisted of 15-17 steps, depending on the initial foot on the blocks and the loading point onto the sled. Ethical approval was granted by a local research ethics committee (EP 18/19 114) and all athletes provided written consent.

The Medilogic (T&T Medilogic, GmbH, Germany) wireless in-shoe pressure measurement system was used in this study. The insoles consisted of up to 240 sensors, each 7.494 mm by 14.989 mm large. Data was recorded at a sampling frequency of 200 Hz and transmitted to a laptop via a wireless modem connected to both the laptop and insole module. The pressure insoles were placed in the athlete's preferred shoe for use on the start track above the existing insole. A 125 g wireless module was strapped around the athlete's ankle to transmit the data directly to a laptop. Each trial was recorded with a video camera at 120 fps to use as a method of verification with the pressure data.

The data was collected and analysed in MATLAB (MATLAB v.2018b, The MathWorks Inc., Natick, MA) to determine the number of foot contacts, duration of each step, estimates for peak force, and compare the plantar pressure patterns throughout the start sequence. An open-source one dimensional statistical parametric mapping (SPM) software for MATLAB (Pataky, 2012) was used to identify any patterns and characteristics between athletes and phases of the push start. Two-sample t tests were used to test how the inside and outside foot stance differs, along with how the stage of the push influenced the resultant plantar pressure maps. The pressure maps consist of a 12 by 20 cell matrix, which was smoothed for a closer geometrical representation of the foot. Smoothing was achieved through linear interpolation of the values, refining the matrix by three times in each dimension. As there is no standardised smoothing process, the results are compared as smoothed and in its raw form for a full evaluation. Pressure maps were created at the peak force point of each step, which was identified from the force-time data (Figure 1).

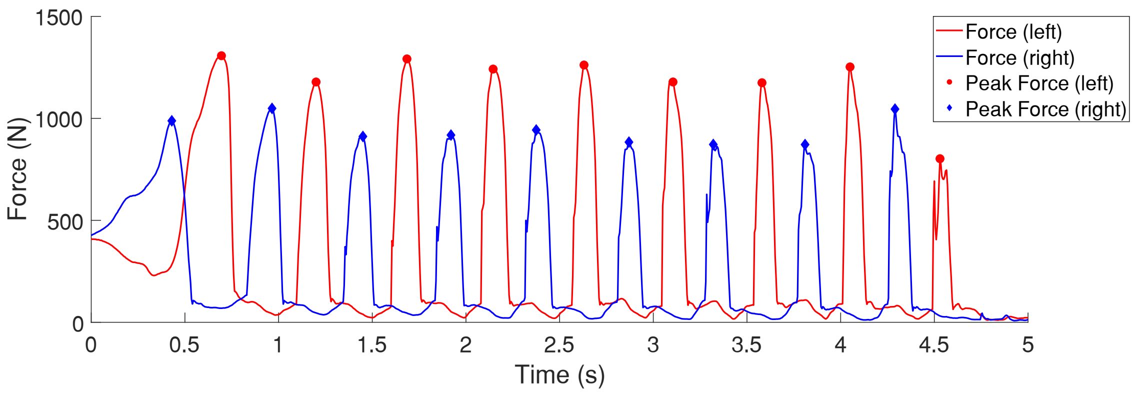

Figure 1: Force vs time plot for one participant's push start trial with the left (outside) and right (inside) foot displayed in red and blue respectively. Peak force is indicated at each contact.

The difference between the left and right foot plantar pressure was evaluated through each trial of the maximal effort push start. As all athletes pushed on the left side of the sled, the left foot was on the outside and right foot on the inside closer to the sled for all trials. Due to a recent foot injury from one athlete, only four of the five athletes start data were used for this analysis. The peak plantar pressure maps of each step during the push, and for all trials, were grouped and averaged for the left and right foot to compare any patterns. These resultant patterns can be identified through the SPM inference results using a two-sample t test (α=0.05) along with the two averaged pressure maps (Figure 2).

RESULTS AND DISCUSSION: The first comparison with the SPM analysis tested the hypothesis that the left and right plantar pressure maps through the entire push start are identical (Figure 2). Therefore, positive t values reject the hypothesis, with the left foot (outside) showing statistically significantly higher pressure than the right (inside), while negative t values reject the hypothesis with the opposite relationship. In both the raw and smoothed SPM data analysis, it was evident that there are consistently higher-pressure regions on the medial regions of the foot, indicating the centre of pressure (CoP) on the outside foot was closer to the first than the fifth metatarsal head. The difference in peak pressure regions may be a result of a few factors such as the athlete's mobility and the position of the foot relative to the body's centre of mass. Due to the body position in pushing a skeleton sled, the outside leg has more room to move without colliding with the arm or upper body, potentially allowing it to generate more peak force. Additionally, its location relative to the sled and centre of mass, the force applied by the foot may be directed outwards, potentially leading to a smaller contact area along the medial edge of the outside foot.

