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Review

The relationship between foot posture and lower limb kinematics during walking: A systematic review

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ABSTRACT

Variations in foot posture, such as pes planus (low-arched foot) or pes cavus (high-arched foot), are thought to be an intrinsic risk factor for injury due to altered motion of the lower extremity. Hence, the aim of this systematic review was to investigate the relationship between foot posture and lower limb kinematics during walking. A systematic database search of MEDLINE, CINAHL, SPORTDiscus, Embase and Inspec was undertaken in March 2012. Two independent reviewers applied predetermined inclusion criteria to selected articles for review and selected articles were assessed for quality. Articles were then grouped into two broad categories: (i) those comparing mean kinematic parameters between different foot postures, and (ii) those examining associations between foot posture and kinematics using correlation analysis. A final selection of 12 articles was reviewed. Meta-analysis was not conducted due to heterogeneity between studies. Selected articles primarily focused on comparing planus and normal foot postures. Five articles compared kinematic parameters between different foot postures – there was some evidence for increased motion in planus feet, but this was limited by small effect sizes. Seven articles investigated associations between foot posture and kinematics – there was evidence that increasing planus foot posture was positively associated with increased frontal plane motion of the rearfoot. The body of literature provides some evidence of a relationship between pes planus and increased lower limb motion during gait, however this was not conclusive due to heterogeneity between studies and small effect sizes.

1. Introduction

Variations in foot posture from normal, such as pes planus (low-arched foot) or pes cavus (high-arched foot), are recognised as an intrinsic risk factor for developing lower extremity injury [1]. Foot posture, also commonly referred to as *foot type* in the literature, may contribute to injury via altered motion of the lower extremity. For example, it has been reported that individuals with pes planus have greater foot mobility compared to those with pes cavus [2–4]. As a consequence, running and walking studies have found that those with pes planus are more susceptible to tissue stress injuries arising from abnormal joint rotation [5] or joint coupling [6]. Conversely, those with pes cavus are reported to have less foot mobility, and are more susceptible to injuries related to reduced shock attenuation [7] or increased peak plantar pressures [8].

While the proposed link between foot posture and injury appears to be biomechanically and physiologically plausible, the results of large prospective studies do not provide definitive evidence that such a relationship exists [9–11]. Systematic and narrative reviews of prospective studies have concluded that further work is needed to develop more robust methods of classifying foot posture and clearer definitions of injury [2,12,13].

In terms of the mechanisms linking foot posture with injury, researchers have principally focused on three techniques for evaluating lower limb biomechanics. These techniques include: (i) kinetics or plantar pressures, (ii) electromyography (EMG), and (iii) kinematics. With regard to kinetics or plantar pressures, it has been found that those with cavus feet display significantly lower plantar pressure in the medial arch and increased plantar pressure in the heel and forefoot compared to individuals with normal or planus feet [8,14–16]. With regard to EMG, there is evidence that planus feet demonstrate greater EMG activation of invertor musculature and decreased activation of evertor musculature compared to those with normal or cavus feet [17]. While these findings indicate clear systematic relationships between foot

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posture and changes in plantar pressures and muscle activation, there is, to our knowledge, no single source available that has critically evaluated the kinematic literature.

Therefore, the aim of this systematic review was to investigate the relationship between foot posture and kinematics of the lower limb during walking.

2. Methods

2.1. Search strategy

A systematic literature search was undertaken in March 2012 using the following electronic databases; Ovid MEDLINE (1966 to March 2012), CINAHL (1982 to March 2012), SPORTDiscus (1830 to March 2012), Embase (1988 to March 2012) and Inspec (1898 to March 2012). Medical subject headings (MeSH) were exploded to include all relevant subheadings and matched with appropriate keywords. The search was limited to adult human subjects and no language restrictions were applied. The search strategy is presented in Table 1.

