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Infant Behavior & Development 23 (2000) 79–89

Infant Behavior & Development

# Changes in arm posture during the early acquisition of walking

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Received 8 May 2000; received in revised form 14 August 2000; accepted 14 August 2000

**Abstract**

Changes in arm posture and movement of the arms in relation to step width were studied longitudinally for 4 to 6 months in 6 infants who had just begun to walk. Arm postures and movements were coded from video recording and step width was calculated from force platform data. The results showed that arms were held in fixed postures during the first 10 weeks. A decrease in these fixed postures was correlated with a decrease in step width. The emergence of arm movement occurred when balance control improved. The hypothesis that arm postures fulfill the dual task of stabilizing the body in an upright posture while moving it forward is discussed. © 2000 Elsevier Science Inc. All rights reserved.

*Keywords:* Locomotion; Balance; Children; Motor control; Arm movement

## 1. Introduction

Reciprocal arm-swing has been described as an important feature of gait, serving to increase postural control of the body and gait efficiency (Elftman, 1939; Murray, Kory, & Bernard, 1967). Swinging the arms during walking counterbalances trunk rotation around the vertical axis (Elftman, 1939), and is an important factor in minimizing vertical displacement of the center of mass (Murray et al., 1967). Arm-swing is not a passive consequence of the forward movement of the body, but is the result of specific muscle action at the shoulder

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PII: S0163-6383(00)00027-8

(Hogue, 1969). Active reciprocal arm-swing is not observed in infants at onset of independent walking, but develops during childhood (Burnett & Johnson, 1971; Sutherland, Olshen, Cooper, & Woo, 1980).

Burnett and Johnson (1971) described the arm position at onset of walking as externally rotated at the shoulder, and flexed at the elbow. This is known as the 'high guard' posture. Within the first 10 weeks of walking it is reported that children lower their arms from this high, flexed position. The first swinging attempts were observed to take place at the shoulder with flexed elbows (Burnett & Johnson, 1971). Sutherland et al. (1980) observed that reciprocal arm-swing first appeared at 1.5 years and was systematically produced by the age of 3.5 years. The high guard position might be a result of balance problem that infants encounter at onset of independent walking (Bril & Brenière, 1992; Bril & Ledebt, 1998). Although it has been suggested that changes in arm position accompany the narrowing of step width (Burnett & Johnson, 1971), there is no empirical evidence for the hypothesis of co-development of arm posture and step width during the acquisition of walking.

If the new walker uses arms as balance regulators any changes occurring in the arms' posture should be reflected in walking parameters which have been viewed as an index of balance control during walking. Breadth of base while walking has been regarded as a good indicator of a compensatory strategy to avert falls in toddlers (Burnett & Johnson, 1971; Shirley, 1931) and elderly (Charlett, Weller, Purkiss, Dobbs, & Dobbs, 1998), and is considered as indexing the balance component of walking (Bril & Brenière, 1992; Bril & Brenière, 1993).

The aim of this study was to document the developmental changes in arm posture and movement in relation to width of base during walking in infants. A longitudinal study during the first 6–7 months of independent walking was carried out since previous studies reported that step width rapidly decreased during this period (Bril & Brenière, 1992; Ledebt, Bril, & Wiener-Vacher, 1995; Shirley, 1931).

## 2. Method

### 2.1. Subjects

Six infants were followed longitudinally twice a month during the first two months of independent walking (IW) and then once a month for the following 4–6 months (the last sessions took place between the 25 and 37 weeks after onset of IW). The onset of independent walking was defined as the ability to make at least three steps without falling while starting and ending the sequence of steps in an upright unsupported position (Ledebt & Bril, 2000). As in the previously published papers of the authors (Bril & Brenière, 1992; Ledebt & Bril, 2000; Ledebt et al., 1995) the functional age (with regard to onset of walking) was used rather than age from birth in order to compare individual trends from infants who start to walk at different ages. All infants started to walk within the normal range: infant 1 at 14 months; n° 2 at 15; n° 3 at 12; n° 4 at 13; n° 5 at 14, and n° 6 at 15 months.

### 2.2. Apparatus

Arm posture and movements were qualitatively assessed from a video film. The video camera was stationed at 2 m on the side of the walkway (sagittal view). A force plate (1 m × 1 m) was placed in the middle of the walkway. The entire walkway was 3 m long and 1 m wide and was raised at 14 cm above the ground. During each session infants walked barefoot from one end of the walkway to the other for 5 to 10 trials.

