Research Article

Decision Trees: Linking Biomechanical and Developmental Characteristics of Preschool Idiopathic Toe Walkers: A Cross-Sectional Study

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Abstract

Background: Idiopathic Toe Walkers (ITW) show specific sensorimotor characteristics with different development, which requires foot, gait and developmental evaluation? Although algorithms facilitate their classification in clinical categories to select the best therapeutic options, decision trees would connect the diverse characteristics of preschool ITW and would help their early and comprehensive approach. The purpose of this study was to design decision trees and to propose their application in the ITW assessment and treatment.

Methods: Fifty-six ITW's (aged 3-6 years) completed this cross-sectional study. The children underwent an orthopaedic foot evaluation and were subjects of a clinical ankle evaluation, a pedobarographic gait analysis and a developmental test - *Cuestionario de Madurez Neuropsicológica Infantil* (CUMANIN) -. Decision trees were developed with the studied variables, by calculating their quality value.

Results: Different decision trees showed the interrelation between biomechanical and developmental variables in the studied ITW. Predictor variables were calcaneal pronation, passive ankle dorsiflexion, percentage of impulse of the forefoot, contact time of the hind foot, peak pressure under lateral area of the right hind foot and the CUMANIN Overall Development farthing.

Conclusion: The decision trees obtained, with high values of quality, demonstrated that the older ITW had a top orthopaedic risk and an inferior level of development. Decision trees allow the integration of biomechanical and developmental variables in the assessment and treatment of the ITW, but their validation in a larger sample is necessary.

Keywords: Idiopathic toe walking; Pedobarography; Foot; Development; Gait; Algorithms

Abbreviations

ITW: Idiopathic Toe Walkers; DF: Dorsiflexion; CUMANIN: *Cuestionario de Madurez Neuropsicológica Infantil*; RCSP: Relaxed Calcaneal Stance Position

Introduction

Idiopathic toe walking is the condition of a tip-toe gait, considered abnormal in children older than three [1-3]. These children usually called idiopathic toe-walkers (ITW) often show alterations in other developmental areas. Their specific characteristics can lead complications such as shortened Achilles tendon, structural abnormalities, and deteriorated balance and development [1,2,4,5].

Authors evaluating ITW mainly focus on the static ankle dorsiflexion (DF) and gait [6] to determine the most appropriate clinical approach [2]. In this term, Armand et al. showed the usefulness of decision trees for the identification and classification of tiptoe gait, in both idiopathic and secondary tiptoe walking patterns [7]. The same authors associated potential causes of tiptoe gait and its clinical characteristics with the gait pattern [3].

Several authors highlighted the developmental testing of ITW [4,5,8] because of the underappreciated severity of this pathology [1]. In this sense, the pedobarographic gait analysis is widely used for its sensitivity to detect children incipient alterations and could be a useful tool in the early evaluation of the ITW [9-12].

The combination of the clinical, gait analysis and developmental evaluation could offer a better characterization and therapeutic indication of the ITW [3]. To our knowledge, the exceptional attempts to provide links between ITW biomechanical and developmental characteristics have just described the symptoms without demonstrating a relationship between these characteristics or the impact of planning a treatment, other than the recommendation of a global approach [2,4,5,13]. Thus, the purpose of this paper was to link clinical, developmental and pedobarographic gait pattern characteristics of preschool ITW, in order to aid clinical practitioners when choosing the best ITW evaluation and treatment plan.

Materials and Methods

One hundred and fifty-one ITW (3 – 6 years old) were evaluated for this prospective investigation (via specific advertising) from

February to July 2010. Both clinical and developmental examination and the pedobarographic gait analysis were performed by the same two experts and experienced Physiotherapists in the Physical Therapy Unit of the Clinic of Chiropody of the local university. The inclusion criteria were to have: toe-walking since the gait beginning; current toe-walking; absence of heel rocker assessed by observational gait analysis; and ability to heel contact on request [5,6,14]. The exclusion criteria included trauma, neurological or developmental disorders, unilaterally tiptoe gait, and previous treatment for tiptoe gait. According to these criteria, we finally selected 56 children.

Parents signed the informed consent before beginning the study according the Declaration of Helsinki (De Helsinki, 2008). This cross-sectional study was approved by the Clinical Investigation Ethics Committee of the local university, with registration number F (EFP)-001/2010.

