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Comprehensive non-dimensional normalization of gait data

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ABSTRACT

Normalizing clinical gait analysis data is required to remove variability due to physical characteristics such as leg length and weight. This is particularly important for children where both are associated with age. In most clinical centres conventional normalization (by mass only) is used whereas there is a stronger biomechanical argument for non-dimensional normalization. This study used data from 82 typically developing children to compare how the two schemes performed over a wide range of temporal-spatial and kinetic parameters by calculating the coefficients of determination with leg length, weight and height. 81% of the conventionally normalized parameters had a coefficient of determination above the threshold for a statistical association ($p < 0.05$) compared to 23% of those normalized non-dimensionally. All the conventionally normalized parameters exceeding this threshold showed a reduced association with non-dimensional normalization. In conclusion, non-dimensional normalization is more effective that conventional normalization in reducing the effects of height, weight and age in a comprehensive range of temporal-spatial and kinetic parameters.

1. Introduction

It is often desirable to normalize clinical gait analysis data to make a more clinically meaningful comparison of data from individuals with different dimensions and body mass. The variance of temporal-distance parameters such as stride length and cadence, for example, includes differences due to height as well as the natural variability of the population. The effect of differences in mass and segmental moments of inertia may similarly affect force, moment and power data [1]. The variation in such body parameters is particularly pronounced in children. Use of appropriate normalization techniques may be particularly important when monitoring progress or outcomes from surgery of other interventions over periods during which the child may have grown.

A range of different normalization techniques were proposed by O'Malley in 1996 [2]. In this paper, normalization was treated as a two-step process: first a model for the data was developed and then data were normalized with respect to the model. The main problems with this approach are that it needs to be applied separately to every variable and dataset under investigation, gives no insight into the underlying mechanisms through which size variation affects walking and rigorous validation requires testing on a dataset separate to that used to develop the normalization scheme.

Hof [3] suggested non-dimensional normalization (NDN) in which measurements are rendered dimensionless by dividing each parameter by combinations of body mass, leg lengths and gravitational acceleration. The resulting variables are often referred to as non-dimensional variables. This provides a general conceptual basis for normalizing all gait analysis variables but is essentially a hypothesis about how they vary with body size that requires experimental validation.

Hof and Zijlstra [4] provided the first such validation illustrating that non-dimensional cadence and stride length remain constant after the age of 3 until adulthood. Pierrynowski and Galea [5], demonstrated (in sample of 10), that inter-subject variability was reduced by non-dimensional normalization in a group of patients with significant variation of their body parameters (heights and weights). Stansfield et al. [6], tested how different normalization techniques affect correlations between a range of temporal-spatial parameters and factors, such as speed and age and concluded, through this rather oblique analysis, that non-dimensional normalization was preferable to semi-dimensional normalization. Moisio et al. [7] showed that appropriate normalization of joint moment

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data reduced the dependence on height, weight and speed and gender substantially in adults. Schwartz et al. [8] have also demonstrated that non-dimensional normalization techniques can be applied effectively to Oxygen consumption and cost data. There has, however, been no previous study to test non-dimensional normalization comprehensively across the range of clinically important gait variables in children and this is the aim of this paper.

2. Materials and methods

Data from typically developing children over an age range of 4–17 were analysed. This dataset was previously captured and analysed as described in Schwartz et al. in 2008 [9]. In summary, participants were given general instructions to walk at very slow, slow, self-selected comfortable (free), and fast walking speeds during a single testing session. The order of the speeds was not prescribed, other than collecting the free speed data first. Only data from free walking speed was included in this analysis. All data had been collected with a Vicon kinematic measuring system (Oxford, UK) and AMTI force plates (Watertown, MA, USA). Trajectories had been filtered with a Woltring spline filter [10] and then processed using Plug-in Gait [11] software (Vicon, Oxford, UK). A subset of the data related to barefoot walking at self-selected walking speed has been used as a basis for this analysis. Weight, leg length (ASIS to medial malleolus) and age data were also recorded.

3. Parameters

From these data 26 parameters were calculated. Three were the basic temporal and spatial parameters: walking speed, cadence and step length defined as the longitudinal distance between the contact of one foot and the contact of the other foot. 23 key features were chosen from hip, knee and ankle moment (14 features) and power (9 features) traces (see Fig. 1).

It is widespread clinical practice (e.g., output of PlugInGait, VICON, UK) to normalize kinetic variables with respect to mass only and this is referred to here as conventional normalization (CN). This was compared with non-dimensional normalization [3,NDN] as described in Table 1. It should be noted that angle is inherently non-dimensional being the ratio of one length (arc) to another (radius) and joint kinematics have thus not been included in this analysis.

