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Short communication

Plantar pressures in identical and non-identical twins

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ABSTRACT

Identifying environmental risk factors for musculoskeletal disorders is challenging due to the number of potential confounders. Twins are of particular interest for researchers interested in studying these types of problems due to their inherent control for the influence of genetic factors. In twin studies, this population can allow environmental risk factors to be more easily identified, and this type of study design may allow the role of biomechanics in injury and disease to be further explored. At present, it is unclear if foot function displays more similarity between certain types of twins. In this study, we hypothesized that the plantar pressures of monozygotic (identical) twins would be more similar between pairs than dizygotic (non-identical) twins. We measured static and dynamic plantar pressures from five pairs of each twin type. Statistical parametric modeling was used to compare pressure distributions at the sensor level. For >80% of stance phase, the pixel level analysis indicated that monozygotic twins had less variation in plantar pressure between pairs. The average z-statistic across the entire trial was 0.88 for the monozygotic group and 1.13 for the dizygotic group. In this study we provide evidence of greater similarity of plantar pressures in monozygotic twin pairs compared to dizygotic twins. This finding supports the use of co-twin studies investigating potentially modifiable environmental and biomechanical risk factors for musculoskeletal conditions that affect the foot and ankle.

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1. Introduction

Determining genetic and environmental risk factors for musculoskeletal conditions is challenging due to the difficulties in controlling for the large number of potential confounders. Twins and twin study designs present a unique opportunity to study the influence of different external factors on the development of musculoskeletal disorders (Goldberg and Fischer, 2005), and have successfully provided insights into osteoarthritis (Spector et al., 1996), hallux valgus (Lee et al., 2014; Munteanu et al., 2017), and club foot (Engell et al., 2006). These types of studies have the powerful advantage that they inherently control for the effects of genetics and, at least to some extent, environment during childhood and adolescence.

There is little information in the literature regarding the functional similarities of twin feet. Shakibi et al. (2015) found no differences in static balance or peak pressures related to foot types or twin status in their investigation of balance tests and walking. In this case, the study variables used were restricted to regional peak pressures during each trial, which have been shown to provide

only a limited resolution analysis of the data (Deschamps et al., 2015; Pataky and Goulermas, 2008). While this approach has been found to be effective and has provided a number of useful insights into diseases affecting the lower limb and helping to inform the design of interventions (Bus et al., 2013; Ulbrecht et al., 2014), more advanced techniques that allow more nuanced analysis of the complete pressure dataset are now available to analyze these types of measurements (Pataky and Goulermas, 2008). These techniques may be more appropriate for understanding levels of similarity in foot function.

In this study, we aimed to determine the levels of variability in foot function measured via plantar pressures between individuals of different twin status. We hypothesized that monozygotic foot pairs will display more similar pressures than those from dizygotic twin pairs. If plantar pressures for paired feet from monozygotic twins are found to be more similar than dizygotic pairs, it may provide a clear path to investigate biomechanical risk factors for the development of foot and ankle disorders using twin study designs.

2. Methods

This research was approved by the University of Washington Institutional Review Board (reference: STUDY00002868), and all participants provided written, informed consent upon enrollment.

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Twin pairs were recruited from the Washington State Twin Registry (Afari et al., 2006; Strachan et al., 2013). Potential participants were considered ineligible for inclusion if they had a recent (<1 year) lower limb surgery, or a neurological, metabolic, or musculoskeletal condition considered likely to impair ambulation. Twin pairs were also required to be the same sex and BMI (within 3 kg/m²).

Participants attended a single laboratory visit during which they underwent a clinical and biomechanical assessment. In some cases, both twins came to the lab at the same time, however they did not witness their twin being tested. Demographic details were recorded, then participants underwent a barefoot plantar pressure assessment using an emed plantar pressure measurement plate (novel GmbH, Munich, Germany). First, they were asked to stand on the plate in a relaxed pose, feet shoulder width apart, looking straight ahead, and with their weight equally distributed across both feet. Plantar pressures under both feet were recorded for 30 s. Following this, a dynamic assessment was performed where the participants were instructed to walk over the pressure plate (recording at 100 Hz) using a 3-step protocol. After a series of practice trials to allow the participant to become comfortable with the task, ten successful steps for each foot were captured at a self-selected walking speed.

2.1. Data processing

Data processing was carried out in R (v3.4.3). Complete datasets and analysis code have been made openly available at <https://github.com/Telfer/Twinfoot>.

The raw data for each pressure trial were exported from the measurement software in an open format. Both feet were analyzed, with trials for left feet mirrored along the long axis of the pressure plate, and both the static and dynamic trials were normalized to 101 points representing the 30 s data collection period and stance phase respectively.

For the static trials, an average pressure footprint was generated for each foot by calculating the mean value for each active sensor across the data collection period. To allow comparison across all feet, these mean footprints were all aligned to a single template footprint using a linear translational, rotational, and scaling registration implemented in the RNiftyReg package (Clayden et al., 2018). This process was repeated for several randomly chosen template feet to ensure the results were not sensitive to the initial template. The transformation was applied to all static data, providing 40 static pressure datasets that were spatially aligned.

