Human Movement Science 35 (2014) 104–120

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Ankle plantarflexion strength in rearfoot and forefoot runners: A novel clusteranalytic approach

Dominik Liebl [a,*], Steffen Willwacher [b], Joseph Hamill [c], Gert-Peter Brüggemann [b]

[a] *Mathematics Department and ECARES, Université Libre de Bruxelles, Belgium*
[b] *Institute of Biomechanics and Orthopaedics, German Sports University Cologne, Germany*
[c] *Department of Exercise Science, University of Massachusetts, Amherst, MA, United States*

ARTICLE INFO

Article history:
Available online 18 April 2014

PsycINFO classification:
2260
3720

Keywords:
Running
Biomechanics
Foot strike
Barefoot
Shod
Functional data analysis
Cluster analysis

ABSTRACT

The purpose of the present study was to test for differences in ankle plantarflexion strengths of habitually rearfoot and forefoot runners. In order to approach this issue, we revisit the problem of classifying different footfall patterns in human runners. A dataset of 119 subjects running shod and barefoot (speed 3.5 m/s) was analyzed. The footfall patterns were clustered by a novel statistical approach, which is motivated by advances in the statistical literature on functional data analysis. We explain the novel statistical approach in detail and compare it to the classically used strike index of Cavanagh and Lafortune (1980).

The two groups found by the new cluster approach are well interpretable as a forefoot and a rearfoot footfall groups. The subsequent comparison study of the clustered subjects reveals that runners with a forefoot footfall pattern are capable of producing significantly higher joint moments in a maximum voluntary contraction (MVC) of their ankle plantarflexor muscles tendon units; difference in means: 0.28 Nm/kg. This effect remains significant after controlling for an additional gender effect and for differences in training levels.

Our analysis confirms the hypothesis that forefoot runners have a higher mean MVC plantarflexion strength than rearfoot runners.

* Corresponding author. Address: Université Libre de Bruxelles, CP 210, local O.9.213, Bd du Triomphe, 1050 Bruxelles, Belgium. Tel.: +49 32 2650 5882.

E-mail address: dominik.liebl@ulb.ac.be (D. Liebl).

http://dx.doi.org/10.1016/j.humov.2014.03.008
0167-9457/

Furthermore, we demonstrate that our proposed stochastic cluster analysis provides a robust and useful framework for clustering foot strikes.

1. Introduction

There have been anecdotal claims from coaches and some runners that forefoot running leads to a strengthening of biological structures surrounding the foot and ankle complex and thereby has a protective character with respect to typical running injuries (Lieberman, 2012). Daoud et al. (2012) could show that in a group of competitive shod cross country runners repetitive stress injury rates were significantly lower for forefoot striking runners than for rearfoot striking runners. Another typical observation is that, e.g., sprinters, who are capable of producing high plantarflexion moments, use a forefoot strike even at moderate running speeds. In fact, Williams, McClay, and Manal (2000) showed that habitually forefoot running subjects show significantly higher initial sagital ankle joint plantarflexion moments than habitually rearfoot running subjects. While all this suggests that there might be a systematic relationship between footfall patterns and the strength of the lower extremities, this relationship has not been investigated and tested yet.

This kind of hypothesis demands for data of subjects that were allowed to use their preferred footfall patterns—an issue which demands for an ex-post classification of the subjects' footfall patterns. This ex-post classification step is crucial, but often treated novercally. In fact, reliability of the chosen classification procedure is a necessary precondition for any subsequent inferential comparison study.

Generally, classification of footfall patterns can either be done visually, using sagittal plane high speed video camera data (e.g., Hasegawa, Yamauchi, & Kraemer, 2007), or on basis of quantitative data. The latter is often preferred in academics—presumably, due to its supposed objectivity. Researchers, who want to rely their judgment on quantitative data, usually use a combination of ground reaction force information and foot kinematics, which describe the initial landing of the feet on the ground. For example, Gruber, Umberger, Braun, and Hamill (2013) use the strike index (SI), ankle angle, and the vertical ground reaction force (GRF) at initial foot–ground contact. Classification of the footfall patterns is then done on basis of some ad hoc decision rules. Unfortunately, just these ad hoc decision rules run the risk of compromising reliability and, particularly, have to be used with caution in inferential studies. In the following, we use the example of the SI in order to discuss the general problem.

The SI of Cavanagh and Lafortune (1980) is the most established measure to quantify foot strikes, where foot strike classification is performed using a 1/3-decision rule: If the SI indicates an initial foot–ground contact in the rear, middle or front third of the subject's foot, the subject is classified as rearfoot striking (RFS), midfoot striking (MFS) or forefoot striking (FFS). This 1/3-decision rule constitutes a widely accepted, well interpretable ad hoc classification procedure.

The main problem with respect to the 1/3-decision rule is visualized in Fig. 1, where we show two scatter plots of the SI-points of the sample of subjects used in this study. Obviously, the scattered SI-points and the corresponding kernel density estimates indicate that there are actually clusters in the SI data of shod/barefoot running subjects. These clusters are likely to represent distinct footfall strategies. Unfortunately, the 1/3-decision rule does not account for these SI-clusters, but truncates them. This kind of truncation leads to groups of subjects with inhomogeneous SI values and the consequential truncation bias is likely to harm any further statistical inferential study (e.g., Cohen, 1991).

Besides this, there is also a conceptual problem with respect to variables like the SI, ankle angles, or GRF, when processed (only) at the initial foot–ground contact. It is indisputable that all of these variables allow for valuable quantitative descriptions of the footfall pattern. Though, it seems unquestionable that appropriate time-continuous statistics, generally shall do a better job in capturing the