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Review

A systematic review and meta-analysis of dynamic tests and related force plate parameters used to evaluate neuromusculoskeletal function in foot and ankle pathology

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ABSTRACT

Background: Force plates are commonly used to register ground reaction forces in order to assess neuromusculoskeletal function of the ankle joint. There exists a great variety in dynamic tests on force plates and in parameters calculated from ground reaction forces in order to evaluate neuromusculoskeletal function of the ankle. The purpose of this study was to evaluate which dynamic tests and force plate parameters are most sensitive to differences between and within groups with regard to foot and ankle pathology.
Methods: A systematic review and meta-analysis was performed evaluating studies that compared force plate parameters of dynamic tests between patients with foot and ankle pathology, and healthy controls. Data were pooled per parameter and test category. Given the clinical heterogeneity, we constructed comprehensive recommendation criteria to indicate a 'proven relevant parameter' or 'candidate relevant parameter'.
Results: A total of 34 studies were included, and 58 relevant comparisons were identified. Results were subdivided by test category: walking, running, landing (in anteroposterior direction), sideways (movement in mediolateral direction) and termination (movement in anteroposterior direction). The 'walking' test showed significant differences in a great variety of pathologies, with the magnitude and timing of the 'second peak vertical force' as proven relevant parameters. The 'landing' test detected differences due to ankle instability, with 'time to stabilization in anteroposterior direction' as proven relevant parameter.
Interpretation: This study provides recommendations concerning the potential of various dynamic tests and force plate parameters as a tool to compare neuromusculoskeletal function between patients with foot and ankle pathology and healthy controls.

1. Introduction

The prevalence of foot and/or ankle pathology due to injury and degenerative disorders is high (Lambers et al., 2012; Thomas et al., 2011). In many cases, these injuries and disorders impair neuromusculoskeletal function and consequently interfere with or even prevent participation in activities of daily life or sports (Thomas et al., 2011). The high prevalence and the associated burden to society have led to great interest among researchers and many studies have attempted to quantify functional deficits in patients.

To quantify impairments of neuromusculoskeletal function in patients with foot and ankle disorders, force plates have been used to register ground reaction forces (GRFs) on the foot while participants perform an activity that challenges neuromusculoskeletal function. The GRF reflects the movement of the whole body that needs to be controlled over base of support provided by the foot or by both feet.

A rough distinction can be made into two types of activities: (quasi-) static and dynamic. In a (quasi-) static test, the participant typically has to maintain his or her balance while standing on either both legs or on one leg, with the eyes open or closed, with or without perturbations (Howells et al., 2011). Given that injuries seldom occur while standing still, it has been argued to test movements that occur during everyday life. This has consequently led to an increase in the number of studies investigating dynamic tests, which consist of an active (e.g. walking or running) or even vigorous (e.g. jump landing or sideways shuffle) movement. In addition to the various dynamic tests, a large number of parameters have been used to characterize the ground reaction force regarding its magnitude, direction, timing and its dynamics (Brown et al., 2008; Dayakidis and Boudolos, 2006; Delahunt et al., 2007; Liu et al., 2012; Ross and Guskiewicz, 2004; Wikstrom et al., 2007).

This abundance of tests and parameters poses a real challenge when designing protocols for research or clinical assessment. Therefore the purposes of this study were to systematically review the

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literature and perform a meta-analysis with regard to dynamic tests using a force plate to evaluate patients with foot and ankle pathology. Specifically, this review attempts to answer the question which dynamic tests, and which force plate parameters are most sensitive to differences between and within groups with regard to foot and ankle pathology. It should be noted that these tests are not used as diagnostic tests to determine the presence or absence of pathology, but to quantify the functional consequences of existing disorders. We make the explicit assumption that foot and ankle disorders do cause neuromusculoskeletal impairments, hence the test or parameter that discriminates better between groups with and without pathology is more sensitive to these neuromusculoskeletal impairments.

2. Methods

2.1. Search strategy

We conducted a literature search using the Cochrane Library, PubMed (Medline), EMBASE, and PEDro databases from inception to January 3rd 2013. The following search strategy was developed for PubMed (Medline): (1) foot OR ankle, (2) forceplate OR force plate OR force platform OR ground reaction force OR ground reaction forces OR kinetic OR kinetics, (3) dynamic OR functional OR gait OR walk OR walking OR run OR running OR step OR stepping OR jump OR jumping OR hop OR hopping OR cut OR cutting OR shuffle, and (4) 1 AND 2 AND 3. For PEDro the following modified search strategy was used: (ankle *force*) OR (foot *force*). Only articles written in English were considered. The reference lists of all included studies were checked for other relevant articles.