### 2.3. Data analysis

The type of arm posture and movement displayed during each trial was coded following five categories:

(1) High guard: arms fixed with external rotation at the shoulder and flexed elbows where the hands were about shoulder level.
(2) Middle guard: arms fixed with flexed elbows where the hands were about waist level.
(3) Low guard: arms extended along the body without noticeable movement.
(4) Flexed movement: the main movements were observed at the shoulder joint and the elbow was flexed. This category includes back and forth as well as circumdunction movements.
(5) Reciprocal arm-swing: arms moved in an out of phase relation with the legs and were extended when passing the vertical (normal pattern in adults).

Although the first two categories concern fixed postures of the arms, small movements could occur but were considered to be related to the transmission of the shock provoked by the contact of one foot with the ground. These kind of shock reaction movements remained within a few degrees of variation (approximately about 10 degrees from the mean position).

The sagittal view allowed coding the behavior of the arm on one side of the body. A trial was not analyzed if the infant was walking while holding a toy or when pointing to something or someone. Initiation and braking phases were determined from the video and were not considered for the analysis in order to study steady-state gait.

The percentage of occurrence of each category was calculated for each session and each child. All of the videotapes were analyzed by the author. A second observer, unaware of the purposes of the study, coded two sessions for two different children, assessed the reliability of the analysis. There was 90% agreement for the categories between the two observers. A total of 282 trials from 44 sessions were analyzed for an average of about 6 trials per session.

Step width, an index of balance control during walking, was calculated from force plate data. The displacement of the center of pressure (CP) was computed from the reaction forces measured by the force plate. Step width was defined as the magnitude of the lateral displacement of the CP between two successive foot contacts (Bril & Brenière, 1992). Using the CP displacement to measure step width can be different than using the actual feet position. Contrary to the heel-to-heel measurement of step width (e.g., from footprints), the CP excursion calculated from the force plate data gives the functional step width that takes into account the eventual rotations of the feet.

A total amount of 728 step widths were calculated with an average of 16 steps per sessions.

## 3. Results

### 3.1. Development of arm posture and movement

The results of the development for the five arm posture and movement categories as a function of weeks of independent walking are shown in Fig. 1.

The high guard arm posture was the most frequent position adopted by infants at onset of independent walking: 4 of the six children showed 100% high guard position up to 6 weeks of walking. The next most frequent position was the middle guard one, which was systematically adopted up to 10 weeks of walking experience (the last 100% was observed at 10 weeks). Child 2 adopted a middle guard position within the first week of independent walking and child 6 never showed high guard position, but started to walk using the middle guard posture.

Despite the interindividual variability (seen from Fig. 1), the average data over the six children (presented in Fig. 2) suggests a global developmental trend. This general tendency involved a decrease of the percentage of trials without arm movement (high and middle guard) with a complementary increase of trials with arm movements (flexed movement and reciprocal arm-swing). The general decrease of trials with high or middle guard was tested by adding the percentage of these two arm categories for all the infants. Because data were collected from the infants at different points from the onset of walking, the sessions were subdivided into seven periods of walking experience (see Fig. 2). A one-way ANOVA showed that the decrease was significant ($F_{(6,\ 38)} = 22.7$, $p < 0.001$). A Bonferroni post hoc test revealed that significant differences occurred between the first two groups of walking experience (0 to 5 and 6 to 10 weeks) and the five other groups.

Flexed movements were observed before reciprocal swinging (Fig. 2). All children but one (child 4) showed reciprocal arm-swing during the period of the study. Once present, the reciprocal arm-swing did not regularly increase but were alternatively use together with flexed movements.

The occurrence of the low guard category started at about the same time as reciprocal arm-swing (Fig. 1). This arm posture seemed to be related to the progression velocity (as observed from the video) during the trial rather than to be a developmental stage per se. Extended arm posture along the body was observed in cases of slow progression (which is also the case for adults who walk very slowly). The trials with extended arm position are not shown in Fig. 2.

