Combining F-Scan and GAITRite® for use in Clinical Gait Analysis: A Validation Study.

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Research

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Abstract

Background

Clinical gait analysis is widely used to aid the assessment and diagnosis of symptomatic pathologies. Equipment based analysis provides clinicians with a more comprehensive assessment using pressure systems such as F-scan, or analysis of the spatial-temporal parameters of gait using GAITRite. There are systems however such as Strideway™ that can measure these parameters simultaneously, but can be expensive. This study aimed to determine whether standalone systems can be used collectively while still providing quality data, as a cost-effective alternative.

Methods

Twenty-six participants walked on a standard floor and a GAITRite walkway, three times wearing the F-Scan system. Mid gait protocols were utilised by analysing the contact pressure of the 2 nd metatarsophalangeal joint of the third, fifth and seventh step from each walk. The Bland-Altman method was used to determine a level of agreement between the two surfaces, using mean values from all walks of all participants who successfully completed all required walks. The intraclass correlation coefficient and Lin's concordance correlation coefficient were calculated as indices of reliability.

Results

The intraclass correlation coefficient was calculated to be 0.991 and Lin's concordance correlation coefficient for the data was calculated to be 0.956, indicating very good reproducibility.

Conclusions

The level of agreement in plantar pressures observed on the two surfaces was very high, suggesting that it is feasible to use F-Scan and GAITRite® together in a clinical setting, as an alternative to other less cost-effective standalone systems.

Background

Clinical gait analysis is widely used by practitioners to aid the assessment and diagnosis of symptomatic pathologies [1]. The analysis of gait can be both subjective and objective. Subjective gait analysis uses observation alone, and as such relies on the experience, skill and knowledge of the observer [2]. Objective gait analysis uses equipment to record either force, pressure or spatio-temporal aspects of gait [1]. Whilst the measurements are recorded objectively, it is recognised that their interpretation by a clinician is subjective.

Pressure systems that record plantar pressures exist as plates, mats and in-shoe devices [3]. In-shoe pressure systems, such as F-Scan, are mobile and flexible, and are able to provide accurate information regarding loading patterns. These systems can provide feedback to both the service user and clinician

regarding the effectiveness of interventions, such as orthoses and gait re-training [3, 4]. This feedback could support the clinician's decision-making process and improve the service user's engagement with the management plan.

In addition to force and pressure, spatial and temporal (spatio-temporal) features of gait such as cadence, step length, stride length, base and angle of gait can provide further information regarding the pathomechanics of a person's gait. These measurements provide the clinician with valuable diagnostic and therapeutic information that can enable gait disorders to be identified, quantified, and interventions to be accurately evaluated [5, 6].

One of the main methods in collecting spatio-temporal data is through the use of walkways. Walkways such as GAITRite® are portable, quick and simple to use and allow individuals to walk without restriction allowing a more natural gait [7]. A validation study of GAITRite® found that the data collected from individual footsteps demonstrated excellent concurrent validity, as well as a high standard of validity in cadence, speed and step length [5].

Whilst many systems exist that are capable of recording both plantar pressures and spatio-temporal parameters of gait in isolation, few systems are available that can record these features collectively. Systems such as Strideway™ incorporate both plantar pressure analysis and spatio-temporal parameters, using a tiled walkway embedded with force sensors [8]. Strideway™ provides a comprehensive evaluation of an individual's gait pressure and spatio-temporal parameters through quantitative analysis [8]. However, there is little research available regarding the reliability or validity of Strideway™ for both research and clinical purposes [8]. Furthermore, whilst the benefits of a system capable of providing such extensive data are evident, more cost-effective alternatives may be required by practitioners.

The combination of F-Scan (in-shoe pressure measurement system) and GAITRite® (spatio-temporal measurement system) may provide an alternative to standalone high cost systems. Numerous studies have shown the value of the F-Scan system and GAITRite® walkway in isolation, with data demonstrating reliability and validity under controlled conditions [5, 9]. However, there is a distinct lack of research investigating the efficacy of the two systems used in combination. One concern is that the thickness of the GAITRite® walkway (5 mm) will interfere with the pressure measurements recorded by F-Scan. GAITRite® introduces a soft external surface and this variable may influence pressure recordings taken by F-Scan. Whilst F-Scan is an in-shoe system, it is usually used when walking on a hard surface. The GAITRite® mat may decelerate pressure, change the location of pressure or alter the timings of the pressure recorded [10].

