**Walking skill versus walking experience as a predictor of
barrier crossing in toddlers**

By

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**A thesis submitted in conformity with the requirements
for the degree of Master of Arts
to the Graduate Department of Psychology
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Walking skill versus walking experience as a predictor of barrier crossing in toddlers

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The aim of the current study was to examine the roles of locomotor experience, walking skill, and body size parameters in determining the abilities of 18- and 24-month-old toddlers in crossing a barrier varying in height. Thresholds for barrier crossing were measured using a modified psychophysical staircase procedure. Overall, older children surpassed younger children in measures of locomotor experience, body size and crossing thresholds; in contrast, few differences were observed in walking skill. Analyses relating the various experiential, size and skill parameters to crossing thresholds revealed that, replicating earlier findings, barrier crossing was most strongly related to locomotor experience. These findings are discussed in terms of the limitations of different forms of skill assessment as predictors of visually guided locomotor ability.

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Walking skill versus walking experience as a predictor of barrier crossing in toddlers.

The first year of an infant's life represents a period of dramatic change in which a number of important milestones are reached. Of particular importance to the developing child during this time is the acquisition of independent locomotion. With the onset of mobility, a new level of autonomy is achieved by the infant. The most immediate effect of this gain is a change in the nature of subsequent interactions between the child and his/her environment, with self-directed locomotion assumed to be critical for the proper organization of the infant's cognitive, perceptual and social systems (Bertenthal & Campos, 1990).

The process of learning to crawl and walk is an incredible accomplishment, and it is not a feat easily achieved by the infant (Adolph, Eppler & Gibson, 1993a). The acquisition of motor skill depends upon the maturation and development of both skeletal and neuromuscular systems (Thelen, Skala & Scott Kelso, 1987), with the increasing refinement and integration of these systems leading to greater proficiency in walking. By the age of six years, a child's walking pattern is fairly well established (Pufall & Dunbar, 1992). The ability to walk successfully through the world is not the result of motor development alone, however; perceptual sensitivity to the surrounding world is also a key element (E.J. Gibson, 1988; E.J. Gibson & Schmuckler, 1989; Schmuckler, 1993, 1996). According to E. J. Gibson (1988), perception guides a child's actions, and action, in turn, participates in perception. Thus, we can consider the perceptual and motor systems as being interdependent (E. J. Gibson, 1988; Schmuckler, 1993).

This functional relation between perceptual and motor systems is central to the concept of affordances (E.J. Gibson, 1982, 1988; J.J. Gibson, 1979; Adolph, Eppler, & E.J. Gibson, 1993b). An affordance can be thought of as the link between perception and action (E. J. Gibson, 1982, 1988), in which the performance of any given action is based on a "fit" between

the physical capabilities of the actor and the constraints imposed by the environment (J.J. Gibson, 1979). Over the course of evolution, animals have adapted as a species to exploit a specific niche or environment (Adolph et al., 1993b). Consequently, the nature of the actor-environment fit varies; what may be of use for one animal may not be for another.

Thus, successful action within the world necessitates at least two components. First, an actor must accurately perceive the affordances of the environment; misperception, or missing the affordances altogether, will result in non-adaptive actions. Second, the actor must utilize the information provided appropriately (Adolph et al., 1993b); a failure to do so may have serious consequences for the individual. For example, misjudgments in the actor-environment fit are believed to be a contributing factor to an individual's level of accident proneness (Plumert, 1995).

To complicate matters, the relation between the actor and the environment is not static. Rather, changes in the skill level or physical characteristics of the actor can bring about related changes in the actor-environment fit. During infancy, the ability to accurately perceive an affordance relies on children's ability to accommodate these changes and update their system. As development progresses, new abilities arise bringing about new affordances (Adolph et al., 1993b).