### 3.2. Development of step width

Step width decreased as a function of weeks of independent walking (Pearson correlation, $r = -0.81$, $p < 0.001$). The decrease in step width between the sessions was significant for all the infants (separate one-way ANOVAs were performed for each child, $p < 0.001$): child

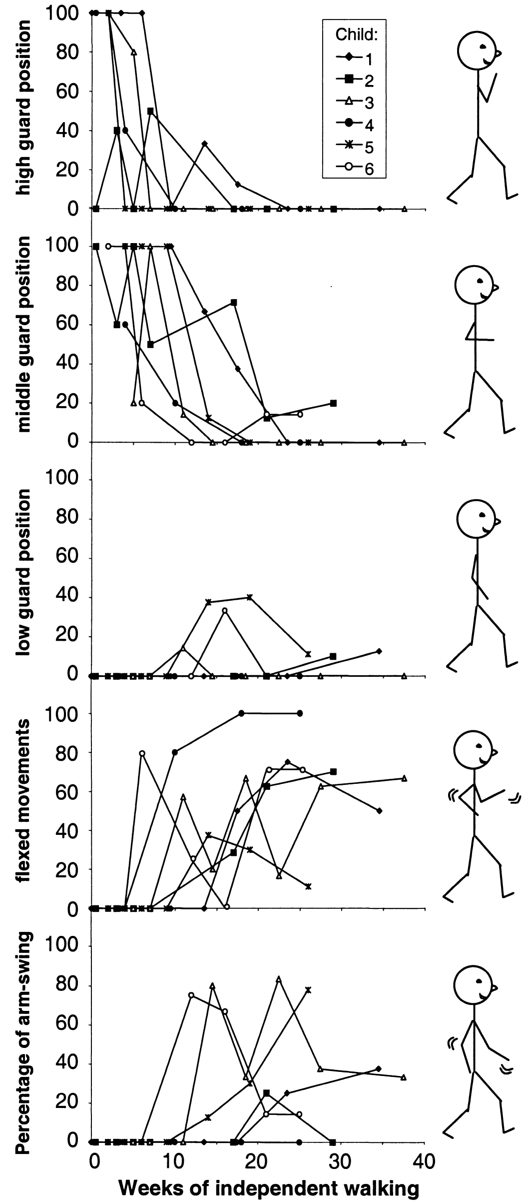


Fig. 1. Individual profiles for the arm categories as a function of weeks after onset of independent walking (one curve per child). From top to bottom: high guard, middle guard, low guard, flexed movements, and reciprocal arm-swing. These categories are illustrated on the right side of the figure.

1, $F_{(7,\ 128)} = 12.3$; child 2, $F_{(7,\ 96)} = 24.8$; child 3, $F_{(7,\ 123)} = 13$; child 4, $F_{(5,\ 117)} = 33.5$; child 5, $F_{(6,\ 102)} = 35.4$; child 6, $F_{(6,118)} = 7.5$. The same effects were observed with relative width (step width was corrected for infants' height). Individual development patterns of absolute and relative width are presented on Fig. 3.

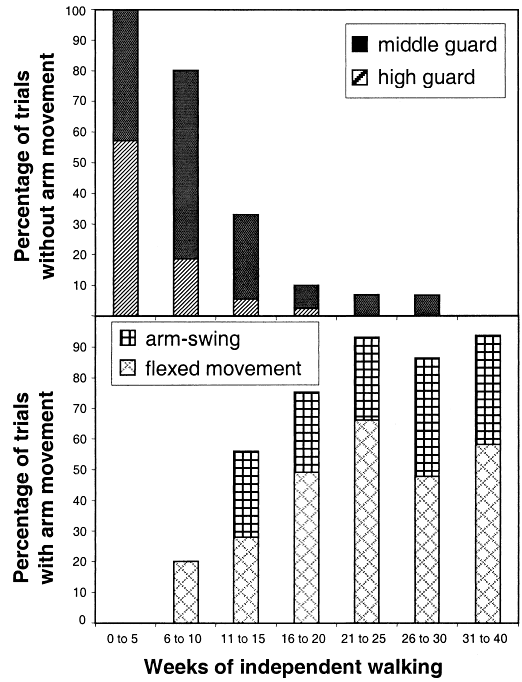


Fig. 2. Mean percentage for high and middle guard (top) and for flexed and arm-swing movement (bottom) as a function of weeks of independent walking grouped in seven categories (averaged over the six infants).

### *3.3. Step width in relation with arm posture*

Relative step width was significantly correlated (Pearson correlation) with the percentage of time the arm was in the high and middle guard positions ($r = 0.84$, $p < 0.001$). But, these two variables were also strongly related to the number of weeks from onset of independent walking (see coefficients mentioned above). A partial correlation between the relative step width and the percentage of high and middle guard positions was calculated controlling for weeks of independent walking. The partial correlation coefficient was also significant ($r_{part} = 0.47$, $p = 0.001$) suggesting that step width and arm posture were strongly related.

