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RAPID COMMUNICATION

Validity of Functional Ambulation Performance Score for the Evaluation of Spatiotemporal Parameters of Children's Gait

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ABSTRACT. Gait characteristics of a healthy adult population have been used to develop the Functional Ambulation Profile (FAP) score to evaluate gait in patients with neuromuscular or musculoskeletal involvement (A. J. Nelson, 1974). Further technological progress allowed a more precise recording of walk parameters and propitiated the development of the Functional Ambulation Performance Score (FAPS). The authors aimed to explore the evolution of the FAPS in healthy children to determine what the lower limit of age would be to ensure reliability of this score. Participants were 32 children with normal development. A GAITRite® walkway was used to log the spatiotemporal parameters. Compared with values obtained in adults, the average FAPS was significantly lower for children under 12 years old. The interparticipant variability was particularly high for the younger children and decreased with age. Similar trends were observed regarding the intraparticipant variability. In conclusion, the authors observed that the FAPS is not suitable to compare the gait of different children younger than 12 years old. At least, the adult standards used to calculate FAPS would need to be modified if the score has to be applied to a pediatric population.

Keywords: children's motor development, gait

Different methods are available to assess gait variations in children with motor impairment. Methods based on questionnaires such as the Functional Assessment Questionnaire (FAQ; Novacheck, Stout, & Tervo, 2000), scales of gait abilities such as the Functional Mobility Scale (FMS; Graham, Harvey, Rodda, Nattrass, & Pirpiris, 2004), or simplified visual tests such as the Edinburgh Visual Gait Score (Hillman, Hazlewood, Schwartz, van der Linden, & Robb, 2007) provide a qualitative assessment of gait capacity. Because these evaluation forms are usually completed by parents or clinicians, the obtained data may lack objectivity and reliability. Techniques based on quantified analysis of gait provide more accurate and detailed data. To integrate data and provide with a single, numerical representation of gait, different scores and indexes have been elaborated. For example, 15 kinematic features are used to calculate the Gait Deviation Index (GDI; Schwartz & Rozumalski, 2008), a measure to evaluate the extent of gait deviations from normal gait. Its predecessor, the Gillette Gait Index (GGI; Schutte, Narayanan, Stout, Selber, Gage, & Schwartz, 2000), included spatiotemporal parameters (STP) in addition to kinematic features. Definition of normal gait depends on normalcy of STP and kinematic parameters but also on adequate motor control. As stated by Schwartz and Rozumalski, it is possible, however, to walk with adequate stride parameters and still have significantly atypical joint motions and orientations. The reciprocal remark is also true: normal joint motions do not necessarily imply adequate spatiotemporal parameters. Because STP could be considered as an indicator of individuals' ability to control their gait, it appears evident that a score based on these parameters would be necessary to complete gait assessment.

Gait characteristics of a healthy adult population have been used to develop the Functional Ambulation Profile (FAP) score to evaluate gait in patients with neuromuscular or musculoskeletal involvement (Nelson, 1974). The first description of the FAP consisted of a three-part paper-and-pencil test based on the principle that walk ability depends on subordinated skills that can be identified and measured. In this way, each part of the test served to estimate a subskill of walking: to (a) provide a stable base of support in orthostatic position, on both legs and on each leg separately, with and without the hand's support; (b) transfer the body weight from one limb to the other in a rhythmical and rapid manner; and (c) alternately transfer the body weight when moving forward.