Infancy, therefore, provides a unique opportunity for studying the development of affordances involved in locomotion and independent mobility (see Adolph et al., 1993b). Studies within this area have looked at infants' ability to discriminate the affordances of surfaces (Gibson, Riccio, Schmuckler, Stoffregen, Rosenberg, & Taormina, 1987; Lockman, 1984; Palmer, 1984; Schmuckler, 1996), walk up and down slopes (Adolph, 1995; Adolph et al., 1993a, 1993b), step over and under barriers (Heinrichs, 1994; Heinrichs, Richardson & Pick, 1993; Schmuckler, 1996), climb stairs (Ulrich, Thelen & Niles, 1990), as well as their ability to

detour around objects and through apertures (Lockman, 1984; Palmer, 1989; Schmuckler, 1993; Schmuckler & Gibson, 1989).

The most common approach taken in studying the development of affordances has been to compare the abilities of infants to those of adults. Investigation of the affordances for locomotion in adults (e.g. Heinrichs, 1994; Heinrichs et al., 1993; Konczak, Meeuwssen & Cress, 1992; Warren, 1984) has revealed three main findings. First, successful performance of basic locomotor actions, such as climbing stairs or moving through doorways, seem most strongly related or “scaled” to an actor’s body size, and not to any absolute measure. Accordingly, researchers have said that action in the world is “body-scaled” (Heinrichs, 1994; Schmuckler, 1996; Warren, 1984). For example, the maximum height for which an actor can efficiently climb stairs is best expressed as a ratio of the stair height to the individual’s leg length (Warren, 1984). By presenting information in the form of body-scaled measurements, performance comparisons across individuals are possible (Heinrichs, 1994). Second, perceptual judgments of capabilities are categorical; once a critical point has been reached, we change our judgment from “able” to “unable” (Heinrichs, 1994; Warren, 1984). And third, perceptual judgments are related to actual action capabilities. In general, adults are usually quite accurate in judging whether they are capable of performing a given action (Plumert, 1995). For example, Warren (1984) found that body size was related to a subject’s view of a staircase as ‘climbable’ versus ‘unclimbable’ with the riser height defining this point of transition a constant proportion of the subject’s leg length. Confidence ratings of climbability also matched these categorical judgments. Similarly, Heinrichs et al. (1993) found that the critical transition points between “stepping over & walking under a barrier” and for “crawling & walking under a barrier” could be expressed as a constant function of leg length.

In addition to anthropomorphic variables, scaling of action may also be determined by other factors, such as proficiency or skill measures, as well as basic kinematic factors (Schmuckler, 1996). Unfortunately, the majority of research within the area of work on investigating action in the world has primarily looked at basic actions (e.g., climbing stairs, sitting in chairs) for which most adults show little variation in proficiency. In an attempt to increase the variability of parameters such as skill or proficiency, Konczak et al. (1992) compared the stair-climbing abilities of young and old adults. These researchers found that action capabilities were determined by multiple biomechanical constraints, some anthropomorphic and others kinematic. In particular, measures of leg strength and flexibility provided a better fit for the abilities of older adults, with almost two thirds of this age group (relative to younger subjects) showing a perfect match between action capabilities and perceptual judgments. Experience with reduced physical abilities may have increased the older adults' awareness of the biomechanical constraints on their actions, resulting in kinematic variables taking on a greater role. A similar situation may be true for young children who are just learning to master a new motor ability.

Research investigating the critical boundaries of motor actions in children has produced varied results concerning the scaling of action to anthropomorphic, skill and kinematic variables. Some work has found that such transition points are related to anthropomorphic measures. For example, Heinrichs' (1994) investigated adults' and five-year-old children's ability in crossing barriers of varying height. Of interest were the heights at which a change in movement was required for successful crossing; two such transition points were identified. The first transition involved a switch from stepping over the barrier to moving under it, and the second, involved a switch from bending under the barrier to moving under it with support. Both transition points were found to be a constant function of the subject's leg length. Likewise, Pufall and Dunbar

(1992) looked at 6-, 8- and 10-year-old children's perceptions of affordances for stepping onto and over objects and found that by age six, children's perceptual judgments of their action capabilities were also related to leg length.