The 44 sessions were divided into 3 categories as a function of the percentage of trials where children had their arms in the high and middle guard (see Fig. 4). The three categories represent sessions with 0%, 1 to 99% and 100% of the trials with high or middle guard. The step width in the third mentioned category (sessions where almost all the trials showed high or middle guard) was significantly larger than in the two other categories (Bonferroni post hoc test, $p < 0.001$).

## 4. Discussion

The results suggest a co-development of changes in arm posture and breadth of base of support during the first weeks after onset of independent walking. The decrease of step width

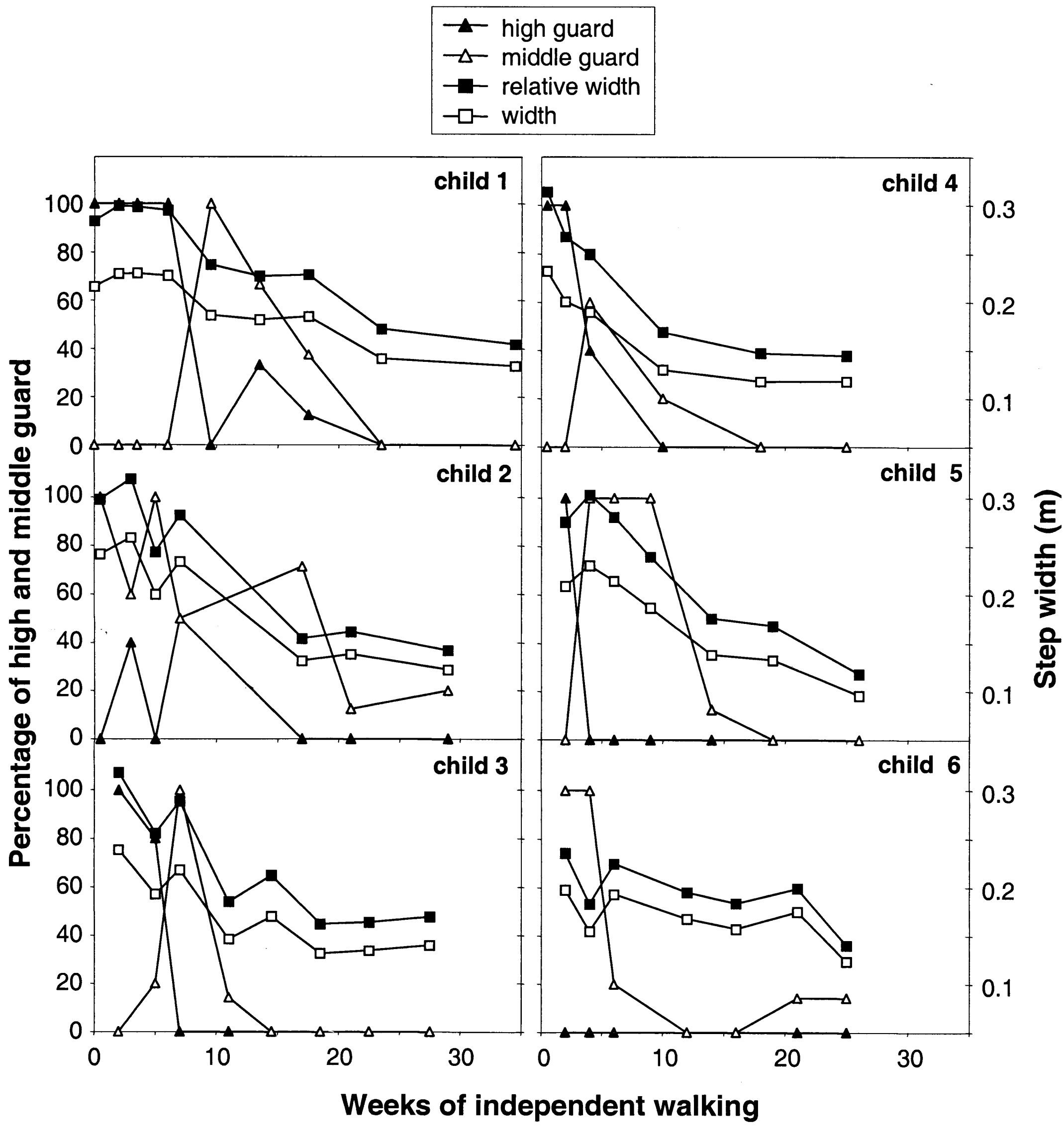


Fig. 3. Individual profiles for high and middle guard and absolute and relative step width as a function of weeks after onset of independent walking.