This study aims to assess the agreement between F-Scan pressure measurements taken from a standard walkway (normal hard floor), and those from a GAITRite® walkway to establish whether these two pieces of equipment (in-shoe F-Scan and GAITRite®) can be used simultaneously. Specifically, it aims to determine if GAITRite® interferes with F-Scan pressure measurements when used concurrently. A measure of the reproducibility of the data will also be obtained. Gait information captured from this study may aid clinical practice in identifying a cost-effective alternative to more expensive commercially available systems.

Methods

Participants

An opportunistic sample of twenty-six participants was recruited for the study from the population of a university in the UK. Ethical approval for the study was obtained from the School Research Ethics Panel at the host university.

To enter the study, participants were required to be over 18 years old, have a self-reported UK shoe size between the range of 5 and 10 and own a pair of training shoes with a secure fastening that they were prepared to wear during the study. This range of shoe sizes was chosen to capture the most commonly observed shoe sizes worn by men and women in the UK. Participants were unable to enter the study if they had a current injury, active foot disease, difficulties with balance, or depth perception.

Data Collection

Data collection took place in a gait analysis laboratory using an F-Scan Research 7.50x and a GAITRite® walkway. The F-Scan equipment consisted of a data logger attached to the waist of the participant and two ankle receiver units linked to the in-shoe pressure plates (insoles). Prior to testing, each participant walked for five minutes whilst wearing the F-Scan equipment to allow the participant to become familiar with the device and to establish their usual walking speed. This reduced the possibility of inaccurate pressure readings being recorded from atypical gait patterns [11]. Following research recommendations [12], new F-Scan insoles were introduced after every five uses to avoid damage to the sensors housed within the in-shoe pressure plates. In accordance with the F-Scan manual, walk calibration was performed automatically using the participants weight whilst the wearing the equipment. [13].

The GAITRite® walkway measured 6 metres in length, 60 cm in active width (89 cm overall) and 5 mm in thickness. The walkway was not connected to the software as this was not required for the study.

Steps taken during gait initiation and gait termination are not representative of mid-gait walking steps, whereas the third and fifth steps have been found to provide an accurate representation of 'normal' walking patterns [14]. Therefore, a starting line was placed 30 cm in front of the GAITRite® walkway to avoid gait initiation steps and ensure the third and fifth steps were captured on the walkway. An additional start line was placed adjacent to that described above to create an adjacent walkway on the laboratory floor (figure 1).

The F-Scan data logger recording time was programmed at 8 seconds. This provided sufficient time for the participants to walk the length of the walkway based upon an average cadence of 100 steps/minute [15]. This equates to approximately 13 steps being taken in the eight second recording.

The participants were asked to walk at their normal pace during the study. Participants are likely to take a different number of steps over the test distance due to varying walking speeds. Whilst research has shown that the third to fifth steps are most reflective of 'normal' walking in relation to pressure and force [4, 14],

the selection of a single step was believed to be less representative of habitual walking than an average of steps. Therefore, an average calculation of plantar pressure recordings from the third, fifth and seventh steps was taken for each participant. For participants who had started walking with their right foot, this would equate to the second, third and fourth ground contact with the right foot. To ensure data from the same foot was collected, participants were asked to start walking with the same foot for each test condition.

Analysis was conducted at the second metatarsophalangeal joint for all participants. This joint is compact, leading to reduced movement and consequently increased reliability [16, 17]. Pressure has been found to vary in the rear foot, mid foot and lesser digits [18] making these areas less reliable for comparison. Whilst the first metatarsophalangeal joint is larger, more prominent and easier to locate, research has shown this area to be inconsistent when measuring pressure values [16, 17].

Once the second metatarsophalangeal joint on the plantar pressure recording was located, an object box was placed in the area. This was completed manually by the researcher, a qualified podiatrist. To ensure the same area was measured for each test condition, a 2cm object box was used. A second podiatrist assessed the placement of the object box to promote reliability.

To calculate average pressure at this location, contact pressure was used. Contact pressure provides an understanding of the pressure acting on an anatomical structure whereas peak pressure is often used to establish the effectiveness of cushioned interventions, such as polyurethane materials [4]. Additionally, contact pressure has been found to demonstrate high retest reliability in all areas of the foot [9].

Following the five minute ‘equipment familiarity’ period, each participant was asked to walk from the start line across the laboratory floor to the end of the room. They were then asked to walk from the start line to the end of the room on the GAITRite® walkway. This procedure was repeated three times on each surface to account for learning and fatigue effects [19, 20]

Statistical analysis

The sample was summarised descriptively. The extent and nature of any missing data was assessed. Complete case analysis was conducted following verification of low proportion of data shown to be missing completely at random. Agreement between plantar pressure recorded by the walks on the standard surface and the GAITRite® walkway was assessed using the Bland-Altman method [21], using mean values from all walks of all participants who successfully completed all required walks. The intraclass correlation coefficient (the proportion of variability between observations due to differences between walkways) and Lin’s concordance correlation coefficient [22] (a measure of the departure of the line of best fit from a 45° line through the origin) were calculated as indices of reliability.

