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Impact of leg length and body mass on the stride length and gait speed of infants with normal motor development: A longitudinal study

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ABSTRACT | **Background:** Gait acquisition is supported by changes in the neuromusculoskeletal system of the child. Changes in the dimensions of the body structures resulting from the growth of the child partly explain gait improvement in the first year of life. **Objectives:** To evaluate whether changes in body mass and leg length modulate the effect of independent gait practice (experience) on gait speed and stride length. **Method:** Thirty-two infants with normal development were monitored monthly from the acquisition of independent gait until six months post-acquisition. Longitudinal evaluations included measurements of the body mass and leg length of each child. Temporospatial variables of gait (speed and stride length) were documented using the Qualisys Pro-reflex® system. The data were analyzed using multilevel regression models, with a significance level of α=0.05. **Results:** An effect of the practice time on speed ($p<0.0001$) and stride length ($p<0.0001$) was observed. The change in leg length had a marginal effect on the rate of gait speed change: children whose leg growth was faster showed a higher rate of speed change ($p=0.07$). No other effects of anthropometric parameters were observed. **Conclusions:** The results suggest that the practice time promotes the improvement of the gait pattern of infants in the first year of life. However, the effects of the leg length and body weight of infants on the benefit of practice time remain undefined.

Keywords: movement; anthropometry; children; gait.

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Introduction

The onset of walking is an important motor development milestone[1-4]. Bipedal locomotion gives the infant the opportunity to explore the environment in a new way, promoting a distinct visualization and freeing the upper limbs for manipulation[3]. It also favors cognitive and social development and precedes more complex motor milestones, such as jumping and running[5,6].

Despite the complexity of the gait, the changes that occur during development, such as the length and frequency of the stride, gait speed and pattern of electromyographic activation, are well described in the literature[6-8], however, the factors that support such changes are not yet fully understood. During the acquisition of gait, changes in anthropometric parameters also occur, including weight gain and body growth, which interrelate with the previous parameters, imposing demands on the emergence and development of this motor milestone[9-11]. The interaction of these factors and the constant changes they undergo result in the emergence of strategies that are consistent with the child's repertoire of skills. This scenario provides opportunities for differentiated solutions among children, as well as changes in a child over time, until the acquisition of mature gait, at around seven years of age[3,12,13]. The accelerated period of infant growth in the first six months after the acquisition of gait[3] imposes challenges on the emergence and the learning of bipedalism. In this phase, infants explore various strategies to remain standing and, at the same time, move around in the environment[6].

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The influence of anthropometric factors on the acquisition of gait is not well understood. In the second year of life, the lower limbs become larger than the torso, reducing the disproportion of the head size in relation to the rest of the body[14,15]. This new body proportion shifts the center of mass of the child downward, toward the support base, facilitating balance and hence independent gait[16]. Adding to these changes, the increased length of the legs leads to increased stride length and hence gait speed[2,17,18].

If, on the one hand, the increase in leg length facilitates walking, on the other, the increase in mass is a major challenge for the development of gait[19]. The increase in body mass is directly related to the increase in the force to be generated during walking, especially in the muscles responsible for thrust[2,18,20]. Hence, the greater the weight gain, the greater the force required to generate the same stride length. Moreover, during gait acquisition, infants are required to coordinate their movements to address the functional consequences of the growth of their limbs and trunk[21]. These consequences include reactive forces generated either by the interaction between their own body segments or by the interaction of these segments with the environment[22]. Therefore, the greater the mass of the child, the greater these reactive forces will be, and the greater the requirement (i.e., demand) in terms of muscle strength. Thus, we hypothesized that a high body mass gain in infants during development negatively influences stride length; consequently, the increase in gait speed is also affected until the child can cope with the rising demands efficiently.

Although the changes in temporospatial parameters are a characteristic of gait development in normal children, the relationships between these parameters and the anthropometric changes can interfere with the process of acquiring this motor milestone. To our knowledge, the complexity of the combination of these factors remains under-explored in the literature. Thus, the objective of this study was to investigate the effect of changes in the lower limb length and body mass of infants with normal development on stride length and gait speed during the six months following the acquisition of independent locomotion.

Method

Study design

A longitudinal study with infants was conducted, from the week of gait acquisition until six months post-acquisition. The onset of walking was defined as the day the child was able to walk five steps independently[22,23]. The families received a home visit to clarify the objectives and procedures of this study. If they agreed to participate, the children were evaluated by the Alberta Infant Motor Scale (AIMS) test for possible inclusion. After the initial visit, weekly contact was made with the parents until the child started to walk independently.

