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Review

Plantar pressure measurements and running-related injury: A systematic review of methods and possible associations

Robert Mann [a,b], Laurent Malisoux [a], Axel Urhausen [a,c], Kenneth Meijer [b], Daniel Theisen [a,*]

[a] Sports Medicine Research Laboratory, Luxembourg Institute of Health, 76, rue d'Eich, L-1460 Luxembourg, Luxembourg
[b] NUTRIM School for Nutrition, Toxicology and Metabolism, Maastricht University, Universiteitssingel 40, 6229 ER Maastricht, The Netherlands
[c] Sports Clinic, Centre Hospitalier de Luxembourg, Luxembourg, Luxembourg

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ABSTRACT

Pressure-sensitive measuring devices have been identified as appropriate tools for measuring an array of parameters during running. It is unclear which biomechanical characteristics relate to running-related injury (RRI) and which data-processing techniques are most promising to detect this relationship. This systematic review aims to identify pertinent methodologies and characteristics measured using plantar pressure devices, and to summarise their associations with RRI. PubMed, Embase, CINAHL, ScienceDirect and Scopus were searched up until March 2015. Retrospective and prospective, biomechanical studies on running using any kind of pressure-sensitive device with RRI as an outcome were included. All studies involving regular or recreational runners were considered. The study quality was assessed and the measured parameters were summarised. One low quality, two moderate quality and five high quality studies were included. Five different subdivisions of plantar area were identified, as well as five instants and four phases of measurement during foot–ground contact. Overall many parameters were collated and subdivided as plantar pressure and force, plantar pressure and force location, contact area, timing and stride parameters. Differences between the injured and control group were found for mediolateral and anteroposterior displacement of force, contact area, velocity of force displacement, relative force–time integral, mediolateral force ratio, time to peak force and inter-stride correlative patterns. However, no consistent results were found between studies and no biomechanical risk patterns were apparent. Additionally, conflicting findings were reported for peak force in three studies. Based on these observations, we provide suggestions for improved methodology measurement of pertinent parameters for future studies.

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1. Introduction

During the last four decades, running as a recreational activity has gained in popularity. Although we have experienced a surge in research on running and dramatic development in running shoes, there is no evidence to suggest that running-related injury (RRI) incidences are decreasing [1]. Various researchers using biomechanical analysis techniques have suggested possible risk factors of injury such as greater vertical loading rate and peak tibial shock [2], greater hip adduction, peak rearfoot eversion and peak absolute free moment of the tibia [3], reduced knee range of motion and reduced preactivation of tibialis anterior, rectus femoris and gluteus medius [4]. Traditionally, force platforms, motion analysis systems and electromyography have been used to assess these biomechanical characteristics of running in the laboratory. Accessibility to kinetic and kinematic measurement systems has increased greatly over the years. These devices are capable of three-dimensional force and marker coordinate measurement with immense precision and are generally considered the gold standard for force and joint angle measurements. Force platforms have been used in a number of studies on running biomechanics [2–4], but the measurements are generally confined to a particular location, often the laboratory. In addition, this setup measures only a single foot contact at a time [5] and can invoke "platform targeting" during overground running. Similarly, the analysis of several consecutive steps is generally not possible with motion analysis systems during overground running, and most published findings are based on an average of between 3 and 10 independent steps [6,7]. The use of instrumented treadmills can overcome these drawbacks, but the natural running pattern can be impacted [8]. Taken together, these elements could partly explain why there is still little consensus today on biomechanical risk factors for RRI. Additionally, these systems cannot provide

* Corresponding author.

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information regarding the plantar loads and distribution of plantar pressures, which have been thought to provide valuable information in the study of specific pathologies and RRI risk factors [9].

Pressure-sensitive measurement tools have existed since the 1980s, and provide an alternative approach to studying the foot–shoe or foot–running surface interactions. They allow for the determination of centre of pressure trajectories during the contact phase of running and can provide data on plantar pressure location and magnitudes. Similarly to force platforms, pressure mats acquire data of a single step at a time, generally in the barefoot condition. Pressure treadmills and carpets are able to capture multiple, consecutive steps, yet remain laboratory-bound. Pressure insoles are inserted into the running shoe and provide insight into the vertical ground reaction forces and pressures acting within the shoe. Since insoles are portable devices, they can acquire data continuously and are not laboratory-bound.

With increasing focus on the relationship between shoe type and running biomechanics [10,11], insole-based sensors represent an interesting methodology that can be used to study the foot–shoe interactions [5,6] in the runner's habitual training environment. Insofar, these devices may aid to relate plantar pressures to RRI and have good potential to improve our understanding of RRI risk factors. So far we have witnessed a very heterogeneous approach by different laboratories when using pressure devices. Therefore, we conducted a systematic review of studies using pressure measurement systems, with the aim to identify pertinent methodologies and pressure-related characteristics measured using plantar pressure devices, and to summarise their associations with RRI.