Results

Data were obtained from 26 subjects (6 male; 20 female) who consented to participate in this study. Each participant completed 6 recorded walks (3 per surface) giving a total of 156 walks. Inadequate calibration

of the insoles led to unusable data in 4 walks. Therefore, usable data was obtained from 152 walks. Separate variance t-tests did not reveal any evidence that missing data was not missing at random and subsequent analysis was conducted on complete case analysis without imputation.

F-Scan results determined the mean plantar contact pressure recorded by valid walks on the standard surface was 241.7 kPa (SD 66.2 kPa). The mean plantar pressure recorded by the walks on the GAITRite® walkway was 241.6 kPa (SD 61.0 kPa). The difference between the mean plantar pressure readings taken from the two surfaces was 0.11 kPa.

Plantar pressure data from included walks is summarised in Table 1

The Bland-Altman plot of the data is illustrated in Figure 2. Limits of agreement are calculated as the mean of observed differences ± 2 standard deviations of the differences.

Values from one participant lie outside the limits of agreement. This proportion of outlying data points is within expectations for a data set of this size. The average absolute discrepancy between values taken from the two surfaces from each participant was 13.9 kPa.

Random scatter of points may be observed, indicating no systematic difference between pairs of readings (hence a single measure of repeatability is acceptable).

No funnelling of points or other features of the data are visible; implying no evidence for a relationship between the magnitude of recorded pressure and the agreement between the two methods.

The intraclass correlation coefficient was calculated to be 0.991. Lin's concordance correlation coefficient for the data was calculated to be 0.956. Both statistics indicate very good reproducibility.

Discussion

F-Scan and GAITRite® are known to provide valuable gait information when used in isolation. The results of this study demonstrate negligible effects on F-Scan pressures when walking on a hard surface compared with walking on the GAITRite surface indicating that it is feasible to use the two systems in combination. Using the two systems in combination enables foot pressures and two-dimensional (spatial and temporal) gait parameters to be collected efficiently and analysed simultaneously. This provides the practitioner with correlations between gait and foot pressures and potential cause/effect relationships which may aid diagnosis and management. Using F-Scan and GAITRite® together could also provide an effective method for monitoring disease progression or the success of an intervention or management plan.

For example, a participant in this study displayed average plantar pressure readings of 81.8kPa (at the second MTP joint), which was lower than mean readings by a factor of 3. When investigated further, the pressure reading was a result of function, with plantar pressure for this participant being predominantly exerted through the lateral aspect of their foot (figure 3). There are numerous reasons for lateral foot

loading when walking, one of which may relate to a reduced range of motion at the hip. Those with weak hip extensors and shortened, tight hip flexors will often show difficulty when extending the hip and consequently difficulty when toeing off from the hallux in the gait cycle [23]. If GAITRite® was used in combination with F-Scan, it may have shown a reduced step length for this participant (due to reduced hip extension) and a possible cause for the plantar pressure in this area. Providing objective, quantifiable evidence for a preferred diagnosis and enable a practitioner to treat the cause of the pathology rather than simply offloading the high-pressure area highlighted by F-Scan. Combining F-Scan and GAITRite® could provide a more comprehensive analysis in treating patients with complex pathologies.

Within-participant variation in plantar pressure recorded on the standard and GAITRite® walkways was low compared to variations recorded between participants, and variations between pressures recorded on different walks on the same walkway by the same participant. These latter sources of variation were considerable; no participant obtained constant pressure values between walks, and pressures obtained from different participants differed by a factor of 5. This finding of high inter- and intra-subject variation is consistent with supporting research [24].

Differences in mean plantar pressure between walks (for one person) on both surfaces ranged from 2 kPa to 39 kPa. Kong & De Heer [25] suggest that such ranges of differences are small, taking into consideration the natural variability of gait and the varied repeatability of plantar pressure. Research analysing the variability of plantar pressure at controlled speeds suggests that this variability can be a result of the speed at which a person walks [26]. Other studies have suggested that the natural variability of an individual’s gait could account for the frequently poor repeatability results exhibited by F-Scan [27]. However, walking speed was not controlled for in this research. The natural changes to walking speed made by a person are believed to form part of their habitual gait and consequently could contribute to associated pathology. As this research was investigating the use of these systems in clinical practice, it was deemed necessary to allow participants to walk at their naturally variable walking speed.