Pedobarographic gait analysis

Pedobarographic gait analysis was performed using Foot scan USB Gait Clinical System® (2 m x 0.4 m x 0.02 m, 16384 sensors, 500 Hz, and 3 sensors per cm²), embedded in a 9 meters experimental walkway. Children were asked to walk onto the gait track looking at the front and at a comfortable speed, after they had being walking in the room for a minute. At least 10 whole footprints of both feet were recorded and their average was used for the analysis. Analyzed variables were calculated directly by the system by means of the automatic division in foot zones [9-12,15,16]. Studied variables were maximum and peak pressure, percentage of impulse and contact time of the hindfoot, midfoot and forefoot, and gait angle of both feet.

Clinical assessment

Clinical examination including the measure of the popliteal angle, the passive ankle DF, both with extended and flexed knee and the relaxed calcaneal stance position (RCSP) [17,18]. Angular measurements were obtained using a handheld goniometer, with modalities which have demonstrated to go from moderate to high reliability. Position and methodology of measurement were respected, avoiding compensations and following the main recommendations to increase reliability measurement [17,19].

Developmental evaluation

Developmental evaluation was performed by *Cuestionario de Madurez Neuropsicológica Infantil* (CUMANIN), test validated in Spain that evaluate cognitive functions, language, motor, perceptive and laterality aspects 20. Global and specific scales results can be expressed as farthings with respect to the reference population. For this study, Motor Skill Scale and Overall Development farthing and foot laterality was used. Overall Development farthing results from the addition of Articulatory, Expressive and Comprehensive Language scales and Motor Skills, Spatial Structuring, Visopercepcion, Memory and Rhythm Scales. CUMANIN has been described as a useful tool for developmental evaluation in some Spanish researches studying different samples of children, both with and without disorders [20-22].

Sample characteristics

Fifty-six children (age: 54.7 + 12.17 months; Weight: 19.56 + 3.49 kg; Height 1.09 + 0.08 m; Body Mass Index: 16.46 + 1.49) were recruited for this study corresponding to 112 lower limbs.
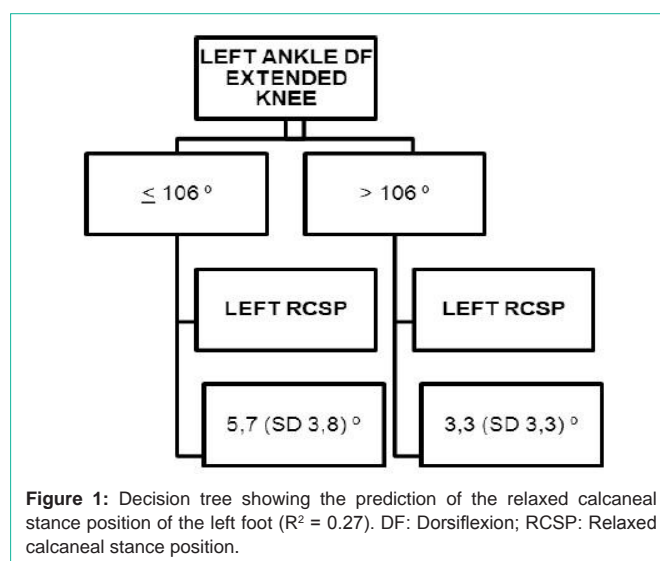

Figure 1: Decision tree showing the prediction of the relaxed calcaneal stance position of the left foot (R^2 = 0.27). DF: Dorsiflexion; RCSP: Relaxed calcaneal stance position.
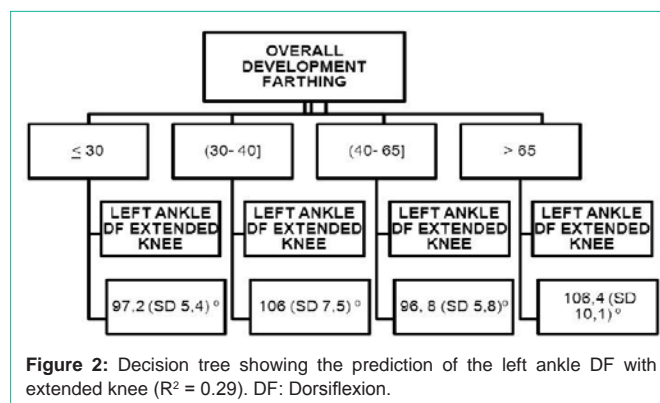

Figure 2: Decision tree showing the prediction of the left ankle DF with extended knee (R^2 = 0.29). DF: Dorsiflexion.