and the decrease of high and middle guard posture of the arms were strongly correlated. These results support the idea that the arm posture observed in toddlers is involved in balance control at the onset of independent walking. The overall developmental trend involves the arms being first lowered and then progressively moved, with the first movements observed at the shoulder joint and then also at the elbow. It is hypothesized that this progression is constrained by the dual requirements of walking i.e., stabilizing the body in an upright posture and moving the body forward. It is quite possible that, in addition to the changing

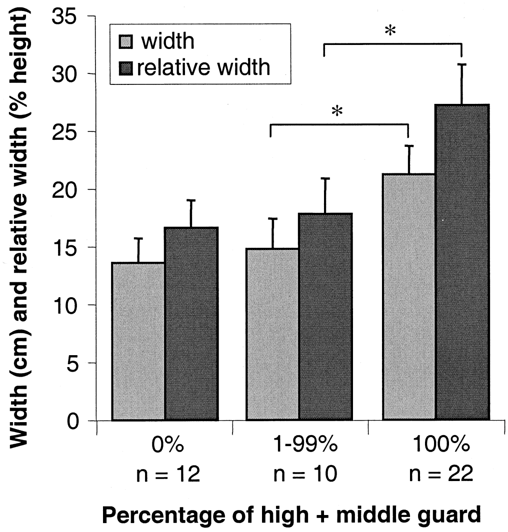


Fig. 4. Mean values and standard deviations of width and relative width as a function of the percentage of arm postures (averaged for high and middle guard) per session: 0%, no trial of those sessions showed high or middle guard; 1 to 99%, in those sessions the trials showed mixed arm postures and movements; 100%, all the trials in those sessions showed either high or middle guard arm posture. The differences between the first category of percentage and the two others were significant (*Bonferroni test, $p < 0.001$).

neural constraints, these requirements will determine the developmental trend signaled above.

The typical high guard posture of the arms at the onset of walking can be interpreted as a way to reduce the problem of controlling the numerous degrees of freedom involved in a complex movement. The mastery of redundant degrees of freedom in motor skill learning is, according to Bernstein (1967), a two-stage process. The learner starts by freezing the biomechanical degrees of freedom. With practice, some degrees are released and the reactive phenomena (forces) that arise from freeing some of the degrees are exploited to improve the skill. As suggested by Newell and McDonald (1994) the search to solve the problem of ‘freeing’ degrees is constrained by dual control requirements in order to simultaneously maintain exploration of the new task and preserving body posture.

Holding the arms in a fixed posture could be a solution to reduce the number of degrees of freedom to control. In order to solve the problem of walking without falling the child may first avoid arm movements that are independent from the trunk. The utilization of arm movements as a source to counterbalance forces arising from pelvis tilt could be discovered by children once they achieve a relatively stable posture during walking. In other words, at the onset of walking, arm movement could challenge the postural integrity, rather than enhance balance control during walking.

The present study shows that arm movements develop as postural control during walking becomes more stable as shown by the reduction of step width. It looks as if a certain level of overall postural stability is required before arm movements can be involved. This idea is supported by the individual developmental patterns (see Fig. 1 and 3). In fact, child 6 who had the smallest step width from the onset of independent walking was also the first to show arm movements. The reverse picture can be seen in child 1 who was the last child to initiate arm movements and was also the last to exhibit a decrease in step width.

Bernstein's intuition that freeing degrees of freedom (e.g., the arms) may help the individual to reach a higher level in a given skill has already been illustrated in children during standing on one leg (Slobounov & Newell, 1994). The increase of compensatory lateral arm movements between 3 and 5 years was related to improvement of balance while standing on one leg (Slobounov & Newell, 1994).

In adults, arm movements are so well incorporated in the gait pattern that a voluntary suppression, or enhancement, respectively impairs, or facilitates, walking (Eke-Okoro, Gregoric, & Larsson, 1997). In a situation where adults had to walk with both arms strapped (held by the side of the body), stride length decreased while full arm swing (up to the shoulder) resulted in longer strides.

