Original article (short paper)

Do sit-to-stand performance changes during gait acquisition?

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Abstract—In a child's daily routine, sit-to-stand (STS) is a prerequisite activity for many functional tasks. The relationship between gait and other abilities has been pointed out by many authors, but there is no study investigating the changes in STS during gait acquisition in children. The purpose of this study was to analyse, in healthy children, changes that occur in STS performance during gait acquisition. Five healthy children were initially assessed with an average age of 13.6 months. The kinematics in STS movement performance of the children was evaluated longitudinally during different periods of walking experience: children who have not acquired independent walking, 8.2 (±8.4) days of independent walking experience, and 86.2 (±8.7) days of independent walking experience. At the gait acquisition period we found a significant decrease in the final trunk flexion angle and an increase in amplitude of the trunk flexion. The walking experience may have changed the execution of the STS movement.

Keywords: motor development, kinematics, gait

Resumo—"O desempenho na transição da posição sentada para em pé altera durante a aquisição de marcha?" Na rotina diária infantil, a transição da posição sentada para em pé (SDP) é um pré-requisito para muitas tarefas funcionais. A relação entre a marcha e outras habilidades tem sido apontada por muitos autores, mas não foram encontrados estudos investigando as alterações de SDP durante a aquisição da marcha em crianças. O objetivo deste estudo foi analisar as mudanças que ocorrem no desempenho do SDP no período de aquisição da marcha em crianças saudáveis. Cinco crianças saudáveis foram inicialmente avaliadas com idade média de 13,6 meses. A cinemática do movimento SDP das crianças foi avaliada longitudinalmente durante diferentes períodos de experiência de marcha: quando as crianças não tinham adquirido a marcha independente ainda, 8,2 (± 8,4) dias de experiência de marcha independente, e 86,2 (± 8,7) dias de experiência de marcha independente. No período de aquisição da marcha observamos uma diminuição significativa no ângulo final da flexão de tronco e aumento da amplitude de flexão do tronco. A experiência do andar pode mudar a execução da atividade SDP.

Palavras-chave: desenvolvimento do motor, cinemática, marcha

Resumen—"El rendimiento en la transición de posición de sentado a de pie se modifica durante la adquisición de la marcha?" En la rutina diaria infantil, la transición de sentado a de pie (SDP) es un requisito previo para muchas tareas funcionales. La relación entre la marcha y otras habilidades ha sido apuntada por muchos autores, pero no se encontraron ningún estudio que investigue alteraciones en SDP durante adquisición de la marcha en niños. El objetivo de este estudio fue analizar las alteraciones en SDP durante adquisición de la marcha en niños saludables. Fueron evaluados cinco niños saludables, con edad inicial media de 13,6 meses. La cinemática de la actividad SDP de los niños fue evaluado longitudinalmente, durante diferentes períodos de experiencia de andar: los niños no habían adquirido lo andar independiente, 8,2 (± 8,4) días de experiencia de andar independiente y 86,2 (± 8,7) días a partir de la experiencia de andar independiente. En el período de adquisición de la marcha, se verificó una disminución significativa en el ángulo da flexión final del torso y el aumento de la amplitud de la misma flexión. Con la experiencia en caminar se puede alterar el rendimiento de la actividad SDP.

Palabras clave: desarrollo motor, cinemática, marcha

Introduction

Sit-to-stand movement (STS) and independent walking are fundamental skills in the process of motor development as they maximise children's daily routine activities, thus expanding their possibilities of action in the environment (McMillan & Scholz, 2000). Both skills are often jointly performed, but they require different postural challenges.

STS movement is a transitional movement to the upright posture that requires movement of the center of mass from a larger to a smaller base of support. It is considered a biomechanical demanding task, since it requires greater knee and hip maximum joint moments than walking, running and stairs-climbing (Ploutz-Snyder, Manini, Ploutz-Snyder, & Wolf, 2002). Moreover, balance, muscle strength and neuromuscular control are necessary to STS performance.