Pedobarographical values could not be shared with studies with the same analysis system, but they appear to be similar to other studies [9,11,12,15]. All orthopaedic and developmental variables were within normal range for similar population, with 64.8% of the ITW showing a right foot laterality [13,23,24].

Statistical analysis

Decision trees were elaborated and their quality value (R^2 coefficients) was calculated throughout SPSS v.19.0 Software for Windows. For all tests p-values < 0.05 (IC 95 %) and < 0.001 (IC 99 %) were considered statistically significant.

Results

Decision trees showed a relationship between some of the studied variables, because some of them could be predicted by others. In this way, left ankle DF with extended knee predicted left RCSP (Figure 1). Right RCSP could not be predicted by any studied variable.

Left ankle DF predicted CUMANIN Overall Development farthing. Right ankle DF predicted CUMANIN Overall Development farthing and also the peak pressure under lateral area of the hindfoot resulted in a predictive variable in the case of children who have obtained a farthing lesser than 65 (Figures 2 and 3).

The percentage of impulse of the left forefoot predicted the percentage of impulse of left hindfoot, whereas the percentage of
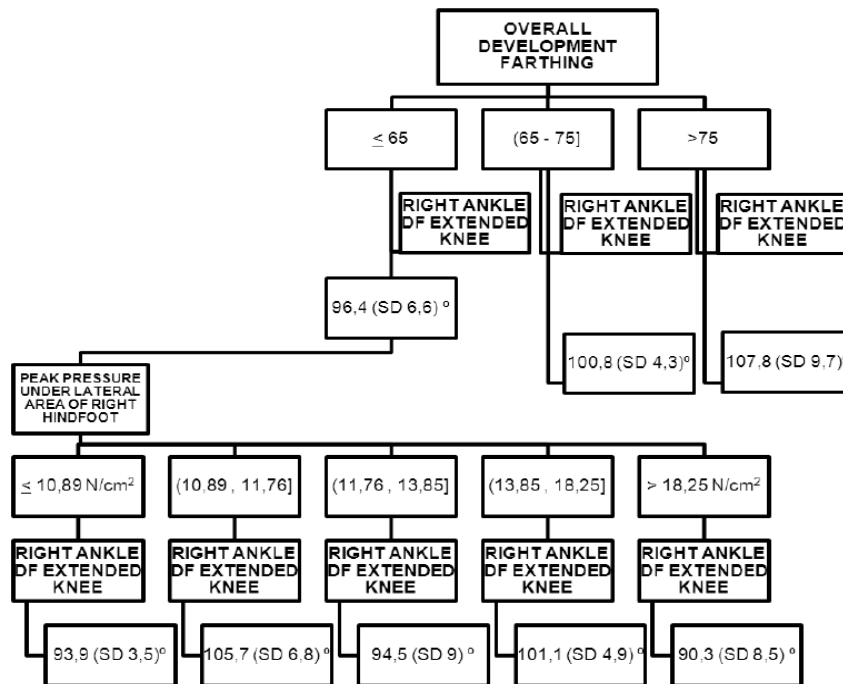
Figure 3: Decision tree showing the prediction of the right ankle DF with extended knee ($R^2 = 0.49$). DF: Dorsiflexion.
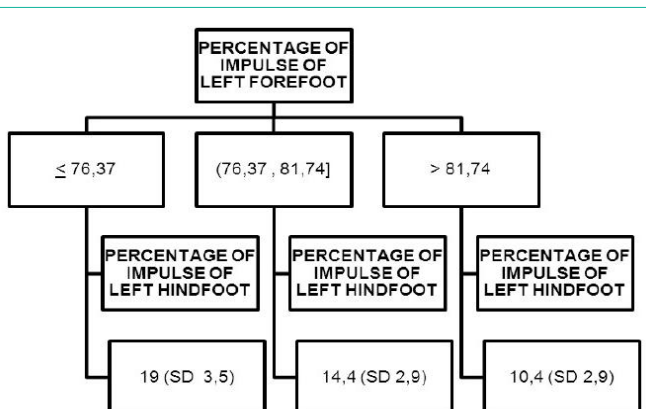