Further technological progress allowed a more precise recording of walk parameters and propitiated the development of the Functional Ambulation Performance Scores (FAPS). This score represents a quantification of patients' gait based on a selection of spatiotemporal parameters obtained at a self-selected speed (Gretz, Doering, Quinn, Raftopoulos, Nelson, and Zwick, 1998). The selected parameters are standard velocity normalized to leg length, step and leg length ratio, step time, right–left asymmetry of step length, and dynamic base of support. From a maximum score of 100, points are deducted according to the variations of the STP of the individual compared to the STP of a healthy population. FAPS ranges from 95 to 100 points in the healthy adult population. The reliability of FAPS using the GAITRite® System was reported by Gretz et al. FAPS has been used to evaluate gait and to estimate the risk of falling among elderly people (Nelson et al., 1999) and to assess gait variations in patients affected by Down syndrome (Gretz et al.), multiple sclerosis (Givon, Zeilig, & Achiron, 2009), Parkinson's disease (Nelson et al., 2002), and chronic stroke (Peurala, Titianova, Mateev, Pitkänen, Sivenius, & Tarkka, 2005). It was also used to estimate the progress of patients

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walking farther to a program of rehabilitation (Freedland et al., 2002).

Whereas the GGI and the GDI, based on a sample of the healthy population specific to every laboratory, have been validated for children (Molloy, McDowell, Kerr, & Cosgrove, 2010; Romei, Galli, Motta, Schwartz, & Crivellini, 2004), the validity of the FAPS has not been investigated for the pediatric population. Several reasons justify our interest in this participant:

- A conglomerate measure of the STP is necessary to provide clinicians the mean to evaluate the complexity of walk with a single, numerical representation. FAPS is, to our knowledge, the only score presently available.
- The GAITRite® System, implemented with FAPS, has been commonly used in gait labs to evaluate gait abnormalities in the pediatric population. The values that serve as a reference for the calculation of the FAPS had been obtained from the adult population. Normative values of STP obtained from the pediatric population may need to be integrated in the system.
- Although some studies reported in the literature (Degache, Perrier, Bayle, D'Anjou, & Gautheron, 2009) advocated the use of the FAPS in the pediatric population, they do not provide any validation data. Sutherland (1997) showed that normalized STP reach adult values by the age of 4 years, even though gait is not fully mature until 7 years. It is not certain whether changes in weight, height, and motor control influence STP values and thus the reliability of the FAPS in the pediatric population.

The aim of the present study was to explore the evolution of the FAPS in healthy children to determine what would be the lower limit of age in order to ensure the reliability of the score.

Method

Participants were 32 children with normal development and no evidence of muscle, bone, joint, and brain or nerve dysfunction. The children were divided into four groups, by age: 6–7 years, 8–9 years, 10–11 years, and 12–13 years; each group included eight children. Those limits of age were based on the maturation of gait and had already been reported in the literature (Moreno-Hernandez, Rodriguez-Reyes, Quinones-Uriostegui, Nunez-Carrera, & Perez-SanPablo, 2010). Eight