In a specific manner, walking also requires integration between dynamic postural control and propulsive force generation (Assaiante, 1998). During walking acquisition, the center of mass is projected onto a constantly changing base of support. For that, children have to bear their own weight, detect ground irregularities and maintain stability, alignment of body segments and muscle force in a controlled challenged way (Ivanenko, Dominici, & Lacquaniti, 2007).

There are evidences that walking acquisition can influence a previously acquired or developing skill (Chen, Metcalfe, Chang, Jeka & Clark, 2008; Chen, Metcalfe, Jeka & Clark, 2007; Corbetta & Bojczyk, 2002; Haehl, Vardaxis & Ulrich, 2000; Zwart, Ledebt, Fong, De Vries & Savelsbergh, 2005). Chen et al. (2007) observed that learning to walk affects infant sitting posture by means of increasing sway properties, becoming unstable. The authors suggest that infants need to re-calibrate their sensorimotor control so as to accommodate the newly emerging behaviour of independent walking (Chen et al., 2007). Haehl et al. (2000) also observed that trunk control during cruising movements improved as walking being acquired. Furthermore, Chou et al. (2003) found that STS is related closely to walking performance in hemiparetic individuals. In this sense, faster rising speed in STS movement is associated to increased velocity and step length during walking.

Therefore, the objective of the present study is to elucidate how infants change their STS movement performance during independent walking acquisition. According to Adolph (2008) and Clearfield (2004), independent walking experience enables the children to further explore their environment, increase their sensory-motor experiences, improve their abilities to use the information available, and refines their standing postural balance, spatial memory, and anticipatory movements (Adolph, 2008; Chen et al., 2008; Clearfield, 2004, Cignetti et al., 2013). For that, the present study hypothesised that, as infants learn to walk, they will change how they perform their STS movement. In this sense, we believe that kinematic characteristics between the different periods of walking experience could be modified due to the distinct neural-motor experiences, especially at the walking acquisition time. Furthermore, such knowledge might be important to clinical practice training of both skills by professional working in the field of developmental disabilities.

Table 1. Age and days of independent walking experience of the children at each test. The days before the acquisition of independent walk are indicated by negative values.

Subject	Age (months)	Gender	Independent walking experience (days)
Period 1			
1	13	F	-16
2	14	F	-26
3	14	F	-29
4	14	M	-28
5	13	M	-10
AVERAGE			-21.8±8.4
Period 2			
1	14	F	14
2	15	F	4
3	15	F	1
4	15	M	2
5	14	M	20
AVERAGE			8.2±8.4
Period 3			
1	16	F	74
2	18	F	94
3	18	F	91
4	18	M	92
5	16	M	80
AVERAGE			86.2±8.7

F: female; M: male. Data expressed in average ± standard deviation.

Methods

Participants

Caregivers of 60 children, ages 10- to 14-months, were invited to participate in the study. Of these, 33 refused to participate, two gave up before evaluation and ten gave up during the study; nine infants acquired independent STS only after they started to walk independently and, therefore, were excluded for not meeting the inclusion criteria, and one cried during the experiment. Therefore, five healthy children, 3 females and 2 males, were included in the study. At the time of the first test, the children had an average age of 13.5 (± 0.55) months, and had not acquired the independent walking although they performed independent STS. Age of the children and days of independent walking experience are shown in Table 1.

Independent STS movement performance was evaluated using kinematic analysis during three different periods of walking experience (Chen et al., 2008), and walking experience was defined as being the time elapsed since its acquisition:

Period 1: Children had *not* yet acquired independent walking, but they managed to perform STS movement independently.

Period 2: Children with 8.2 (±8.4) days of independent walking experience.

Period 3: Children with 86.2 (±8.7) days of independent walking experience.

All children were born full term (mean gestational age 38.1 ± 1.9 weeks) with mean birth weight of 3.4 kg (± 0.29), and mean Apgar score of 9.5 (± 0.5) at the fifth minute. Participants did not have history of lower-limb injury and/or neurological disorder.