There are also some indications that arm movement during gait may lead to improvement of gait efficiency for patients with neurological damages. Studies of patterns of co-ordination during walking showed some evidence that instruction to move the arms resulted in improvement in gait patterns in stroke patients (Wagenaar & Emmerik, 1994) and patients with Parkinson's disease (Emmerik, Wagenaar, & De Goede, 1995). A single case study in a child with cerebral palsy also supports the results found with adults about the co-occurrence of changes in walking characteristics and arm posture (Carmick, 1995). Specifically, Carmick (1995) reported that a hinged ankle-foot orthosis (HAFO) improved the gait of a 47-month-old child in terms of increased step length and systematic heelstrike and also changed the posture of the arms. Before wearing the HAFO, the arms' posture was the typical high flexed position of young toddlers. After one week with HAFO the arms were lowered and moved along the body. In conclusion, Carmick suggests that a nonadapted ankle brace (solid ankle foot-orthosis) that the child used to wear before the articulated brace (HAFO) iotrogenically caused the need for gait deviations in order for the child to move the body forward.

This suggestion leads to the next point of the discussion concerning the type of fixed arm posture adopted at the onset of independent walking.

The hypothesis that toddlers would first avoid arm movement during walking to facilitate the problem of redundant degrees of freedom to keep balance does not provide an explanation concerning the type of posture they adopt. One can imagine different postures that may fulfill this requirement (e.g., arms along the body). Adopting the typical high guard position might be directed by safety and/or by biomechanical effects. The argument that the high guard position is adopted for safety reason is limited by the fact that other positions could be viewed as equally safe in case of a fall (i.e., more lower and forward position). It is therefore likely that high guard position is adopted because of biomechanical consequences during walking. First, the high position of the arms raises the center of mass, which has the advantage of creating a greater angular acceleration caused by gravity than a lower position of the center of mass. Raising the center of mass might help create the acceleration necessary to move the body forward at a moment when the infant is not yet able to propel himself purely by the lower limbs muscular force (Brenière & Bril, 1998). Second, the external rotation of the arms in the high guard posture increases the inertia of the upper body, which could help to stabilize the trunk in the vertical position. One can then hypothesize that the flexed elbows constitute a compromise position between full lateral extension of the arms and total and internally rotated flexion with arms on the torso. The first position would lead to too much inertia with regard to the energy costs during walking, while the second would lead to high rotational velocities of the upper body.

The irregular progression of the occurrence of arm movements during the period studied may reflect the fact that walking still represents a challenging equilibrium task. After 4–6 months of walking the infants are not yet able to control balance with the leg muscles and may sometimes drop back to a previous arm position to cope with disequilibriums that are inherent to walking (Brenière & Bril, 1998). Interestingly, Burnett and Johnson (1971) observed that the high guard position and a large step width reappeared at the first attempts to run though these features had already disappeared during walking in the infants they observed. Although this observation was not quantified, it supports the idea that the high guard position of the arms is part of the solution adopted to cope with a new equilibrium task where the body has to move forward.

## 5. Conclusion

The present study suggests that the diagonal pattern of interlimb co-ordination between arms and legs is not simply an automatic 'hardwired' synergy involving the firing of spinal generators but that it emerges from postural requirements linked to the selection of adapted and efficient locomotion. Furthermore, the ability to move the arms and legs in a coordinated pattern is present in infants before independent walking. A study of hands-and-knees crawling (Freedland & Bertenthal, 1994) showed that infants adopt a diagonal interlimb pattern (i.e., two diagonally opposite limbs moving at the same time) after a few weeks of experience in crawling. The authors suggested that the convergence towards this stable coordination between arms and legs was driven by the organism's propensity to maximize gait efficiency.

In the case of independent walking, this propensity is constrained by the dual task of keeping the upper body stable while moving the body forward. Shifting the body weight from one leg to the other, however, may not only challenge a toddler's equilibrium, but also the equilibrium of elder persons when either the environment (e.g., when walking on ice), or the organism (e.g., when walking after a long confinement to bed) has changed. In principle, the same problems may occur when learning specific motor tasks like, for example, skiing or roller-skating.

Therefore, it might be fruitful to conceptualize walking acquisition in toddlers as a motor learning process instead as of a pure reflection of neural maturation.

## Acknowledgments

Thanks to the children and to their parents, to M. S. M. Waardenburg, G. J. P. Savelsbergh and T. Westra for their help during the experiment, and to K. S. Rosengren, G. J. P. Savelsbergh, and P. C. W. van Wieringen for their comments on this paper.

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