Figure 4: Decision tree showing the prediction of the percentage of impulse of the left hindfoot ($R^2 = 0.58$).
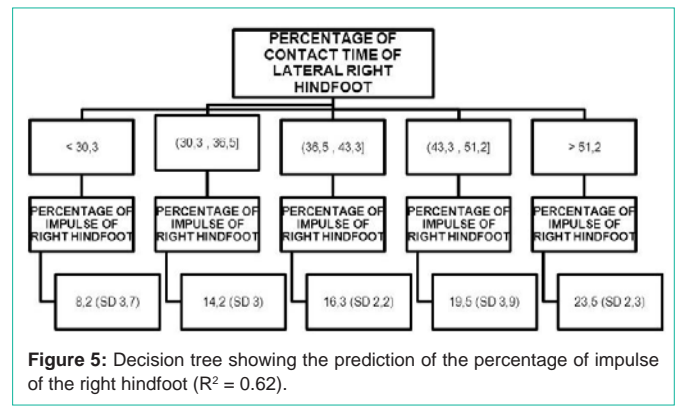

Figure 5: Decision tree showing the prediction of the percentage of impulse of the right hindfoot ($R^2 = 0.62$).

contact time of the right lateral hindfoot predicted the percentage of impulse of right hindfoot (Figures 4 and 5).

ITW age, expressed in months, predicted CUMANIN Overall Development farthing when left lower limb variables were analyzed. Moreover, left RCSP also had a predictive value in children under 45 months old or at that age (Figure 6).
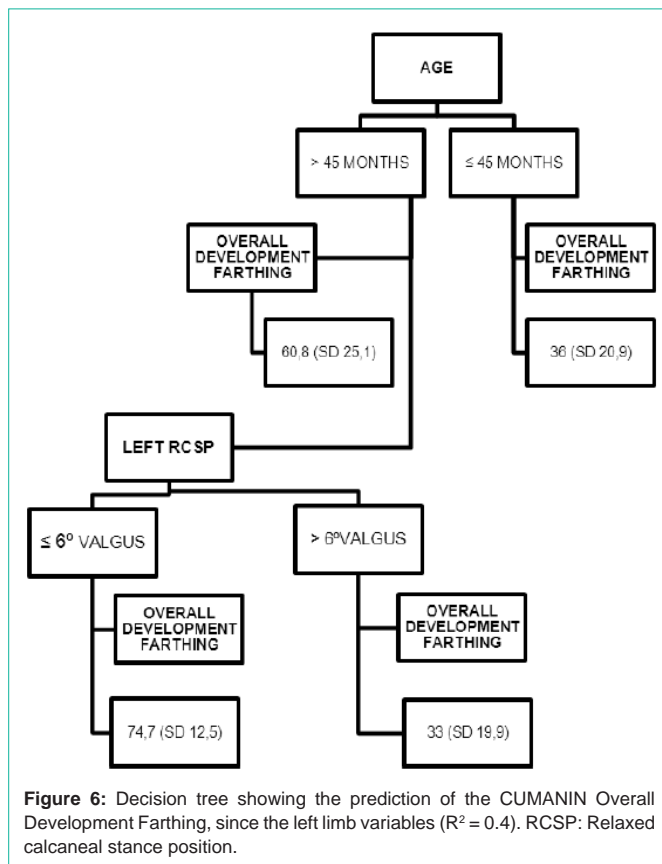
Discussion

The interaction between clinical, pedobarographic and developmental variables has been analyzed using decision trees, for their interest in the clinical setting when classifying patients according to their characteristics and for its recent use when trying to understand the links between the different patterns that occur on tiptoe gait caused by different disorders [3,7,25]. Using these models has allowed us to evaluate the predictable value of different variables,

with regard to those that are considered as fundamental for the evaluation of ITW [2,4,14].

Between these variables, left RCSP could only be predicted by ankle DF with extended knee (Figure 1). ITW with a lower DF presented a major calcaneal eversion, but within the normal limits for the studied population [19,26]. This fact shows the relationship between lower gastrosoleus elasticity and the foot pronation already described in previous literature [27], and confirmed recently in a ITW sample [14].

The main predictive variable of the passive ankle DF with extended knee was the CUMANIN Overall Development farthing, as well as the peak pressure under the lateral area of the right heel in children with a lower Overall Development farthing (Figure 2 and 3). In our sample, the ITW with an Overall Development farthing less than the 65th presented ankle DF values inferior to 100°, the minimum range considered as necessary to carry out a physiological gait [7]. These results could be related to frequent finding of persistent tiptoe gait in

Figure 6: Decision tree showing the prediction of the CUMANIN Overall Development Farthing, since the left limb variables ($R^2 = 0.4$). RCSP: Relaxed calcaneal stance position.

children with severe developmental disorders [28].