2.2. Inclusion criteria

Articles that fulfilled the following criteria were included:

(i) Foot posture was used as an inclusion criterion or independent variable;
(ii) Main outcome measures were related to kinematics of the lower limb;
(iii) Testing did not include postural perturbations or activities other than walking (i.e. running, balance exercises, hopping, etc.);
(iv) Testing included adult participants that were free of neurological, systemic or degenerative conditions;
(v) Hypothesis testing with statistical analysis was undertaken;
(vi) Article was published in a peer-reviewed journal.

Only studies that used 3-D kinematic analysis were included, as transverse plane foot position has been found to influence frontal plane motion, which creates parallax errors in 2-D studies [18]. Furthermore, only studies that utilised stereophotogrammetry (the use of photography, radiography or video images to reconstruct coordinates of anatomical landmarks) were included, as this is the most commonly used method of movement analysis [19].

2.3. Quality assessment

There is no validated procedure to test the methodological quality of laboratory-based kinematic studies. Therefore, we used a two-stage assessment that comprised: (i) a modified version of an existing quality assessment tool, and (ii) a new set of items to assess methodological quality of 3-D kinematic gait analysis.

For the first stage, we used an adapted version of the Quality Index [20] to test methodological quality. The total maximum score available for this stage of quality assessment was 16.

The second stage involved the assessment of methodological variables related to 3-D kinematic gait analysis using stereophotogrammetry. A series of items were developed using highly referenced articles related to stereophotogrammetry [19,21–23]. Other sources used to develop items were the conclusions and recommendations of 4 systematic reviews related to 3-D kinematic gait analysis [24–27]. The items are presented in Table 2. The total maximum score for this stage of quality assessment was 7.

Additional information relating to the assessment of articles included in the systematic review is presented in an additional data file at http://dx.doi.org/10.1016/j.gaitpost.2013.01.010.

2.4. Data analysis

Relevant data were extracted from all included studies, including means, mean differences, standard deviations, confidence intervals, r- and r^2-values, and p-values. Where possible, percentage mean differences with 95% confidence intervals and effect sizes (difference in mean scores divided by pooled standard deviation) were calculated for studies that reported statistically significant findings. In order to provide a consistent measure, effect size (i.e. the standardised difference in means) was classified as trivial (0–0.2), small (0.2–0.6), moderate (0.6–1.2) and large (>1.2) [28]. Pooling of data and meta-analyses were not performed due to a lack of homogeneity in techniques related to foot posture classification, kinematic methodology and kinematic parameters. Where positive and negative Euler angles were reported, negative joint angles were rectified to positive values to normalise the calculation of effect sizes.

3. Results

3.1. Search results

The results of the review process are shown in Fig. 1. A total of 3864 citations were retrieved from the search of electronic databases. After inspecting the title and abstract, 50 articles were assessed for full text review. Of these, 12 were suitable for full review.

The included studies were grouped according to method of analysis. Firstly, there were studies that compared mean differences via t-tests or analysis of variance. Secondly, there were studies that investigated associations via regression and correlation analyses. A summary of the selected articles is presented in Tables 7 and 8.

Table 1
Search strategy.

Subject heading	(1) Exp. foot/or pronation/or supination/or flatfoot
Keywords	(2) Pes planus or pes cavus or pes planovalgus or 'high arch* foot' or 'low arch* foot' or foot arch or 'medial longitudinal arch' or foot posture or foot structure or pronat* or supinat* or evert* or invert*
Combine	(3) 1 or 2
Subject heading	(4) Exp. biomechanics/or motion
Keywords	(5) Kinematics or kinetics or 'human movement analysis' or gait analysis or gait measurement* or motion analysis or gait pattern or 'lower limb motion' or foot motion or 'lower limb biomechanics'
Combine	(6) 4 or 5
Subject heading	(7) Exp. walking/or running/or gait/or locomotion
Keywords	(8) walk* or run* or jog* or locomotion or ambulation
Combine	(9) 7 or 8
Limit	(10) Limit to humans and all adults (18 years plus)
Combine	(11) 3 and 6 and 9 and 10