The children were evaluated by the validated Brazilian version of the Paediatric Evaluation of Disability Inventory, and their scores were within the expected range for healthy children of same age, thus confirming no developmental delays.

The onset of independent walking was considered when infants walked more than five steps without support of upper limbs or any other help from the parents (Clearfield, 2004; Kingsnorth & Schmuckler, 2000). The infant's parents were instructed to take note of the day their child took five steps without support. We contacted parents weekly to get the data (Hallemans, De Clercq, & Aerts, 2006).

The study is in accordance with Resolution 196/96 of the National Health Council and was approved by the local research ethics committee under number 307/2008. All the caregivers signed an informed consent form.

Procedures

Upon arrival at the laboratory, children were given time to acclimate by playing with toys and with the research team members. Subsequently, children were dressed with lycra© shorts to allow accurate marker placement. Double-sided hypo-allergenic tape was used to attach reflective markers (0.5 cm diameter) to the following body landmarks on the left and right sides (Seven, Akalan, & Yucesoy, 2008): base of the 1st and 5th metatarsals, calcaneus, medial and lateral malleolus, medial and lateral femoral epicondyles, anterior superior iliac spines, greater trochanter, and inferior and lateral aspect of the acromion process. Markers were also placed on the back, at the level of the first sacral spine, and manubrium sternum.

The initial seated position was carefully controlled, and each child was placed in a standardized position for each trial. Children wore barefoot and sat on an adjustable chair, maintaining their knee joints positioned as close to 90° as possible (McMillan & Scholz, 2000). Toys were given to the children at midline and arms' length and shoulders' height based on standing position in order to motivate them to stand up. The first two STS movements were freely performed by the children so that they could get used to their positioning. After that, the next three trials were recorded for analysis. If the child was not able to stand up independently to reach for the toys, even after being motivated by the parents, a hand support was provided at the height of the xiphoid process and at the child's arm's length distance away (Wilson, Haideri, Song, & Telford, 1997).

At the end of each evaluation session, anthropometric measures were taken (body weight, height, lower leg length – bottom of the heel to knee joint space – and distance between anterior superior iliac spines). These measurements were used as parameters in a solid body modeling program (body segment program – Kwon 3D, version 3.1) (Schneider & Zernicke, 1992; Van Dam, Hallemans & Aerts, 2009).

Table 2. Values of time to perform the sit-to-stand movement and angles assessed in the evaluated periods.

	Period 1	Period 2	Period 3	*p*
Time (sec)	2.1±0.4	1.7±0.3	1.8±0.5	0.074
Ankle				
Initial (°)	-3.3±4.4	-1.3±3.5	1.89±2.3	0.247
Final (°)	4.5±4.2	3.6±5.2	1.2±2.8	0.549
Maximum (°)	17.8±3.8	13.0±2.8	9.1±4.3*	0.007
Amplitude (°)	26.1±7.4	19.1±7.5	11.4±4.7*	0.015
Knee				
Initial (°)	95.7±6.3	91.4±1.3	92.1±3.2	0.819
Final (°)	28.11±13.4	30.8±18.7	24.1±9.9	0.247
Maximum (°)	104.2±3.3	101.4±7.0	102.0±8.7	0.449
Amplitude (°)	78.2±15.6	68.7±24.2	83.1±9.3	0.819
Trunk				
Initial (°)	29.5±7.0	26.5±5.3	17.7±3.2	0.074
Final (°)	26.6±5.8	17.5±3.2*	3.8±4.2*	0.007
Maximum (°)	48.2±4.2	43.3±4.5	30.4±3.8*	0.015
Amplitude (°)	21.8±4.4	28.7±4.0*	27.7±4.9	0.022

Data expressed in average ± standard deviation. $^*p<0.005$ comparing with Period 1

The entire experimental phase was recorded using a four-camera motion capture system. Four cameras (*Sony HDSSR 12*) were positioned at 45° from the sagittal plane of the child's body, in both left and right sides, shuttered (1/500 second), genlocked to synchronize their scans (60 fields per second), and adequately calibrated to determine the 3D scaling factors. The average mean square error for calibration was 3.36 mm.

