



Evaluation of toddler different strategies during the first six-months of independent walking: A longitudinal study



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ABSTRACT

Twenty infants (age 10–16 month) were analyzed using inertial sensors over a 6-month period after the onset of independent walking. Changes in gait temporal parameters, coordination and gait strategies were evaluated. Gait temporal parameters showed a developmental shift at 2 months of walking experience: after this period, a change in the developmental trend was present in most of the analyzed parameters. Cadence results showed that the increased velocity is more due to an increase in step length than to an increase in cadence, after the first two months of independent walking. Different gait strategies were identified during the first month of independent gait based on collected data; after one month, characteristics of the pendulum mechanism were present in each examined toddler.

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1. Introduction

Many studies analyzed toddlers at the onset of walking in order to evaluate the development of different locomotion strategies and coordination [1–9].

To the authors’ knowledge, the changes in gait parameters after the onset of walking in healthy toddlers were quantitatively analyzed in studies by Sutherland et al. [8], Bril and Brenier [5], Ledebt and Bril [9], Looper and Chandler [7]. Sutherland et al. [8] evaluated many different gait parameters on more than 180 children from 1 to 6 years of age in a non-longitudinal study. Bril and Brenier [5] observed developmental changes in gait velocity and related these changes to gait parameters (step width, lateral acceleration, cadence and step length), observing 5 toddlers for 2 years in a longitudinal study. Ledebt and Bril [9] measured head and trunk rotations together with global gait parameters for 46–80 weeks on 7 infants in order to evaluate the acquisition of upper body stability. Looper and Chandler [7] evaluated changes in velocity, cadence, and step length in 8 toddlers for 5 months.

Toddlers included in longitudinal studies were always less than 8 [1,5–7]; while studies including more numerous groups of subjects were not longitudinal [8].

Thus, results found in the literature were either representative of the whole group analyzed at a specific developmental stage or could hardly be generalized due to the small number of participating subjects.

Given these limitations, literature results are sometimes in contrast with each other: e.g. the recent study by Looper and Chandler [7] showed a constantly increasing cadence during the first 5 months of walking experience, while previous studies [8,10] showed an increase during the first 2–3 months and then a decrease afterwards. All studies agreed that the first 5–6 months of independent walking (IW) produce the integration of postural constraints into the dynamic requirements of gait movement, while afterwards, a tuning phase begins, characterized by a more precise adjustment of the gait parameters [5]. Thus, a better evaluation of this important period of gait maturation is necessary to analyze if this integration process is continuous during these months and to better understand literature contrasting results. Literature studies [5,9,10] suggested that during the first weeks after the onset of IW, an integration of posture and movement occurs, with particular focus on the improvement of postural control. If the postural control significantly improves before the end of the 5–6 month period, it is expected to see significant changes in gait parameter trends during these months. Until now, no significant evidence of developmental shift during the first 5–6 months of IW has been shown.

A longitudinal quantitative study on a relatively large group of toddlers, analyzing changes in gait parameters during the first 6 months of IW, can provide relevant information about the

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influence of postural control during this period. Longitudinal assessment was deemed necessary, since the rate of walking development strategy modifications may differ in children [5]. The walking pattern of toddlers is characterized by a high inter-subject variability: following the same group for a certain period is fundamental to observe trends and modifications that can occur in some children and not in others.

To the authors' knowledge, literature studies were always based on data collected in laboratory using stereophotogrammetry, force platforms, pressure sensing mats or electromyography. The necessity of performing tests in the laboratory with time-consuming instrumentation is probably one of the major factors that led to include a relatively small number of subjects in longitudinal studies.

Inertial sensors allow estimating gait temporal parameters [11] and coordination indexes [12] out of the laboratory, are easy to use, need no calibration and can be worn for long periods. Moreover, they can be worn under the clothes, facilitating the experiments with toddlers.

Inertial sensors data may be used not only to investigate gait parameters but also early walking forms [13] used by toddlers. Mc Collum et al. [13] presented three extreme modes of walking used at the onset of walking: (i) the Twister, who uses trunk twist to facilitate step progression, (ii) the Faller, who exploits gravity for the progression of the center of mass, and (iii) the Stepper, who controls foot progression to stabilize the trajectory of the center of mass. During the first weeks of walking experience, toddlers use one of these mechanical strategies or a combination of them; after this period, they begin to show more similar walking forms starting to develop the pendulum mechanism [14].