For the dynamic trials, an average trial was generated for each foot by aligning the ten collected trials using the linear translational and rotational process described above and averaging the results for each timepoint at the pixel (individual sensor) level. Once this was complete, the average trials for each foot were aligned across all feet using the same process, with additional degrees of freedom added to this registration phase to allow scaling of the pressure image, thus allowing different sizes of feet to be registered. This provided 40 dynamic pressure datasets (one for each foot) that were spatially aligned.

2.2. Data analysis

Data analysis was carried out in R (v3.4.3) and Python (v2.7.14). Figures were generated using the ggplot2 library (Wickham, 2009). For the aligned static and dynamic datasets statistical parametric mapping (SPM), (Pataky and Goulermas, 2008) was performed to determine the z-statistic across the measurements at the pixel level at each timepoint for both the monozygotic and dizygotic twin groups. A paired analysis was used with each individual acted as the comparator for their twin, i.e., for each co-twin pair, the right foot of twin A was compared to the right foot of twin B, and the left foot of twin A was compared to the left foot of twin B. Finally, overall contact time was calculated and used to determine temporal consistency between twin pairs.

3. Results

Five pairs of monozygotic and five pairs of dizygotic twins were recruited (20 individuals/40 feet total). Demographic details are provided in Table 1.

Overall, results from the statistical parametric modeling analysis showed that monozygotic twin pairs had lower variability between their dynamic pressure distributions for the majority of stance phase (Fig. 1). For ease of visualization in this manuscript, Fig. 2 presents mean z-statistic results at the sensor level for the dynamic trials for each 20% of stance phase, however an animation of the full stance phase, normalized to 101 time points, has been included in the linked supplementary data. The average z-statistic across the entire trial was 0.88 for the monozygotic group and 1.13 for the dizygotic group. Similarly, for the static measurements, variation was found to be lower in the monozygotic pairs than the dizygotic pairs, with mean z-statistics of 1.15 and 1.26 respectively (Fig. 2).

Stance contact time was not found to be different between co-twins, with mean contact times of 0.74 s (SD 0.07) for the monozygotic group and 0.71 s (SD 0.07) for the dizygotic group. Contact time differences between co-twins were 0.06 s (SD 0.03) and 0.05 s (SD 0.03) for the monozygotic and dizygotic groups respectively.

4. Discussion

This study found that plantar pressure measurements of twin pairs showed greater similarities for monozygotic twins compared to dizygotic twins. Previous work on twins and musculoskeletal disorders has focused on estimating the heritability (the role of genetics) of different conditions. Here, our primary aim was to determine the biomechanical similarities in foot function as measured via plantar pressures between different types of twins, and we showed that monozygotic twins had less variation in static and dynamic pressure distributions than dizygotic twins. This was particularly apparent through midstance, where there are fewer high frequency effects commonly seen on impact that could potentially confound the measurement (Simon et al., 1981).

Table 1
Demographic details.

| | DZ group | DZ co-twin difference | MZ group | MZ co-twin difference |
|--------------------------|----------------|-----------------------|---------------|-----------------------|
| Sex | 6F/4M | N/A | 4F/6M | N/A |
| Age (years) | 34.2 (SD 8.9) | N/A | 39 (SD 14) | N/A |
| BMI (kg/m ²) | 25.2 (SD 2.5) | 1.4 (SD 1) | 24.6 (SD 3.6) | 1.7 (SD 1.1) |
| Mass (kg) | 72.2 (SD 13.8) | 3.3 (SD 2.7) | 78.1 (SD 9.2) | 3.5 (SD 3.0) |

MZ: Monozygotic; DZ: Dizygotic.

