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Original article

Collection of normative data for spatial and temporal gait parameters in a sample of French children aged between 6 and 12

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ABSTRACT

Objective: Normative data on gait is essential for clinical practice – especially in children whose gait pattern changes over time. Sets of normative gait data in healthy children vary significantly from one country to another. We decided to generate a specific reference database of gait parameters for French children.

Method: Three hundred and eighty-two children (228 boys and 154 girls, aged between 6 and 12) were asked to walk as naturally as possible and at a self-selected speed on a GAITRite® track. Velocity, step count, cadence, step time, step length, cycle time, stride length, base width, swing time, stance time, single support time and double support time were recorded. Parameters were analyzed by age group, height group and BMI.

Results: Velocity, step and stride length increased regularly with advancing age and height. Cadence decreased with height. All temporal parameters (except for double support) differed significantly ($P < 0.05$) when comparing the 6-year-old group or the 7-year-old group with the 9-year-old group and older groups. A small number of temporal parameters (cadence, step time, cycle time and stance time) differed significantly when comparing 7-year-olds and 8-year-olds. Temporal parameters appeared rise in proportion height from 110 cm to 130 cm and then reached a plateau. Overweight was associated with a longer stance time and more double support.

Conclusion: The gait pattern in French children aged between 6 and 12 differs from those recorded elsewhere in the world; although gait parameters appear to change in much the same way with age worldwide, our values (even when normalized) are different. Our local database should be of value in French studies of childhood gait disorders. Given that gait patterns do not appear to mature by the age of 12, it would be valuable to study gait patterns in a population of teenagers.

1. Introduction

Gait is a complex but unconscious motor pattern that forms part of the human identity. It is therefore important to characterize an individual's gait and understand how the gait pattern is acquired during childhood (i.e. how infants and children build their gait pattern with age). This type of knowledge is critical for assessing healthy development. One key question concerns maturation of the gait pattern in developing children, and so there always a need for normative values in the assessment of normal development. Indeed, it is important to build a reference database for comparison of changes over time in a child's gait.

A number of studies have generated reference data on gait patterns in children in various several countries: Dusing and Thorpe (438 children in the USA) [1], Holm et al. (360 children in Norway) [2], Lythgo et al. [3], Lythgo et al. [4] (980 children in Australia), and Moreno-Hernández et al. (120 children in Mexico) [5]. As already noted by Moreno-Hernández et al., anthropomorphic differences between countries and especially between continents (Europe vs. Australia vs. Central America) might be associated with significant differences in gait parameters. Hence, there is always a need for robust local reference data.

Changes in gait parameters during childhood have also been investigated. Most of the studies in the literature included large

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groups of children, with ages ranging from 5 to 13. The critical parameter is usually the maturation of gait parameters, in order to link the changes in gait over time to the achievement of an adult pattern. However, divergent conclusions have been drawn: although Sutherland et al. [6] suggested that the gait pattern matured at just 3 years of age, most studies have found that gait parameters start to stabilize at around 7 years of age [1–4]. In contrast, Ganley and Powers [7] reported that 7-year-old (y.o.) children may lack the neuromuscular maturity required for an adult-like gait pattern. Correct assessment of the age at which gait parameters start to level off requires the observation of a large population of children (such as those studied by Lythgo et al. and Holm et al.), in order to build single-year age groups.

The primary objective of the present study was to generate a relevant, local reference database on spatiotemporal gait parameters in French children. The study's secondary objective was to include enough children to build single-year age groups and thus assess spatiotemporal gait parameter as a function of age and height.

2. Materials and methods

2.1. Participants

Children aged between 6 and 12 were recruited into the study between August 2008 and April 2009. Written, informed consent to participation was provided by the parents in all cases. The children were attending a summer camp in northern France, and all had a medical certificate authorizing their participation in leisure sports. Anthropometric data (weight, age and height) were also recorded. Children wearing orthopaedic soles or presenting with claudication or pain while walking at the screening visit were not included.

2.2. The gait analysis protocol

Verbal instructions were given to all participants prior to the experimental session. The children were asked to walk as naturally as possible at self-selected speed on a GAITRite® track (CIR Industries, Clifton, NJ, USA). The total recorded walking length was 7 m, with one additional meter at the start and several additional meters at the end to allow proper acceleration and deceleration. All the children walked barefoot and trousers were folded to above the knee as required.

The following parameters were recorded or calculated: velocity, step count, cadence, step time (sec), step length (cm), cycle time (sec), stride length (cm), base width (cm), swing time (sec), stance time (sec), single support time (sec), and double support time (sec).