Data analysis

The beginning of STS movement was defined as being the point at which the manubrium sternum marker started to move uninterruptedly in the horizontal direction (Y axis). The end point of STS was defined as being the point at which the manubrium sternum marker ceased to move upward (z axis). The total duration of STS motion was normalized into a 100% scale. Cubic spline interpolation was used to determine the X-Z coordinates values for each STS percentage of missing data.

Motion data were processed by using the body segment program Kwon 3D version 3.1, with a cut-off frequency of 6 Hz (fourth-order zero phase shift Butterworth filter). Each lower limb segment coordinate system was realigned to obtain anatomically referenced joint angles. The kinematic parameters (ankle, knee and trunk joint angles) were computed based on a 3D model including five segments: feet (base of the 1st and 5th metatarsals, calcaneus, medial and lateral malleolus), shank (medial and lateral malleolus), thigh (medial and lateral femoral epicondyles, greater trochanter), pelvis (anterior superior iliac spines, first sacral spine) and trunk (right and left lateral aspect of the acromion process, first sacral spine and manubrium sternum). Ankle angle was defined as the angle between the feet and the shank segments. Knee angle was defined as the angle between the shank and the thigh segments. Trunk-flexion angle was calculated as the angle between trunk segment and vertical pelvis axis. The pelvis axis was defined based on the pelvic plane, and passed through the mid-point between the right and left ASIS markers and the sacrum marker according to Seven, Akalan, and Yucesoy (2008).

To correct for small differences in marker placement between participants, a static calibration was performed to determine offset angles. For the ankle joint, dorsiflexion had positive and plantar flexion had negative signal. We calculated total duration, values of trunk, knee, ankle, joint angles and frequency of successful STS.

Dependent variables

a) Time of execution – defined as the time elapsed between beginning and end of the movement in seconds (Park et al., 2003).

b) Joint angles – Initial, maximum, minimum and final values of ankle, knee and trunk joint angles were obtained (Seven, Akalan, & Yucesoy, 2008).

c) Movement amplitude – Calculated as the difference between maximum and minimum values of ankle, knee and trunk flexion angles during STS movement. The amplitude between minimum and maximum values can be easily obtained, enabling interpretation of the joint excursion and degrees of freedom involved (Van Geert & Van Dijk, 2002).

Statistical analysis

The SPSS software (16.0 version) was used for statistical analysis. We applied the Shapiro-Wilk test and observed that data were not normally distributed. The graphic analysis of residuals did not suggest any particular pattern to the data and various transformations did not satisfy normality. Therefore, non-parametric ANOVA for repeated measures (Friedman's test) was used to identify differences between ages in each variable. Dunn's *post hoc* test was applied when appropriate. We adopted a 5% significance level.

Results

Forty-five trials of STS movements were recorded, with a mean of three trials for each child being used for analysis in each period. Table 2 shows data regarding the analysed variables in the periods in which the children were evaluated.

STS Movement Performance Time

No significant difference was found in the total time of STS movement over periods of walking experience ($\chi^2(2) = 5.2$).

Joint angles

Ankle. Initial ($\chi^2(2) = 2.8$) and final ($\chi^2(2) = 1.2$) ankle angles did not differ significantly across periods. However, children presented lower maximum dorsiflexion ($\chi^2(2) = 10$) over walking experience. *Post hoc* tests showed differences between period 1 and 3 ($p = 0.0067$). Amplitude during the movement arc of the ankle was also decreased significantly ($\chi^2(2) = 8.4$), demonstrating lower excursion in period 3 compared to period 1 ($p = 0.015$).