It was expected that the GAITRite® walkway would reduce the plantar pressures recorded by F-Scan. However, the extent of the reductions, and whether they would prevent the use of both systems together was unknown. This difference was anticipated because the GAITRite® walkway comprises of a neoprene rubber base layer, which was expected to decelerate ground reaction forces. Price et al. [10] found that in-shoe pressure systems with foam top surfaces between 1.6 mm and 2.2 mm thick reduced plantar pressure values, when compared to the thin plastic film of F-Scan. As the GAITRite® walkway has a thickness of 5 mm, a similar or greater reduction in plantar pressure was expected. About 70% of individual pressure values recorded on F-Scan were slightly lower when the participants walked on GAITRite® compared to when they walked on the laboratory floor. However, lack of familiarity of the GAITRite® surface among the participants may have contributed to the observed differences in pressure values in earlier walks. Increased familiarity with the GAITRite® mat during the study may have reduced the differences observed between surfaces. Future research could provide participants with time to walk on the GAITRite® mat to become familiar with this surface.

Whilst this study suggests that the GAITRite® walkway does not detrimentally affect the plantar pressure recordings of F-Scan, the effects of F-Scan on the data collected by GAITRite® has not been investigated. The total weight of the F-Scan system is approximately 1.5-1.8kg, with the majority of the weight being from the waist unit. Whilst participants were given time to acclimatise to wearing the equipment, the effect that this additional weight might have on the spatiotemporal measurements taken by GAITRite® (such as step and stride length, base and angle of gait) was not investigated. Research suggests that the body can withstand posteriorly positioned loads of up to 20% of their body weight before spatio-temporal factors are affected [12, 25, 28]. Therefore, considering that the average weight for men and women in the UK is estimated 83.6 kg and 70.2kg respectively, the weight of the F-Scan equipment would equate to only 1.5% and 1.3% of body weight [29]. This suggests that the equipment would not impede the spatio-temporal parameters recorded. However, this requires further investigation because the total mass of F-Scan is distributed between the ankles and waist units rather than on the participants' backs. Divert et al. [30] found that stride frequency decreased as shoe mass increased. Therefore, it is possible that the weight of the F-Scan units that are attached to the ankles could influence step frequency and length.

Conclusions

This study demonstrates that although plantar pressure values were expected to decrease when walking on the GAITRite® walkway rather than a hard surface, the level of agreement in plantar pressures observed on the two surfaces was very high. Reliability of measures was also very high. These findings suggest that it is feasible to use F-Scan and GAITRite® together in a clinical setting, as an alternative to other less cost-effective standalone systems. Further research conducted on a larger and possibly more homogenous cohort of participants would be beneficial to establish whether the levels of agreement observed in the current investigation between data obtained from the two surfaces can be repeated. Furthermore, research is also required to investigate the effects F-Scan has on the spatio-temporal measurements recorded by GAITRite®.

Declarations

Ethics approval and consent to participate

Ethical approval for the study was obtained from the School Research Ethics Panel at the host university.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Stephanie Speight: Conceptualization methodology, Investigation, Resources, Writing – original draft, Supervision, Project administration, Validation, Visualization

Selina Reidy: Conceptualization, Writing – Review and editing

Sarah Reel: Writing – Review and editing,

John Stephenson: Writing – Review and editing, Formal Analysis, Data Curation Software, Visualization

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Tables

Due to technical limitations, table 1 is only available as a download in the Supplemental Files section.

Figures

Figure 1: Walkway setup

Figure 1

Walkway setup

Figure 2: Bland-Altman plot for plantar pressures measured on the GAITRite® walkway and a standard hard surface