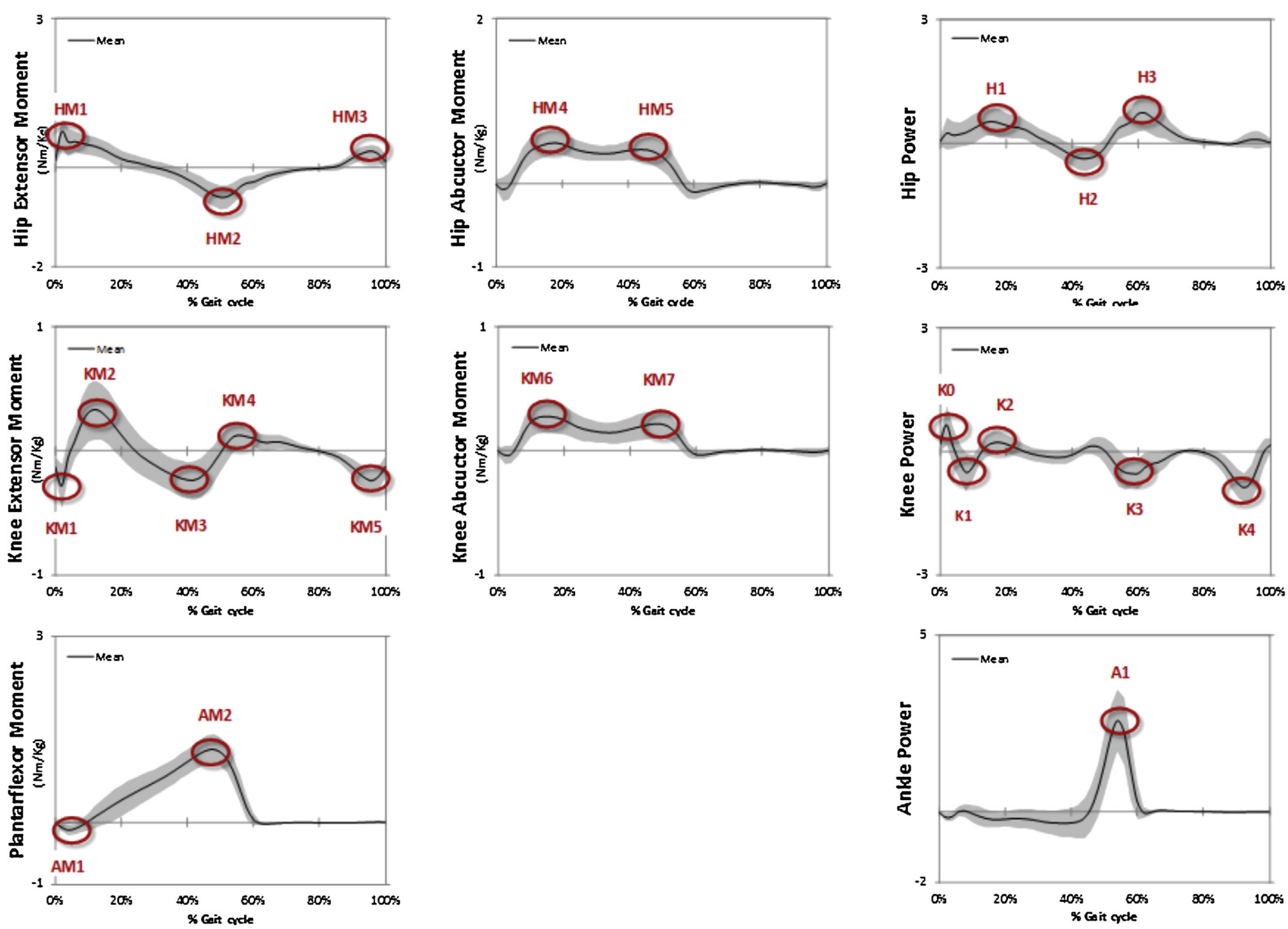

Fig. 1. Kinetic parameters selected for analysis in this study (mean–solid line and +/− one standard deviations–shaded area). All are defined as maximum values over a particular interval of the gait cycle. HM1/3, maximum hip extensor moment in first half of stance/second half of swing; HM2, maximum hip flexor moment in second half of stance; HM4/HM5, maximum hip abductor moment in first/second half of stance; KM1/3/4, maximum knee flexor moment in first double support/single support/second half of swing, KM2/4 maximum knee extensor moment in first/second half of stance; KM6/7 maximum knee abductor moment in first/second half of stance; AM1/2 maximum dorsiflexor/plantarflexor moment in stance; H1, maximum total hip power generation in between opposite foot off (OFO) and mid-stance; H2 maximum total power absorption in second half of stance; H3, maximum hip power generation between mid-stance and mid-swing; K0/2, maximum total knee power generation in first double support/between OFO and mid-stance, K1/3/4. Maximum total knee power absorption in first half of stance/second half of stance/second half of swing; A1, maximum total ankle power generation in second half of stance.