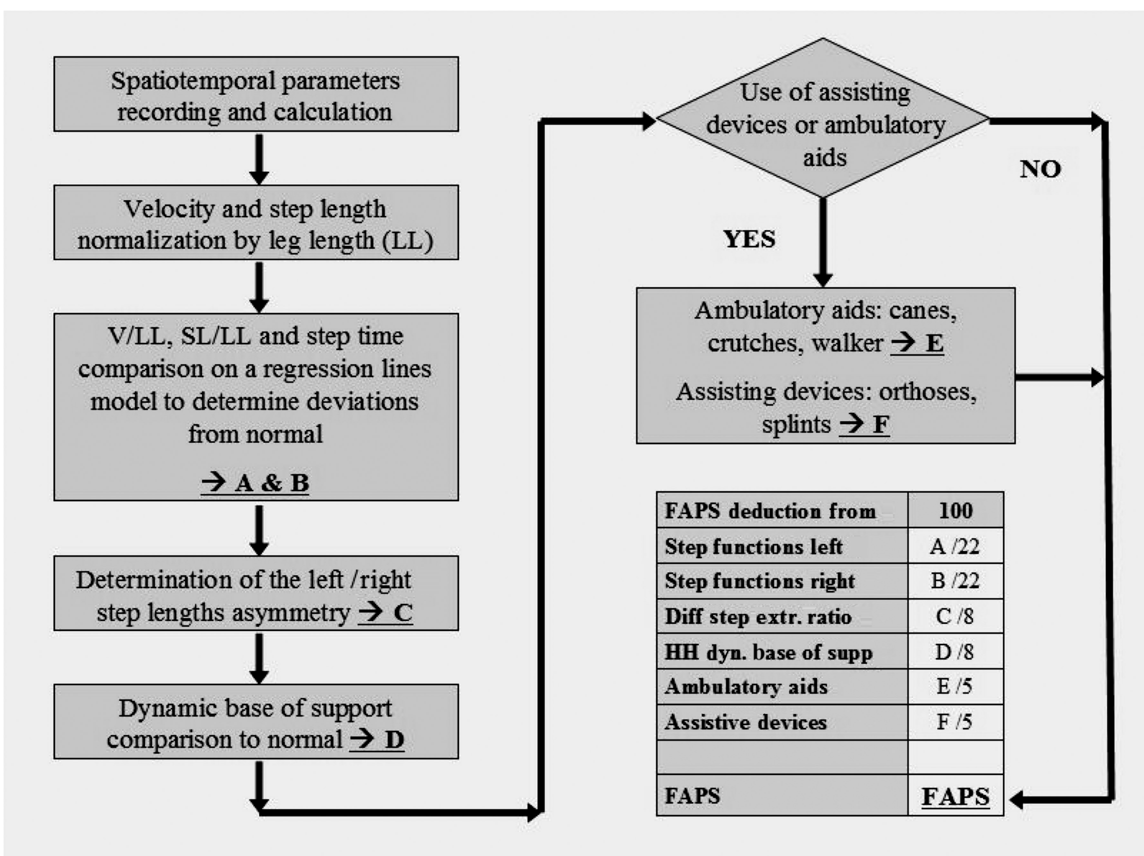

FIGURE 1. Flow chart of Functional Ambulation Performance Score (FAPS) processing algorithm. FAPS = Functional Ambulation Performance Scores; SL = Step length; V = Velocity.

young adults (22–28 years old) were also included in the study. Informed consent was obtained from parents, children, and adults before each inclusion. None of the participants had reported lower limb injuries within the previous month.

A GAITRite® walkway (v4.0, CIR Systems Inc., Hinckley, IL) was used to log the STP. Several studies have shown that the GAITRite® system was a reliable method to obtain gait parameters data in children (Dusing & Thorpe, 2007; Sorsdahl, Moe-Nilssen, & Strand, 2008; Thorpe, Dusing, & Moore, 2005). The mat was 5.79 m long, with an active area of 4.88 m long and 0.61 m wide. We asked the participants to walk barefoot at their own self-selected speed, starting 2 m before and finishing 2 m after the mat to minimize acceleration and deceleration effects. Each participant completed six walking trials. The spatiotemporal parameters were automatically calculated by the GAITRite® software. Step time, step and leg length (SL/LL) ratio, normalized velocity (V/LL) for each leg, degree of asymmetry for SL/LL ratio between both limbs, and the dynamic base of support (i.e., the vertical distance from heel center of one footprint to the line of progression formed by two footprints of the opposite foot) were collected to calculate the FAPS. Lower limb length was measured manually and represented by the distance from the greater trochanter to the floor transecting the lateral malleolus.

The FAPS calculation, illustrated in Figure 1, was realized by subtracting points from a maximum score of 100 for a self-selected speed walk (GAITRite® Manual; Nelson & Gross, 1996). The deducted points are included in six categories (from 5 to 22 points).