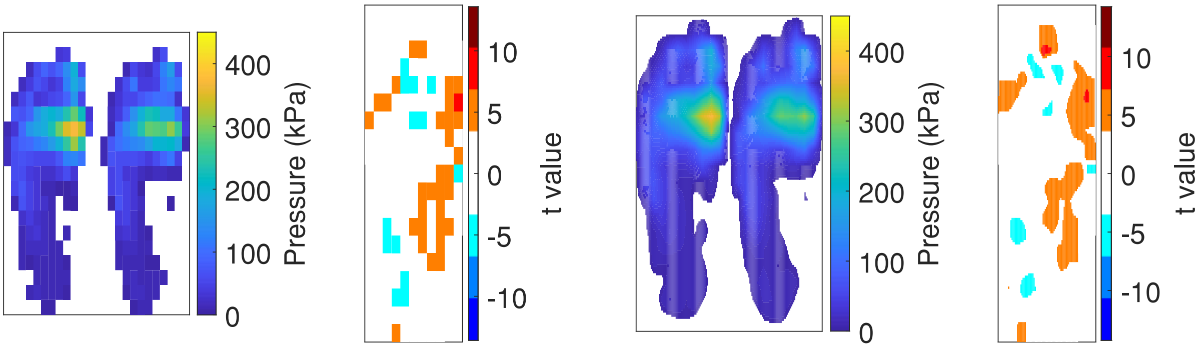

Figure 2: Average pressure and SPM inference plots for both raw and smoothed datasets of the peak force for each foot contact on the left (outside) and right (inside) foot. Right foot pressure data was mirrored for comparison in SPM analysis.

Figure 3 shows the difference in plantar pressure between the first four steps (acceleration) and final four steps (loading), two on each foot. As with the evaluation above, the SPM analysis was testing the hypothesis that the plantar pressure during the acceleration phase will be identical to the loading phase of the push start. Therefore, the positive t values indicate the initial steps have a higher pressure and negative t values show the loading steps have a higher pressure. These results indicate that during the later stages of the push start, closer to loading, the stance has a more flat-footed pressure map, with the pressure dispersed across both the forefoot and midfoot regions. While during the initial acceleration, the CoP was toward the anterior region on the foot and the peak pressure was concentrated closer to the first metatarsophalangeal (MTP) joint. The change in pressure patterns through this phase was a result of a few possible factors, including a different gait due to the aim to accelerate quickly to increase or maintain velocity at the time of loading, reduction in foot contact time, and the increasing track gradient through the push start, as identified by Colyer et al. (2018). Each of these factors would lead to the primary contact point being concentrated along the toes and MTP joints during the acceleration and shifting to a larger contact area as the athlete approaches their maximum sprinting velocity and the track gradient increases. While there are few similar studies that collect and investigate athlete plantar pressure across a full upright sprint, Bezodis et al. (2015) have shown similar trends through a kinematic analysis of the lower limbs during a maximal upright sprint. A lower range of ankle dorsiflexion in the early stance, hence a smaller contact area at the foot's anterior edge, is directly related to a reduction in horizontal power production (Bezodis, Trewartha, & Salo, 2015).

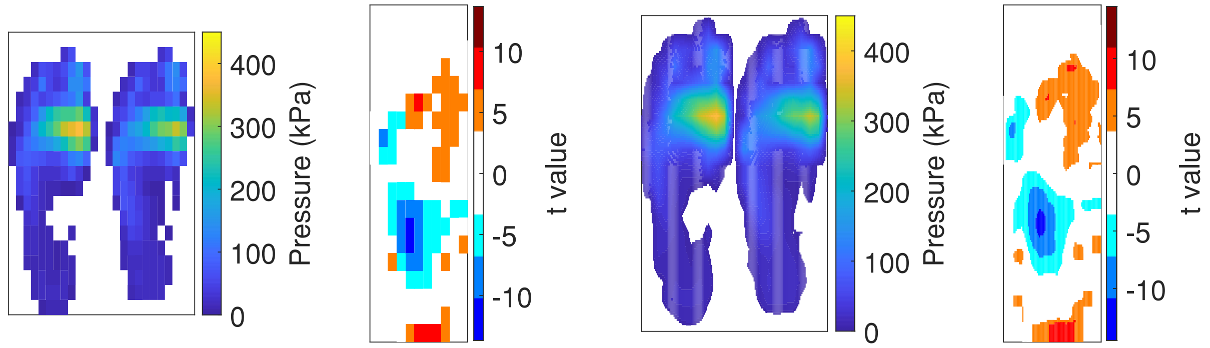

Figure 3: Average pressure and SPM inference plots for both raw and smoothed datasets of the peak force for each foot contact during the acceleration phase (left) and loading phase (right) of the push start. The right foot pressure data was mirrored to be included in each dataset.

CONCLUSION: The outside foot in the skeleton push start tends to have higher peak forces and, therefore, peak plantar pressure throughout the entire push phase. While the peak pressure located under the MTP joint shifts the CoP forward, as the athlete reaches their peak velocity and the gradient of the track increases, the athlete's gait shifts to a flat-footed stance, leading to a more evenly spread plantar pressure distribution and a posterior shift in the CoP. The application of plantar pressure analysis with a focus on the change in plantar pressure can help ensure that performance is not being impacted when selecting footwear. Additionally, the nature of skeleton is such that there is a long off-season where majority of the athletes are unable to train on ice. Therefore, future work collecting plantar pressure data of the push start on different surfaces could be crucial to aid with training during the off-season, allowing for comparisons between the two training surfaces to be developed. Through these comparisons, it could be possible to quantify how the change of surface impacts the athlete's stance.

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