Anthropometric data and temporospatial parameters of gait were collected in the first week of gait acquisition and monthly during the six months following the acquisition, totaling seven data collections per child. The study was approved by the Research Ethics Committee of the Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, MG, Brazil, (ETIC approval number 609/07). All of the legal guardians for the participants signed informed consent forms.

Participants

The study included 32 children selected by convenience. The inclusion criteria were term birth (i.e., gestational age greater than or equal to 37 weeks), without complications in the pre-, peri- and postnatal periods, with birth weight greater than 2,500 g and normal gross motor development at the time of enrollment in the study, according to the AIMS test[24]. This test was used as an inclusion criterion, in which only infants with normal development were selected, i.e., higher than the 10th percentile of gross motor performance. The participants were excluded if they made systematic use of medication or exhibited sensory impairments (i.e., visual and/or auditory).

Measures

Anthropometry

Each infant's body mass (kg) and length of the right lower limb (cm) were measured with a precision digital scale and measuring tape, respectively[25]. The measurements were performed by the same previously trained examiner to ensure the standardization of the procedures and the consistency of data collection.

Temporospatial parameters of gait

The gait speed and stride length were measured using the motion analysis system Qualisys MCU Pro-reflex (QUALISYS® MEDICAL AB, 411 12 Gothenburg, Sweden), with six capturing cameras. Children roamed barefoot on a walkway that was 4.8 m long and 1 m wide. Passive reflector tags of

10 mm diameter were attached to the right lower limb of the child, all by the same examiner who was trained in this activity, using hypoallergenic adhesive tape on the calcaneal tuberosity, over the lateral and medial malleolus, in the space between the heads of the first and second metatarsals and over the 5th metatarsal, with the objective of defining the reference segment (i.e., right foot) for the identification of gait temporospatial parameters.

The Qualisys system was calibrated according to the manufacturer's instructions[26]. Then, the child remained in the standing position in the center of the runway, with the feet aligned for ten seconds, to record the reference position and orientation of anatomical sites. To stimulate the child's independent walking, parents or caregivers were positioned at the opposite end of the runway relative to the child, with toys and drawings of cartoon characters. Data were collected with a sampling frequency of 120 Hz and processed using Visual 3D software. Each child performed approximately 12 gait cycles on each assessment day. The same procedures were repeated on the six subsequent evaluations.

Data reduction

Initially, the data were checked, such that gait cycles with no markers were excluded, resulting in at least three and up to 10 complete motion cycles of the right lower limb of the child. Next, the data were transferred to the Visual 3D software for processing. A biomechanical model of the foot segment was constructed based on the position of the anatomical markers. The delimitation of the gait cycle, including the events of contact and loss of contact with the ground, was obtained using the trajectory of markers located between the first and second metatarsals and the calcaneus marker. The data were filtered with a fourth-order Butterworth low-pass filter and cutoff frequency of 6 Hz to reduce the noise from the movement of the markers.

The events were visually defined by the trajectory of the calcaneus markers and the marker placed between the first and second metatarsals, using the Visual 3D program. The graphs representing the displacement of these markers on the *y*-axis (anterior-posterior) were used, allowing the visualization of the markers in the sagittal plane, recording times in milliseconds, in which the initial contact event 1, removal of fingers, and initial contact 2 occurred in each gait cycle[27,28]. From the definition of those events, temporospatial gait parameters (i.e., speed and stride length) were calculated using Visual 3D software. Data were analyzed by the same examiner, with an intraclass correlation coefficient greater than 0.99, indicating excellent consistency.

Statistical analysis

Multilevel regression analyses tested whether anthropometric variables (i.e., mass and leg length) modulated the effect of the time of practice (i.e., experience) of independent walking on the temporospatial variables of gait speed and stride length. For each temporospatial variable, three models were computed.

The objective of Model I was to partition the variance of the temporospatial variables into two components: the variance between measurements of the same child (intra-child) and the variance between measures of different children (inter-child). If the result of Model I indicated significant intra-child variation, it would suggest an effect of time on the dependent variables analyzed.

In case of significant variance in intra-child measurements, Model II was conducted to evaluate if the variation could be explained by time (i.e., experience). In other words, Model II aimed to test whether the practice time of independent walking predicted the change in temporospatial variables of gait. Furthermore, the objective of Model II was to test whether the pattern of change of temporospatial variables showed significant effects among children over time.