- Left and right step functions (A and B): The normal values of the SL/LL ratio, the step length, and the V/LL ratio are plotted on a double abscissa chart to delimit some areas that would determine the number of points to deduct. The farther the position determined by the patient values is from the normal area, the greater the number of points to deduct (from 0 to 22 points for each right and left step).
- Differential of SL/LL ratio (C): Eight points are respectively deducted to the right–left asymmetry of the SL/LL ratio (i.e., absolute difference between left and right SL/LL). No point is deducted when the difference is under 0.03.
- Heel-to-heel dynamic base of support (D): Eight points depend on the value of the base of support when walking. Walking with a wide base of support or crossing steps induces deductions.
- Ambulatory aids and assistive devices (E and F): Some extra points can be deducted if walk aids (E, 5 points) or some assistive devices (F, 5 points) are used.

The means and the standard deviations of STP values, FAPS, and demographic data have been calculated for each group. The intraparticipant variability has been estimated by the coefficient of variation (CV). Mann-Whitney U tests were used to statistically compare adult versus children parameters.

Results

The means and the standard deviations for age, height, FAPS, and STP values are represented in Table 1. The FAPS evolution through age groups is represented in Figure 2 (*M* and *SD*). The statistical results that compare pediatric and adult parameters are shown and the threshold for statistical significance is indicated.

The average FAPS was significantly lower for children under 12 years old. The 6–7-year-old group showed a mean of 81.5 ± 12.0 points, with only 37.5% of scores equal to or above 90. The FAPS increased with age to reach identical values to those in adults for the 12–13-year-old group, with 100% of scores being in the 90–100 range of values. The FAPS also showed higher standard deviation values for children under 12 years old. Similar trends have been observed regarding the intraparticipant variability; the children demonstrated higher coefficients of variability than the adults.

The normalized velocity followed a decreasing curve, ranging from 1.90 ± 0.25 for the 6–7-year-old group to 1.49 ± 0.25 for the adult group. The normalized step length was significantly higher in children. The step time was significantly lower for the youngest group. The dynamic base of support value did not vary through the groups.

Regarding the deductible points intervening in FAPS calculation, we observed that a greater amount of points were deducted for functions of right and left steps in children from 6 to 11 years old. The average was 9.2 ±, 6.1, 4.7 ± 4.5, and 3.7 ± 2.2 points for the 6–7-, 8–9-, and 10–11-year-old groups, respectively. The deductions for asymmetry of step length and dynamic base of support were nonexistent or close of zero in all groups.

Discussion

After a review of the literature, we found some studies that reported similar STP values for adults and children older than age 7 years. We expected to find similar results in our population. However, our results showed FAPS values significantly reduced for children younger than 12 years old, these values increasing with age. Some previously reported studies had pointed out that spatiotemporal parameters still evolve after age 7 years because of gait maturation (Hausdorff, Zemany, Peng, & Golsberger, 1999). We found that V/LL and SL/LL values significantly increased in the 6–7-, 8–9-, and 10–11-year-old groups, whose FAPS were significantly lower. The 6–7-year-old group showed the highest deviation from the adult pattern. The higher cadence in this group could explain the higher velocity and shorter step time observed. The values of cadence and base of support were similar to those obtained in previous studies in which the gait pattern of the children changed with maturity (Dusing & Thorpe, 2007; Sutherland, 1997). Normalized gait parameters reported in the literature are dependant on normalization

TABLE 1. Mean Values for Spatiotemporal Parameters and Functional Ambulation Performance Score (FAPS) Deductions, by Group