The percentage of impulse of the hindfoot was predicted by the percentage of impulse of the forefoot on the left foot, with an inverse relationship between both variables (Figure 4). This inclination in applying the impulse mainly by the forefoot in the ITW has been partially defined by other authors as a characteristic advancement of load during gait [2,7]. On the right foot, the percentage of impulse of the hindfoot was predicted by its percentage of time support (Figure 5), confirming the direct relationship between impulse and contact time [15]. Pedobarographic gait variables has not been linked with ankle FD, according to other contributions carried out with different gait analysis systems [2,16,29,30] while a static correlation has been recently stabilised [14].

The differences between the two feet could be related to the functions of "load" and "dynamic" that are adopted by the left and the right foot, respectively, according to the laterality and which cause asymmetries that have been associated with different degrees of severity in ITW 2. In this investigation both feet have been analyzed separately because of the absence of an unanimous criterion to choose the foot of study in other pedobarographic studies [9,12]. In our sample, there are slight asymmetries between the two feet, similar to those found in children without alterations and which have proved to be transient [31]. These characteristics have caused different interrelations between variables of the two lower limbs, which show the importance of always taking into account all variables in both limbs [2].

CUMANIN Overall Development farthing could only be predicted by age, with an inverse relationship that had not been reflected in any of the revised studies [4,5,8,13]. The younger ITW who had also a more pronated hindfoot, with a left RCSP in valgus higher than 6°, had also had a lower development (Figure 6). In this way, child's age has only been linked with RSCP, an association that some authors have discussed in children without alterations [26], and CUMANIN Overall Development farthing. Although this relation between age, foot pronation and development is unknown in previous ITW literature as far as we know, some authors have demonstrated more limited ankle DF with growing [13,32]. Furthermore, rising on the prevalence of minor developmental disorders with increasing age has been confirmed by some studies in other groups of children, because of the generally more complex tasks that are required in older children developmental evaluation could help to reveal light disorders such as minimal cerebral dysfunction [21].

These results showed that there was a higher orthopaedic risk in the older ITW, due to the limitation of the ankle DF and the hindfoot pronation, and a minor development. This association has been partially discussed in several papers but without conclusive results [2,4,13,32,33]. Relation between orthopaedic, gait and developmental variables highlights the priority of considering in the ITW evaluation the developmental alterations as well as the biomechanical ones. Nevertheless, pedobarographic gait variables have not demonstrated any predictive link with others, except peak pressure under the lateral area of the right hindfoot, and the ITW gait pattern appears not to have almost any relation with development nor static measures, in accordance with other studies [2]. At last, some studied variables have not shown any predictive relation with the other variables in our sample, such as popliteal angle, ankle DF with flexed ankle, mean hindfoot pressure, percentage of impulse and contact time of the midfoot, percentage of contact time of the forefoot, gait angle and CUMANIN Motor Skills Scale farthing.

Although these estimation models need to be validated to obtain definitive conclusions that lead to clinical decision-making, these results are in accordance with previous literature [2,4,8,13,33]. Our decision trees could be useful to establish the adequate evaluation and also the aims and modalities of a more appropriate treatment in the ITW. Prospective longitudinal studies with larger cohorts would improve the knowledge about the natural history of the ITW and the possible prognostic factors. The implication of a multidisciplinary team would facilitate a deeper analysis, enabling the integration of the various aspects of children's development and their behavioral changes, both from the biomechanical and the developmental point of view [13]. This would make it possible to propose protocols for evaluation and therapeutic approaches suitable to the whole characteristics of the ITW and to assess their validity and effectiveness.

Conclusion

The present study highlights the links between orthopaedic, gait and developmental characteristics in the studied ITW. Different algorithms showed the interrelation between biomechanical and developmental variables, improving the knowledge repository of this frequent gait deviation. Calcaneal pronation, passive ankle dorsiflexion, percentage of impulse of the hindfoot and forefoot, contact time of the hindfoot, peak pressure under the lateral area of the right hindfoot and the CUMANIN Overall Development farthing

were predictive variables. These results, with high quality values, also showed that the older ITW had a top orthopaedic risk and a fewer developmental level. Although these estimation models should be validated to achieve definitive conclusions, these decision trees could be useful to support tip-toe gait interpretation and to establish the more appropriate ITW evaluation and therapeutic approach.

Acknowledgement

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