In case of differences in the pattern of change over time between children (i.e., captured by regression coefficient *b* of the predictor time variable), Model III was performed to test if the rates of change in mass and leg length explained some of this difference between children.

Results

The mean age of acquisition of independent gait was 378.72 days (SD = 26.08). The mean and standard deviation of the anthropometric measures (weight and leg length) and the temporospatial gait parameters (gait speed and stride length) in each of the evaluations performed are shown in Table 1.

Gait speed

Model I showed an overall speed average of 0.68 m/s (SD=0.06). The intra-child variance was significant (z=9.80, $p<0.0001$), suggesting a difference between measurements obtained from the same child. This variance accounted for 93% of the total variance of this variable. In turn, the inter-child

Table 1. Mean values and standard deviation of anthropometric measures (mass and leg length) and temporospatial parameters of gait (gait speed and stride length).

Time (month) of data acquisition	Speed (m/s)	Stride length (m)	Mass (kg)	Leg length (cm)
0 – Gait acquisition	0.41 (0.1)	0.32 (0.1)	10.05 (1.2)	33.43 (1.4)
1 – 1st month after acquisition	0.57 (0.1)	0.40 (0.07)	10.10 (1.2)	33.77 (1.5)
2 – 2nd month after acquisition	0.66 (0.1)	0.44 (0.07)	10.64 (1.4)	34.75 (1.6)
3 – 3rd month after acquisition	0.69 (0.2)	0.46 (0.07)	10.82 (1.4)	35.55 (1.5)
4 – 4th month after acquisition	0.74 (0.2)	0.49 (0.08)	11.11 (1.5)	36.26 (1.5)
5 – 5th month after acquisition	0.80 (0.2)	0.52 (0.08)	11.40 (1.5)	37.11 (1.7)
6 – 6th month after acquisition	0.86 (0.2)	0.54 (0.08)	11.61 (1.5)	37.64 (1.6)

Data are presented as the mean (standard deviation).

variance did not show statistical significance (z=1.37, p=0.17), as it only explained 7% of the total variance.

Model II indicated that part of the intra-child variation was related to post-acquisition time. Specifically, Model II showed an increase in speed related to the time of independent gait practice (b=0.07 ± 0.008, T (74)=8.05, p<0.0001). This model also demonstrated significant difference in the pattern of change of speed over time among children. Differences were found in the estimated regression coefficients for each child (z=2.88, p<0.0001).

In Model III, the rate of change in body mass did not significantly affect the effect of time on the speed gain (mass effect=–0.30±0.07 , T(29)=–0.460, p=0.65). However, the rate of change in leg length had a marginal effect on gait speed in the expected direction. Children whose leg growth was faster showed a higher rate of speed change (leg length effect=0 .07±0.04; T(29) = 1.92; p=0.07).

Stride length

In Model I, the overall average of stride length was 0.45 m (SD=0.01). The inter-child variance represented only 7% of the total variance, showing no significance (z=1.27, p=0.20). Conversely, a significant intra-child variance was found (z=9.80, p<0.0001), which explained 93% of the total variance.

Model II confirmed the hypothesis that the time of independent gait practice would increase the stride length, demonstrating a significant effect of the acquisition time on this temporospatial variable (b=0.03±0.002, T(96)=11.09; p<0.0001). This model also demonstrated a significant difference among children in the rate of change of stride length over time (variance=0.0004±0.00009, z=2.39, p=0.02).

Model III did not confirm the hypothesis that the rates of change in body weight and leg length would partially explain the difference among children observed in the rate of change in stride length. Neither the rate of change in body mass nor the rate of change in leg length significantly affected the effect of time on the increase in stride length (mass effect: 0.01±0.02, T(29)=0.54; p=0.60, leg length effect: 0.02±0.01, T(29)=1.44, p=0.16).

Discussion

This study aimed to evaluate whether the independent variables of body mass and right leg length modulate the effect of time of walking practice independently of the speed and stride length in infants with normal development. The practice time was associated with a significant intra-child variation of speed and stride length.