The aim of the present study was to observe longitudinally a relatively large group of toddlers (>15) using inertial sensors over a 6-month period after the onset of IW (period in which the most dramatic changes of many gait parameters occur [14]). These data allowed focusing on this period, having an integrated vision of how different aspects of gait change. Accurate measurements of gait parameters and quantitative observation of gait strategies throughout the development of mature gait can provide a framework on which building a better understanding of the physiological events in human locomotion [8].

2. Materials and methods

2.1. Study subjects

Twenty toddlers participated in the study. All of the toddlers were full-term at birth and had no known developmental delay and/or musculoskeletal pathology. Detailed information about each child is shown in Table 1. The Bioethical Committee of the University of Bologna approved this study (July 11, 2012). Written informed consent was obtained from participants' parents on behalf of the children enrolled in the study. Tests on the toddlers were scheduled: during the very first week of IW (T0), at month 1 (T1), 2 (T2), 3 (T3), and 6 (T6) after the onset of IW. The onset of IW was defined as the child's ability to perform 5 consecutive steps without help. Due to illness, holiday and lack of cooperation, 77 of 100 scheduled tests were performed.

2.2. Experimental setup

Two tri-axial wireless inertial sensors (OPALS, Apdm, USA) were mounted respectively on the lower back and on the right leg using straps.

Measures of acceleration and angular velocity of the trunk and of the right leg were recorded at 128 Hz. The participants were asked to walk at self-selected speed along a corridor while moms or nannies called them. Toddler tests were also video-recorded in order to posteriorly check if they either were helping themselves with something or were hurrying up for some reason. In those cases, the identified steps were excluded from the analysis.

2.3. Data analysis

Stride [15] detection was estimated from the angular velocity around the medio-lateral axis of the leg [11]; even if the algorithm was designed for healthy adults, it was used on toddler data identifying local minima before and after swing phase, which were evident. The first and last two strides of each test were excluded from the analysis. For participants, 10 consecutive strides were analyzed.

Matlab R2009b (MathWorks BV, USA) was used for data analysis.

Gait parameters, described in Table 2, were calculated for each participant and each test session.

Table 1
Analyzed toddler details and trials.

	Age of first steps (months)	Gender	Weeks of pregnancy	At birth		At 12 months		Trials
				Length (cm)	Body mass (kg)	Length (cm)	Body mass (kg)	
1	11	Male	40	54	3.66	77	8.5	T0, T1, T2, T3, T6
2	13	Female	40	50	2.99	75	8.5	T0, T1, T2, T3, T6
3	12	Female	40	52	3.33	80	10.1	T1, T2, T3, T6
4	11	Male	40	52	3.56	81	11.0	T1, T2, T3, T6
5	13	Female	38	47	2.18	76	9.0	T0, T1, T2, T3, T6
6	14	Male	41	55	3.85	79	13.0	T0, T1, T2, T3, T6
7	14	Male	39	50	3.07	79	11.9	T0, T1, T2, T3, T6
8	15	Male	41	50	3.52	77	9.0	T0, T1, T3, T6
9	14	Male	40	48	2.84	73	8.8	T0, T1, T2, T3
10	14	Male	40	50	3.50	75	9.0	T0, T1, T2, T3
11	14	Male	40	52	3.75	81	13.0	T1, T2
12	10	Male	40	52	3.80	77	12.9	T0, T1, T2, T3, T6
13	16	Male	36	49	2.30	75	10.0	T0, T1, T2, T3, T6
14	15	Female	36	48	3.10	77	8.9	T0, T2, T3, T6
15	13	Male	38	54	3.80	70	10.0	T1, T2, T3, T6
16	13	Male	40	50	3.20	75	11.4	T0, T2
17	14	Male	41	56	4.30	79	12.5	T2, T3, T4, T5
18	12	Female	40	49	2.30	74	8.4	T1 T3
19	13	Female	39	51	3.30	77	9.8	T1 T3
20	13	Male	41	55	3.60	81	9.4	T3 T6

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