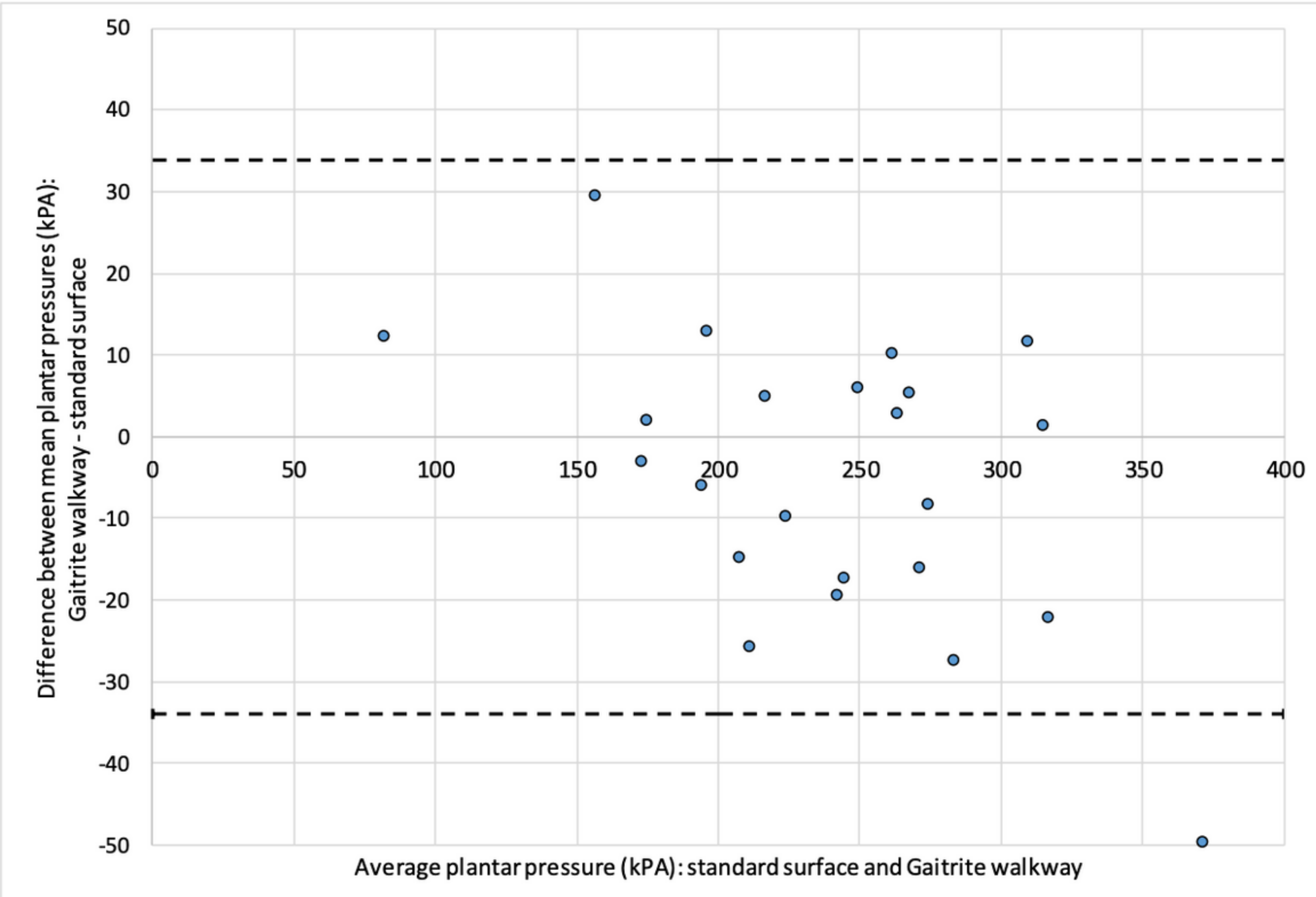

Figure 2

Bland-Altman plot fot plantar pressures measured on the GAITRite@ walkway and a standard hard surface

Figure 3: Pressure map demonstrating lateral pressure

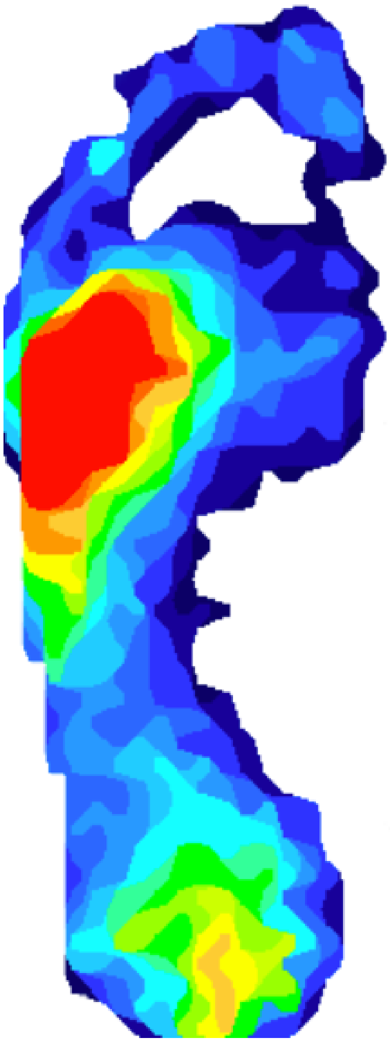

Figure 3

Pressure map demonstrating lateral pressure

Supplementary Files

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- Table1Meanplantarpressure.png