2.3. Data pre-processing and analysis

All statistical analyses were performed using MATLAB (Mathworks, Natick, MA, USA) and the Statistical Toolbox. Firstly, a number of parameters were tested for left/right similarity: step time, step length, cycle time, stride length, base width, swing time, stance time, single support time, and double support time. The correlation coefficients were all above 0.9, and so left-foot values and right-foot values for these parameters were averaged into a single dataset for each participant (as already proposed in the literature [1,5]).

Secondly, gender differences were assessed. Datasets were sorted into groups of girls and boys of same age or same height category and then tested for a normal distribution in a Lilliefors test. Next, boy/girl differences were assessed using a *t*-test (for normally distributed groups) or a rank sum test (for non-normally distributed groups). None of the groups showed significant differences ($P < 0.05$), and so boys and girls were merged into the same age or height groups.

For each age and height group, the mean ± standard deviation were calculated for all parameters. Differences between age or height groups were assessed in a two-way analysis of variance. The threshold for statistical significance level was set to 5% and then lowered to 0.38% for tests with Bonferroni correction. Lastly, we attempted to perform the same analysis for BMI. Each age group was dichotomized into two subgroups: overweight and normal weight. A one-way analysis of covariance (ANCOVA) was performed in order to determine whether weight status (the independent variable: normal vs. overweight) had an influence on each gait parameter (the dependant variable) while controlling for age (the covariate). The criteria for application of an ANCOVA were met. Overweight (obesity stage 1 and stage 2) was defined according to the criteria issued by the *Institut national de prévention et d'éducation pour la santé* (the French National Institute for Health Prevention and Education).

3. Results

Measurements were made on a total of 382 children (228 boys and 154 girls; age range: 6 to 12). The study population's anthropometric and spatiotemporal data are summarized in Table 1.

In order to explore the results in detail, the children were sorted by age (6 to 12, in single-year groups) and by height (110–119 cm, 120–129 cm, 130–139 cm, and 140–149 cm). Temporal and spatial data are presented by age group in Fig. 1 and by height group in Fig. 2. Fig. 1 shows the change over time in spatiotemporal gait parameters with age, sorted into 1-year age groups. Spatial parameters (velocity, step and stride length) increased regularly with advancing age. However, for each parameter, the differences

Table 1
Characteristics of the study population by age group. The data are presented as the mean (standard deviation).

Age in years	Gender	Number	Height (cm)	Weight (kg)	Velocity (cm/s)	Cadence (steps/min)	Step length (cm)	Step length (cm)
6	Female	20	120.9 (6.9)	23.3 (5.4)	94.7 (17.4)	120.6 (17.4)	47.8 (7.3)	46.3 (4.2)
6	Male	41	119.0 (6.1)	23.2 (4.5)	97.0 (19.3)	127.3 (17.5)	45.6 (6.4)	45.8 (6.4)
7	Female	20	124.3 (5.8)	23.8 (3.3)	107.0 (16.9)	128.0 (14.0)	50.6 (7.1)	50.0 (6.8)
7	Male	33	125.6 (4.5)	26.4 (3.9)	101.1 (18.6)	127.1 (17.1)	50.5 (5.8)	50.5 (5.5)
8	Female	22	131.5 (4.9)	27.9 (7.6)	101.3 (18.6)	118.2 (16.1)	50.8 (5.0)	51.7 (5.5)
8	Male	34	132.2 (5.6)	26.7 (9.6)	107.6 (17.2)	115.5 (16.5)	55.7 (6.0)	56.5 (7.8)
9	Female	27	137.3 (8.0)	33.6 (6.8)	110.5 (18.4)	119.1 (9.3)	55.5 (6.9)	55.6 (6.3)
9	Male	30	137.6 (6.2)	31.9 (5.7)	105.9 (23.2)	113.4 (19.7)	55.5 (5.9)	56.0 (6.1)
10	Female	20	144.8 (8.3)	37.6 (6.5)	116.5 (14.9)	119.1 (9.3)	58.6 (4.0)	58.3 (5.6)
10	Male	34	143.5 (6.9)	37.4 (6.7)	110.5 (19.6)	112.9 (12.6)	58.6 (5.7)	58.3 (5.6)
11	Female	20	151.5 (6.8)	41.1 (5.8)	122.1 (16.1)	117.5 (12.5)	62.5 (5.2)	62.2 (4.2)
11	Male	34	148.1 (6.7)	39.2 (6.5)	114.4 (18.5)	112.3 (13.4)	60.6 (5.8)	61.4 (6.1)
12	Female	25	154.9 (5.6)	47.8 (9.9)	128.6 (13.0)	117.5 (5.6)	65.6 (5.0)	65.6 (4.6)
12	Male	22	152.2 (8.1)	45.5 (7.6)	116.8 (13.7)	114.9 (9.4)	60.5 (5.6)	61.6 (6.2)