	6–7 years			8–9 years			10–11 years			12–13 years			Adults		
Parameter	*M*	*SD*	%	*M*	*SD*	%	*M*	*SD*	%	*M*	*SD*	%	*M*	*SD*	%
Age (years)	6.4	0.5		8.4	0.5		10.3	0.5		12.5	0.5		24.4	1.8	
Height (cm)	124.8	5.2		130.4	4.2		144.1	4.8		155.3	5.0		168.9	7.8	
Step time (s)	0.45	0.05**		0.50	0.03		0.49	0.04		0.52	0.03		0.52	0.03	
Normalized step length	0.84	0.08*		0.85	0.08**		0.81	0.04*		0.82	0.02*		0.77	0.03	
Normalized velocity	1.90	0.25**		1.70	0.25*		1.67	0.15*		1.59	0.09		1.49	0.11	
Cadence (steps/min)	135.0	15.4**		119.4	8.3		123.1	10.2		116.2	6.4		116.3	6.6	
Asymmetry of normalized step lengths	0.02	0.01		0.02	0.01		0.02	0.01		0.02	0.01		0.02	0.01	
Dynamic base of support (cm)	8.25	1.49		7.76	1.87		8.34	1.35		8.84	1.18		9.78	3.27	
Participants with FAPS $\geq$ 90 (%)			37.5			62.5			62.5			100			100
Intraparticipant variability of FAPS (CV in %)			10.2**			4.5**			3.4**			2.7*			0.7
FAPS deductions for															
Step functions left (/22)	8.9	6.0**		4.3	3.6**		3.6	2.3*		2.2	1.3		0.7	1.2	
Step functions right (/22)	9.5	6.1**		5.1	5.4**		3.8	2.1**		1.7	1.4		0.9	1.3	
Step length differential (/8)	0.1	0.1		0.2	0.2		0.2	0.2		0.2	0.2		0.0	0.0	
Dynamic base of support (/8)	0.0	0.0		0.0	0.0		0.0	0.0		0.0	0.0		0.1	0.3	

Note. CV = coefficient of variation.
$^{*}p < .05$. $^{**}p < .01$.

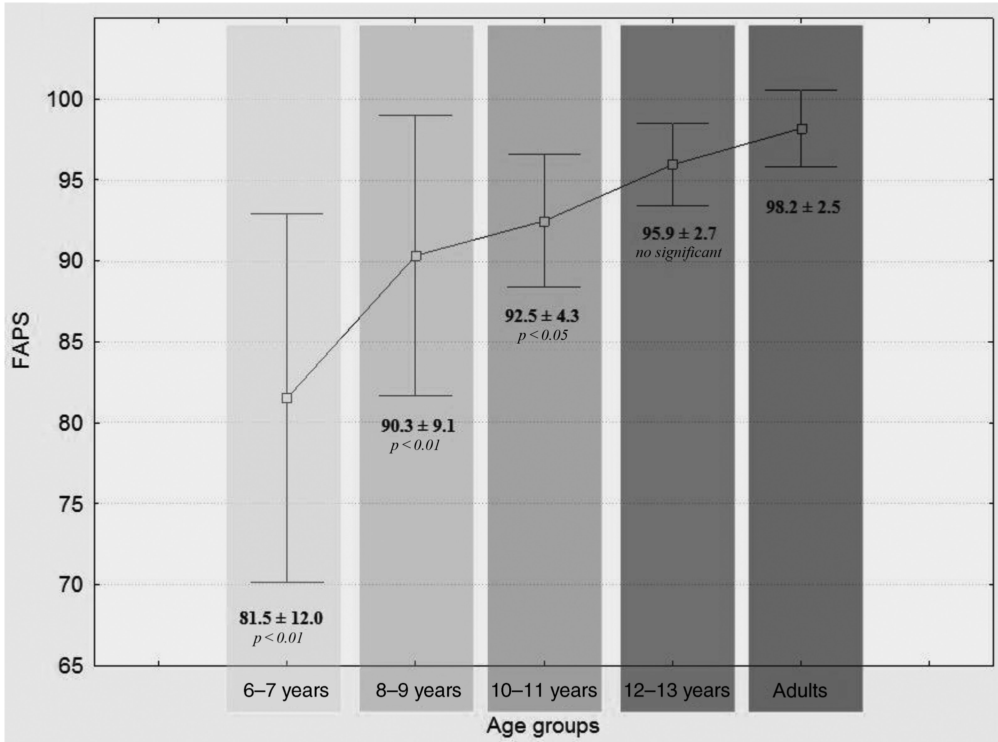

FIGURE 2. Functional Ambulation Performance Score (FAPS) means and standard deviations, by age groups ($M \pm SD$). Thresholds of significance (p) for Mann-Whitney U tests used to compare adults and children FAPS are indicated.

criteria (e.g., body size, limb length) and cutoff points relative to age; which makes it difficult to compare values of spatiotemporal parameters obtained from various studies.