The lack of significant effect of the body mass change rate on variations in speed and stride length over time suggests that, in children with body mass values within the normal range, as in the present sample, the possible negative effect of mass gain is compensated by other factors associated with skill gain that directly affect gait maturation, including the gain in muscle strength, better balance control and increased neuromotor efficiency. Garciaguirre et al.[20] demonstrated that the gait of infants was negatively affected when backpacks with weights were positioned on their torsos during the acquisition phase. However, with development, the children learned to adjust their locomotor strategies to compensate for this condition, maintaining their performance even in the presence of extra weights added to their bodies. Thus, adaptation to the increase in mass appears to occur gradually. Infants possibly adapt over time to changes in their body mass, and a specific destabilization stage is not observed. While this mass modification occurs, new compensation strategies, such as increase in strength and improvement of balance, are gradually acquired and incorporated into the emerging gait pattern.

However, if the sample of this study had included overweight children, the accelerated mass gain could have hampered such adaptations, and a negative effect of the mass change rate on the temporospatial parameters of gait might have been demonstrated. However, this assumption remains a hypothesis to be empirically tested.

The rate of change of the leg length exerted a marginal effect on the gait speed, which suggests that the increase in speed could be associated with the effect of increased leg length on the stride length. However, our analysis did not confirm this hypothesis. It is possible that an explanation for this result is the fact that infants do not have the pendulum gait pattern of the adult, in other words, their steps are not delivered directly to the front or in the sagittal plane. Due to the enlargement of the support base, which is typical in these children because of their low balance control, their steps are more to the diagonal; therefore, until the emergence of the pendular gait pattern, an increase in leg length will not result directly in increased stride[29].

In the sample studied, the anthropometric changes did not affect the changes in temporospatial parameters of gait in the first six months post-acquisition. These results corroborate those obtained by Bartlett[15], who analyzed longitudinally the relationship between anthropometric changes and gross motor development of 132 infants with normal motor development. They calculated body mass index but found no significant correlation of this parameter with the motor development of infants. Similarly, Adolph et al.[17] longitudinally examined the gait of infants of both sexes. Both male and female infants showed a similar increase in their body size over time. However, anthropometric measurements were poor predictors of the ability to walk in these infants. Moreover, after controlling for the effect of time on the ability to walk, the modest effect of anthropometric variables was no longer significant.

The effects of anthropometric changes on gait performance throughout development might have been obscured in these studies by the fact that the analyses only captured linear relationships between these variables. According to the dynamical systems theory, the motor development of children results from changes in a complex system, under the influence of multiple components[30,31]. However, these changes do not occur in a linear pattern[32]. In other words, temporospatial parameters of gait may be altered without modification of body mass or leg length. In addition, a small increase in mass or leg length can contribute to changes in these parameters. Thus, it is possible that the linear analyses performed have not been able to capture the nature of this effect, which may manifest as a non-linear phenomenon.

A constraint on the conclusions of this study is that the sample was composed only of infants with mass values within the normal range. The absence of overweight infants in the sample might have reduced the variance in the rate of mass change over time, which may have hampered the identification of the hypothesized association between the rate of mass change and gait performance. Future studies that compare the development of gait in infants with and without overweight should test the association between the rate of mass change and temporospatial variables (speed and stride length).

A possible limitation of the study is that data were collected of only the right leg of each infant. Nevertheless, the placement of the markers did not alter the gait pattern of infants, and the analysis only considered regular and stable steps, ensuring the validity of the gait parameters collected. A strength of the data collection procedures in this study included the motivational strategies used to keep the child's interest during ambulation in each collection, allowing the infants to stay motivated and focused.

This study may contribute to the field of physical therapy by indicating elements that should be considered in the evaluation process and clinical examination. During the onset and first six months of gait acquisition, the infant is faced with the demands of learning this new motor skill along with fast changes to the structures directly involved in gait (i.e., lower limbs). Although the results show that such anthropometric changes do not impact the development of temporospatial parameters of gait in infants with normal development, it is important to consider the possibility that, in the presence of a health condition, the demands inherent to body growth along with the demands of learning and improving gait may present major challenges for children with disabilities in the structures and functions of the body. Rehabilitation professionals who address children of different clinical groups should pay attention to the impact of child growth on the development and acquisition of motor milestones, such as gait, and pursue the adaptation of the body functions to compensate for the changes in these structures during periods of accelerated growth.

The results of this study demonstrate that accelerated increases in right leg length and body mass are not related to changes in temporospatial variables of gait, specifically, speed and stride length, in normal children. Despite finding significant intra-child variation in both speed and stride length, this variation was explained by the experience time, in other words, longitudinal follow-up period. In addition, there was a significant inter-child difference in the rates of change of speed and stride length. However, anthropometric changes at this age do not appear to be associated with such differences.

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