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A footprint-based approach for the rational classification of foot types in young schoolchildren

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Abstract

Background: Discrepancy in the classification criteria among footprint parameters complicates attempts for rational classification of feet.
Objective: To develop a footprint-based classification technique for the rational classification of foot types by allowing simultaneous use of several parameters (co-classification).
Method: Static standing footprints were recorded from 132 schoolchildren. The Arch Index (AI), Martirosov's K Index (KI), Footprint Angle (FPA) and Chippaux-Smirak Index (CSI) were determined. *k*-means cluster analysis was applied to obtain individual classifications and co-classifications.
Results: Identification across classified foot types coincided with all parameters for 0.8–3.5% of the sample. Values ranged from 2.3 to 10.6% when classification coincided with three out of four parameters. The inconsistency between every initial individual classification and co-classifications corresponded to 15.2% for AI, 49.2% for KI, 41.7% for FPA and 48.5% for CSI.
Conclusions: The co-classification process indicated low percentages of correctly identified foot types from all parameters that suggest the dependence of the classification on the parameter of choice used to assess arch configuration. The AI gave the lowest percentages of misclassified cases during the co-classification process. The co-classification model with the 4-cluster solution is proposed and confidence limits are reported for a rational classification of feet in young schoolchildren.

Keywords: Footprint; Classification; Arch; Children

1. Introduction

Footprint parameters are capable of detecting the wide variation in foot morphology and provide information about the distribution of foot types [1–9]. Previous research [6,9] has used the shape of footprints to categorize foot types and has shown that the distribution of foot types was normal for approximately 85–88%, high-arched for approximately 7–10% and intermediary for 4.8–5.5% of young schoolchildren. Examination of the distribution of feet in schoolchildren demonstrated higher percentages of flat feet than normal feet during the first 5 years of age, which were reduced in the older age groups and a higher frequency of normal feet was observed [2,3]. However, in the former study, results indicated that the distribution of foot types could be sensitive to the footprint parameter used to assess the arch configuration [2]. Some foot types, e.g., pes planus or pes cavus, are well recognized as separate clinical entities [1]. On the other hand, it is generally believed that a relationship between foot shape and foot structure exists. Knowledge of the distribution of different foot types reflecting the existent variations in foot shape could prove to be useful in any attempt to examine this proposed relationship.

Despite the ongoing controversy about the reliability, validity and variation in the measurement techniques of the foot [10], footprint-based parameters are systematically used to assess the configuration of the arch [1,2,6–8,11–16]. The Arch Index (AI) has been one of the most cited footprint parameters in the literature. Recently, McCrory et al. [17] have shown that the AI provides a simple quantitative means of assessing the height of the medial longitudinal arch and explains 50% of the variance in arch height. Forriol and

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Pascual [2] have used the Chippaux-Smirak Index (CSI) [18,19] and the Footprint Angle (FPA) [20] parameters to classify the individual shapes of foot arches of schoolchildren between 3 and 17 years of age. Martirosov's K index (KI) [21] has been developed to be used in large-scale anthropometric studies in order to diagnose the condition of the medial region of the foot either in athletic or non-athletic populations.

Footprint-based parameters thus provide the required information to quantify the configuration of the foot arch. However, the discrepancy in the classification criteria used by every footprint parameter complicates any attempt to evaluate the shape of the foot using several parameters simultaneously. Moreover, given the fact that the distribution of feet will be dependent on the footprint parameter of choice as to the number of identified foot types (e.g., a 3-foot type distribution comprising of high, normal and low foot type in the case of AI), it appears straightforward to examine to what degree the classification of feet would be affected when several footprint parameters are simultaneously used in the classification process (co-classification).

This issue could be confronted with a classification process capable of identifying the structure in footprint-based data and providing groups distinct in composition. Cluster analysis is a technique that involves the identification of groups of cases, observations or data that are cohesive and separated from other groups [22]. The purpose of cluster analysis is to classify data of previously unknown structure into meaningful groupings [22]. Its strategy is structure-seeking in the sense that it seeks to identify a set of groups, which both minimize within-group variation and maximize between-group variation [23]. One class of nonhierarchical clustering methods is the *k*-means clustering procedure, where the number of groups or "clusters" to be formed should be determined in advance. It follows that the optimum number of clusters depends on the research purpose. However, when the desirable or hypothesized number of clusters can be specified, *k*-means cluster analysis seems more appropriate than the hierarchical clustering methods, because with the latter methods the clusters are nested rather than being mutually exclusive, since larger clusters may contain smaller clusters. As aforementioned, depending on the selected parameter, feet will be assigned to as many foot type groups as the parameter of choice determines. Furthermore, examining the combined use of several parameters in the classification process requires that the number of clusters represents the range of all possible identified foot type groups. *k*-means cluster analysis allows this possibility and could therefore be used to provide a footprint basis classification technique for the rational classification of the shape of the foot. This type of cluster analysis has been previously used as a classification technique for the purpose of identifying homogenous groups of morphological characteristics [24–27].

The purpose of this study was to develop a footprint-based classification technique for the rational classification of foot types in young schoolchildren and test this approach by examining possible differences between distributions obtained from initial individual classifications of footprint parameters and co-classifications.

2. Methods

2.1. Subjects

A random sample of 132 children from five primary schools participated in the study. A total of 25–30 children were randomly selected from the classes' name list (i.e. from the last three grades) in every school. The five schools were randomly selected from a pool of 65 primary schools of the A′ Directory Office of Primary Education of the Perfecture of Attica, Athens. Written informed consent was obtained from the school's principal and the responsible physical education teacher and research procedures were approved by the Hellenic Ministry of Education and the Ethical Committee of the University of Athens. All subjects had no history of lower limb injury and exhibited no major foot deformity. The sample comprised 67 boys and 65 girls, of mean age (S.D.), weight and height, 10.4 (0.9) years, 41.0 (9.3) kg, 143.1 (8.0) cm. Static footprints of both feet were obtained for each subject. Graphic prints were then reproduced onto grid paper and diverted into digitized images of high-spatial resolution. Standard technical computing software (AutoCAD, R14) was used to geometrically chart digitized images and calculate the selected parameters.

2.2. Static footprint collection method

The subject was asked to cover the sole of the feet with water-soluble ink and step onto a sheet of coated paper. Footprints were recorded from a standing full weight-bearing position. The graphic print was retrieved and the border of the image was immediately outlined in permanent marker to ensure that any future distortion of the print could be ignored. Three trials were obtained for each subject and the clearest print was used for further analysis. Criteria for rejection of the prints were the following: (a) if significant overshoot occurred during the transference of the body weight from the initial sitting to the final standing position, because in that case, the derived footprint parameters could be overestimated, and (b) if the subject's movement while acquiring the standing full weight-bearing position caused a significant degree of distortion to the print. In total, 264 (132 subjects × 2 feet) footprints were analyzed. Four parameters were determined from each footprint: AI, KI, FPA and CSI. The distributions of parameters for left and right foot were initially checked and were found normal. Paired *t*-tests were then used to examine any differences between left and right parameters. Results showed no significant differences for the three parameters (AI: $P = 0.63$; FPA: $P = 0.22$; CSI: $P = 0.48$), except for KI ($t = -3.709$, $P < 0.001$). However, both left (mean (S.D.) = 1.07 (0.11)) and right (mean (S.D.) = 1.11 (0.10)) mean foot values indicated the same