The analysis of point deductions for each category of algorithm allowed a better appreciation of the observed differences. The deductions for the differential of the right and left step length/LL and for the dynamic base of support were the same (close to zero) in all groups. With all participants being healthy, we did not expect to observe asymmetry for normalized step length. Asymmetry usually indicates the presence of some gait disorder. In FAPS calculation, asymmetry is considered normal when the difference between the left and right normalized step lengths does not exceed 0.03. The values of the dynamic base of support parameter were not different in children and adults, so no deduction was applied. According to previous research, the dynamic base of support parameter would be stabilized by the end of the second year of independent walking (Bril & Brénière, 1992) and would vary little afterward. Regarding the deductions for the right and left step functions, their calculation is made according to a linear regression model including step time, normalized velocity, and normalized step length values. The amount of deduction is determined by taking into account the degree of patient's deviation from the normal pattern. If one or more of those parameters falls out of normal values, a point would be deducted. This was the case for children from 6 to 11 years old who had more deducted points, particularly those at younger ages. We observed that FAPS values evolved similarly through groups to those of STP.

FAPS do not consider gait variability (intercycle and intertest variability). The interparticipant variability (*SD* of FAPS within the same group) reveals the differences of walk patterns between the participants of a same age group. This variability was particularly high for the younger children (interparticipant variability decreased with age). The range of STP and standard deviation values within the same age group was larger for the youngest group. Given that the degree of maturation is multifactorial and specific to every child, it is difficult to accurately establish a cutoff age regarding the moment of the acquisition of the adult pattern. However, the percentage of children within the same group showing adult patterns increases with age, leading to a reduction of the range of possible normal values and thus the interparticipant variability (i.e., differences between children in a same age group). Our results demonstrated that this same principle applied for the intraparticipant variability (CV of FAPS for a same participant) that manifested a good reproducibility of gait patterns for the same child through several trials. Thus, although some children showed good intertrial reproducibility for the FAPS, velocity, and step length, other children showed more variability, demonstrating a weaker walk pattern. As reported by Hausdorff et al. (1999), this variability is particularly present in children at 6–7 years of age and tends to decrease with age and gait maturity. Their results showed that regarding stride-to-stride fluctuations of stride time, the variability was higher for 6–7-year-old children compared with 11–14-year-old children, suggesting that walking is not completely mature by 7 years old. Despite the small number of participants in our study, our results were concordant with those observations.

In conclusion, we observed that the FAPS does not allow comparing the gait parameters of children before the age of 12 years old. Thus, the adult standards used to calculate FAPS would not be suitable for children. When we think about the validation of FAPS for children, it becomes evident that a simple modification of standards by age categories would be insufficient. FAPS has a strong dependence on velocity and step length (actually deducting up to 44 points in the final score). To improve FAPS, we intend to introduce in the calculation complementary parameters that are recognized to be markers of walk deterioration. For example, the Walk Ratio (Hillman, Stansfield, Richardson, & Robb, 2009), which represents the relationship between the amplitude and the frequency of the rhythmic movements of the legs during walk, could be used. Defined as the average step length divided by cadence, the Walk Ratio has the advantage of remaining unaltered by walk speed in healthy individuals. In any case, it is preferable to adopt the normalization proposed by Hof (1996). When it comes to children older than 12 years, the use of the FAPS seems appropriate. It can represent a valuable tool to complement the clinical evaluation. If researchers are particularly interested in determining STP changes, these should be examined individually. The capacity of FAPS to assess gait in children with locomotion impairment is examined in future research.

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