2.2. Study selection

Duplicate references were removed from the search results. Two authors (DPF and AH) independently screened the identified articles based on title and abstract to identify potentially relevant articles for extensive review. A study was included if it: (1) compared patients who had a musculoskeletal injury of the foot and/or ankle with healthy controls (between groups) or with the uninjured limb (within group), (2) conducted dynamic tests that involved an active component (e.g. walking, running or jump landing) in contrast to a static test (e.g. single leg stance), and (3) described performance with parameters that can be calculated solely based on force plate data.

We excluded studies that recruited participants that were skeletally immature or had congenital deformities, a neurodegenerative or vascular disease, a history of knee or hip disorders (e.g. osteoarthritis or ligamental tear) or an amputation of any part of the lower extremities. Furthermore, we excluded studies with interventions (e.g. orthotic devices, altered shoes, braces, robotics, crutches, cast) or instigated perturbations (e.g. vibration, nerve stimulation, obstacles, damped surface, slippery surface, uneven terrain, backward gait, added mass, ligament anesthesia) within the study protocol. Finally, we excluded studies that needed additional data (e.g. 3D kinematics) to calculate the parameters used (e.g. joint moments), studies that did not present the mean and standard deviations of the calculated parameters, and studies that had a sample size smaller than six participants per group.

2.3. Data extraction

The extracted data were sample size and participant characteristics, the tests used and instructions given, the comparisons made, the parameters calculated, the group outcome and SD (or an alternative from which SD can be calculated). In addition, the reported significant differences between or within groups were extracted.

2.4. Data analysis

The extracted data were subdivided by test type conducted and into 'between groups' and 'within group' comparisons. Group outcome and SD were imported into Review Manager for a meta-analysis (RevMan, Computer program. Version 5.2. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2012). The following settings were used: data type — continuous; statistical method — inverse variance; analysis model — random effects; effect measure — std. mean difference; totals — totals and subtotals; study confidence interval — 95%; and total confidence interval — 95%. Consequently, pooled effect size, 95% confidence interval, P-value and heterogeneity (I^2) were calculated per test and per parameter. Pooled effect size was interpreted according to Cohen's suggestion: small = 0.20, medium = 0.50, and large = 0.80 (Cohen, 1988). Heterogeneity of outcomes was determined by means of the I^2 test (Higgins et al., 2003).

Our inclusion criteria (diverse pathologies and tests) will in some cases lead to a suboptimal pooling of comparisons and consequently to a high heterogeneity (I^2). Therefore, we constructed comprehensive criteria:

1) A 'proven relevant parameter' showed a significant difference in more than one study, and in at least 50% of the comparisons, plus the pooled effect size was 'large'.
2a) A 'candidate relevant parameter' showed a significant difference in more than one study, and the associated pooled effect size was 'medium' at least, or
2b) showed a significant difference in more than one study and, while the associated pooled effect was not significant, the heterogeneity (I^2) exceeded 60%, or
2c) was used in only one study, which reported a significant difference.

3. Results

3.1. Included studies

The original search identified 3773 articles. After submitting these studies to the selection process (see Fig. 1), we included 34 studies. The characteristics of all studies are presented in Table 1, subdivided by test category, i.e. 'walking', 'running', 'landing' (in anteroposterior direction), 'sideways' (movement in mediolateral direction) and 'termination' (movement in anteroposterior direction). Table 2 provides an overview

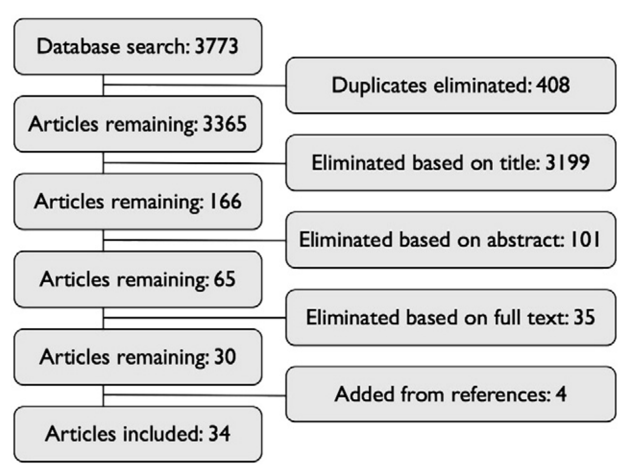

Fig. 1. Flowchart of study inclusion. Reasons for elimination based on full text: No GRF data were presented (15); additional data (e.g. 3D kinematics) were needed to calculate the parameters used (11); literature review (3); perturbation (2); number of participants was less than 6 (2); no comparison between or within groups was made (1); and two studies reporting on the same data, which led to the inclusion of Wikstrom and Hass (2012) and the exclusion of Wikstrom et al. (2010a) (1).