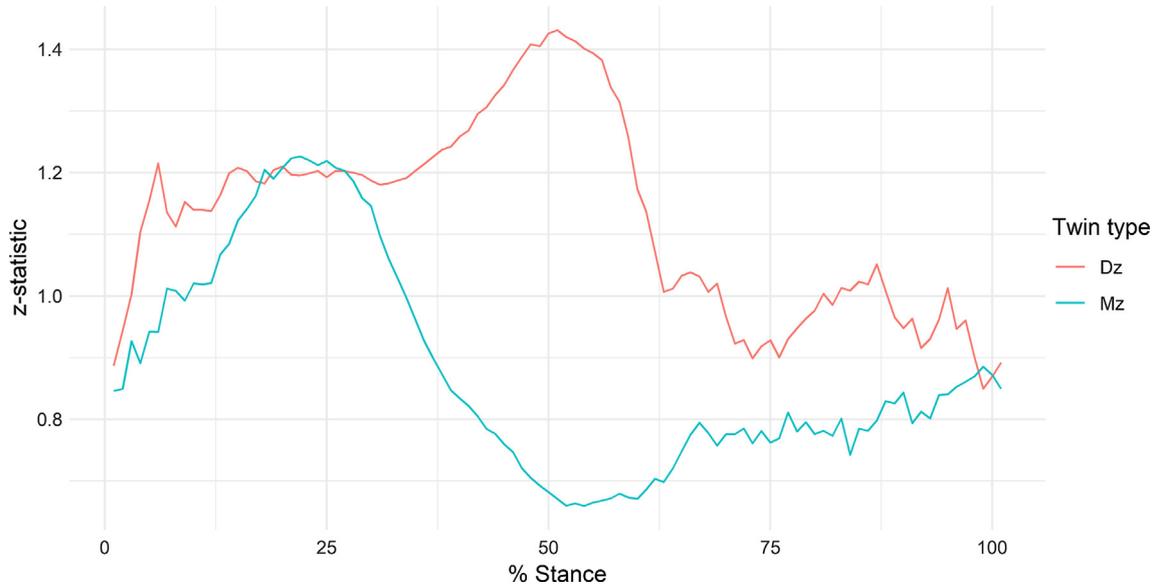


Fig. 1. Mean z-statistic for all sensors across stance phase (normalized to 101 points) by twin group. DZ: Dizygotic group; MZ: monozygotic group.

We used plantar pressure measurements to assess foot function in the study participants. This has been shown to provide a range of insights into foot biomechanics (Telfer and Bigham, 2019), however other techniques, for example, multisegment foot models for kinematic and kinetic analyses (Al-Munajjed et al., 2016), could provide further information on differences in foot function and may be explored in the future. In comparison to other biomechanical measurements of function however, plantar pressure measure-

ment is a technique that lends itself to larger scale epidemiological studies, due primarily to the relative portability of the measurement systems and the ability to quickly collect data without, for example, the need for the participant to be instrumented or wear tight fitting clothes.

The reporting of discrete variables drawn from regional plantar pressure measurements remains common in the biomechanics literature (Telfer and Bigham, 2019). However, this low resolution approach to processing the data has been found to have a number of limitations (Keijsers et al., 2009; Pataky et al., 2008). Therefore, given our aim of comparing pressure measurements in detail our analysis was based around statistical parametric mapping. Using this approach, we were able to show clearly that static and dynamic foot function is more similar for monozygotic twins than dizygotic twins. This study also included a relatively small number of subjects, however the nature of the twin population helps to account for a number of potentially confounding factors. Given the small study population, we used measurements from both left and right feet, datasets which are not strictly independent. However, when the data for only one foot was used, the results were very similar. We controlled for sex and BMI in our recruitment for this study, and co-twins were well matched in terms of mass. However, there are other environmental factors that were not controlled for that could potentially affect plantar pressures, such as exercise levels and footwear history (Menz et al., 2016).

The mechanism by which monozygotic twins develop similar plantar pressures is almost certainly genetic in origin. There is existing evidence in the literature of genes that are strongly associated with musculoskeletal factors such as power generation in athletic performance (Guth and Roth, 2013), bone density (Grant et al., 1996), and shape (Waarsing et al., 2011). Further research is required to identify if particular genes are associated with foot function.

While twins have been used in a number of musculoskeletal investigations, for example spinal deformity (Stone et al., 2015) and neck pain (Visscher et al., 2018), these study designs have been utilized in only a small number of foot related investigations. The heritability of hallux valgus (Lee et al., 2014; Munteanu et al., 2017) has been estimated, as has club foot (Engell et al., 2006). One previous study has looked at plantar pressures during a balance test and found no influence on plantar pressures (Shakibi et al., 2015). Beyond this, little attention has been paid to the role

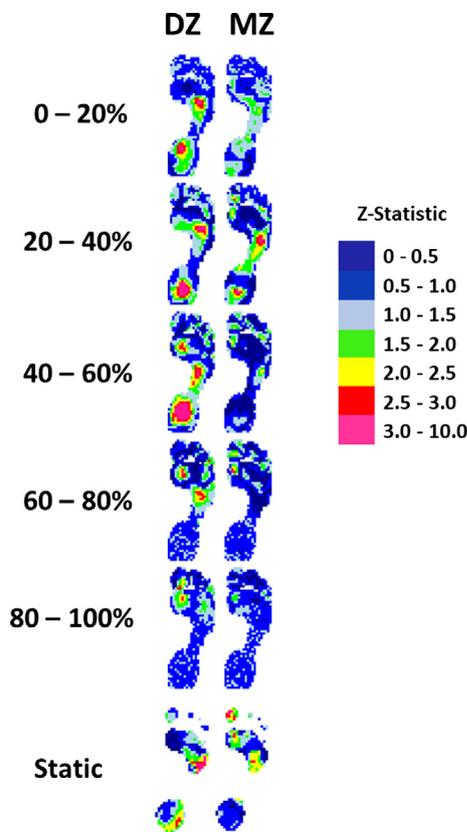


Fig. 2. Visualizations of sensor level z-statistics for twin groups. Each row represents 20% of stance phase. DZ: Dizygotic group; MZ: monozygotic group.

of biomechanics in twin studies that have investigated risk factors for musculoskeletal conditions. The present study provides strong evidence that levels of similarity in foot function varies between twin types, and provides support for the use of co-twin study designs to help identify biomechanical risk factors for musculoskeletal injury and disease.

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Conflict of interest statement

The authors declare that they have no conflict of interest relating to the material presented in this article.

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