Knee. Initial ($\chi^2(2) = 0.4$), final ($\chi^2(2) = 2.8$) and maximum knee flexion ($\chi^2(2) = 1.6$) angles did not differ significantly across periods. No significant difference in knee amplitude was also found ($\chi^2(2) = 0.4$) across the periods of experience.

Trunk. Children started to stand up from the chair with equal trunk flexion angle over the studied periods, confirming no significant difference ($\chi^2(2) = 5.2$). On the other hand, significant decrease at the final trunk flexion was observed over the periods of walking experience ($\chi^2(2) = 10$). This difference was significant between the period 1 and 2 ($p = 0.049$), as well as, between period 1 and 3 ($p = 0.007$). Children had a significant decrease in the maximum trunk flexion over periods ($\chi^2(2) = 8.4$). *Post hoc* test showed that children in the period 3 exhibited lower maximum trunk flexion than those during period 1 ($p = 0.015$). Finally, we found a significant increase in trunk amplitude over the studied periods ($\chi^2(2) = 7.6$). This difference was significant between period 1 compared to period 2 ($p = 0.0224$).

Discussion

We analysed the STS movement during gait acquisition and identified changes in the angular kinematic variables. In the present study, reduction in the final angle and maximum angulation of the trunk occurred in period 2 compared to period 1, and an increase in the trunk amplitude in period 2 compared to the initial period, possibly due to trunk extension. Body extension can indicate acquisition of neuromuscular control, with the child keeping a less flexed posture and improving postural control, as result. In the literature, there is evidence that postural control during sitting changes for children at the onset of independent walking (Chen et al., 2007). The transition to independent walking may provide motor demands and sensory-motor experiences that changes postural control in STS movement.

As expected, we observed greater reduction in both the maximum angles and amplitude of the ankle angle between period 1 and period 3. Children may exhibit reduction in knee, hip and ankle flexion during gait as walking experience increases, thus indicating greater joint extensions (Hallemans et al., 2006). The reduction in ankle angles observed in the present study may be associated with the extension of body segments involved in STS movement.

We observed no change in STS movement performance time over the experimental periods. In the literature, less time to perform a task indicates more agility, balance and efficiency during performance (Durward, Baer & Rowe, 2001; Van Der Heide, Fock, Otten, Stremmelaar, & Hadders-Algra, 2005). The absence of time reduction may indicate that the onset of independent walking changes STS movement performance, but does not provide more efficiency to that movement. This result is in accordance with a previous study that also observed changes in balance control, but no reduction in average time to perform the task (Chen et al., 2007).

We observed a decrease in the trunk movement amplitude during the STS movement in the children who had not yet acquired independent walking, and an increase during the period in which the children were starting to walk independently. Before the onset of independent walking, the STS movement may be performed through an 'en bloc' control, a balance strategy that minimizes the degrees of freedom to be controlled during the movement using muscle contraction to stabilize the surrounding joints (Assaiante, 1998). As the walking experience increases, a child acquire postural control and starts to control each joint involved in the movement, rather than using the 'en bloc' control (Assaiante, 1998; Assaiante, Mallau, Viel, Jover, & Schmitz, 2005). This strategy allows a child to improve the movement components during the walking experience, thus acquiring more skills to perform a motor task more efficiently (Ivanenko et al., 2007).

Independent walking acquisition provides sensory-motor experiences and motor demands similar to those observed in the STS movement. Therefore, walking experience and spontaneous practice with STS movement may help a child to improve her or his performance in these activities. Trunk extension and alignment of body segments may indicate important changes of both independent walking and STS skills.

Limitations can be observed in the present study, such as the small number of participants. The study design required a specific sample of children capable of performing STS movement despite not being able to walk independently.

Conclusion

The walking experience may change the STS movement performance and improve postural control. Therefore, we suggest that the greater the independent walking experience, the better the alignment of body segments, which are important for a child to successfully perform the STS movement. Further studies with larger number of participants are needed to confirm the changes we observed in STS movement performance during gait acquisition.

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