2. Methods

We followed the PRISMA guidelines for this systematic review [12]. PubMed, Embase, CINAHL, ScienceDirect and Scopus were searched up until March 2015 using the following search terms:

(injur* OR running-related injur*) AND (pressure[MeSH Terms] OR pressure* OR centre of pressure* OR center of pressure* OR footstrike*) AND (running OR runner* OR jogg*)

Inclusion criteria of the initial screening of articles were as follows: RRI (pain in the lower limbs, resulting from and causing a reduction in running activity, and/or resulting in medical consultation) as an outcome measure, biomechanical analyses during running, retrospective case–control, prospective follow-up or randomised controlled trial study design and original data reported in any language. Studies on animals, cadavers, youths (<18 years old), orthotics, bracing/taping and case reports were discarded. The initial filtering of articles was performed by one of the investigators (RM), and an initial selection of articles was identified based on title and abstract. The remaining articles were screened by two investigators (RM and LM) independently based on title, abstract and if necessary, the full-text, selecting those articles which included RRI as an outcome measure, plantar pressure measurements during running and peer-reviewed articles (i.e. not conference abstracts, theses, book chapters). The reference lists of relevant articles were hand-searched for additional articles. All articles in the final selection compared an injury group with a control group.

A quality assessment of the articles fulfilling the above-mentioned criteria was carried out. The assessment tool used was an adapted version of an existing checklist put forward by Munn et al. [13]. This checklist was developed for non-randomised and non-intervention studies and deemed appropriate as no randomised control trials or intervention studies were found in this systematic review. A new item five was added to the checklist to distinguish between retrospective and prospective studies. The former introduces a greater risk of bias and confounding in their study designs. Therefore, a score of 1 was awarded to prospective studies, and 0 to retrospective study designs. Items 12 and 13 are concerned with how reliably RRI was determined and how accurately the pressure measurement systems could measure the parameters. Diagnosis of RRI by a medical professional resulted in a score of 1, whereas self-reporting RRI scored 0. Item 13 refers to the sampling rate of the pressure device, with a score of 1 awarded if it was reported to be greater than or equal to 100 Hz, as this has been reported to be the minimum sampling frequency required for accurate measurement of running biomechanics [14]. The quality was assessed by two of the authors individually, and any discrepancies in scores were discussed with and resolved by a third reviewer (DT) assigning a deciding score. We maintained the quality brackets of Munn et al. [13] with studies achieving an overall score of <60% being classed as "low", 60–74% as "moderate" and ≥75% as "high" quality studies.

Measurements obtained from injured runners and control groups were compared based on the standardised mean differences (SMD) determined from extracted means and standard deviations (SD) using the Review Manager (RevMan) [Computer program] (version 5.3. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014). SMDs (absolute values) were classified as large (≥1.2), medium (0.60–1.19) or small (<0.60) [15].

3. Results

After removing duplicates from the initial 1289 search hits, 811 studies were identified based on our search terms and through hand searching, 681 were excluded by one reviewer based on title and abstract, and two reviewers were unanimous on the final selection of eight studies for inclusion based on title, abstract and full text (Fig. 1). Of these eight articles, three are prospective follow-up studies including between 102 and 131 participants (Table 1). We must point out that although these were three independent studies, they all originated from the *Department of Rehabilitation Sciences and Physiotherapy* of Ghent University, Belgium. All three studies were concerned with novice runners from a start-to-run programme, and it is strongly believed that there was overlap of participants within these cohorts [16–18]. The other five studies are independent, retrospective, cross-sectional studies testing between 22 and 105 participants. Four studies used pressure platforms to collect their data, and the other four used insole devices. Three studies focused on Achilles tendinopathy, whereas the others focused on lower leg overuse injuries, patellofemoral pain, iliotibial band syndrome, 2nd metatarsal stress fractures and general running-related injuries. Five of the studies measured their runners on runways between 10 and 16.5 m, one study used a runway of 40 m, and the remaining two studies had their participants run on treadmills. Table 1 summarises the methodologies of the eight selected articles.

3.1. Quality assessment

Assessing the quality of the eight included articles resulted in one article being rated low quality (below 60% quality score), two articles rated as moderate quality (between 60 and 74% quality score) and five articles rating as high quality (above 75% quality score). The scores of each of the quality items are summarised in Table 2.

3.2. Division of plantar surface area

We identified five different subdivisions of plantar areas. For the purposes of this comparison, we will use universal terminology, to ensure clarity. The results from devices that provided high

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