In contrast, anthropomorphic measurements have been of little use as predictors for the action capabilities of very young children; rather, locomotor experience and skill appear to better predict the abilities of toddlers (Adolph, 1995; Schmuckler, 1996; Ulrich et al., 1990). For example, Ulrich et al. (1990) looked at the role of muscular strength, leg length and postural constraints of 8- to 15-month-old infants in determining the heights that afford stairclimbing. Infants had the choice of climbing one of three available staircases, differing in riser height. Interestingly, differences in stair climbability were related to locomotor capabilities (walking and stair climbing experience) and not to variations in body build. These researchers also looked at the abilities of 20-month-old infants. In keeping with the younger group, body size was not a good predictor of the infants' choices. Moreover, their choices were not determined by differences in walking or stair-climbing experience either. It may be that once a certain level of skill is achieved, the riser heights chosen in this experiment no longer represented a constraint, or more accurately, varying degrees of difficulty.

Schmuckler (1996) investigated the action capabilities of 1- and 2-year-old toddlers for crossing barriers varying in height as well as spatial extent and transparency. The measures of interest were the rates of successes, failures and refusals for each age group at each of a number of predetermined heights. Walking experience, height and weight, along with various indices of body proportion were assessed. The study found that increases in barrier heights systematically varied responses along a continuum moving from successful crossing to failed attempts and finally to complete refusals to attempt crossing. A more surprising result, though, was the fact that walking experience, and not body size, was the best predictor of infants' actions.

Unfortunately, this study did not attempt to disentangle the relative roles of walking experience and walking skill; such a distinction has been suggested as critical by others (Adolph, 1995).

From the reported studies, it would appear that the action choices of toddlers are determined by different variables than those of a mature individual, and specifically, appear to be related to locomotor experience. It may be that body-scale measurements are only useful as predictors once a mature level of skill has been reached (Heinrichs, 1994; Schmuckler, 1996). A number of conceptual limitations must be considered when walking experience is used as an explanatory variable, however. First, walking experience is often measured through retrospective parental reports, making it difficult to reliably index (Walk, 1966, cited in Heinrichs, 1994). Second and more importantly, walking experience is often confused with walking skill. Although experience and skill are positively correlated in the early days of walking (Bril & Brenière, 1992), they nonetheless represent two distinct concepts.

Walking experience refers to the number of days between the onset of walking and the test session (Adolph, 1995) and thus reflects opportunities for learning about the environment (Schmuckler, 1996); it is not at all clear, however, what activities contribute to or make up such “opportunities”. The question of whether walking experience is a measure of practice with or exposure to the surfaces under investigation is difficult to answer (Adolph, 1995). For instance, previous experience with stairs or climbing gyms may change the nature of new encounters with barriers. A past history involving a serious accident has also been suggested as a possible mediator of children’s perceptual judgments of their abilities (Adolph, 1995; Plumert, 1995). Although researchers try to match experience levels by holding age constant, this procedure does not guarantee equivalence in actual experience.

Walking skill, on the other hand, is determined by the interplay of a number of contributing kinematic variables, including flexibility, strength and balance, and interlimb

coordination (Heinrichs, 1994; Schmuckler, 1996). Differences in walking skill between children may reflect differences among these kinematic variables. For instance, regardless of experience, some children are better walkers from the moment they take their first steps. Other children may show vast improvements over short periods of time during which others may struggle (Adolph, 1995). Thus, when investigating differences in the action capabilities of children, it is important to use measures that take these concepts into account and reflect the true developmental differences among the sample.

Only two studies to date have specifically addressed the conceptual difference between walking skill and walking experience in young children (Adolph, 1995; Adolph et al., 1993a). Adolph et al. (1993a) looked at 8.5- and 14-month-old toddlers' perceptual judgments as to whether a hill was safe for climbing up and down, examining the relative contributions of walking experience, walking skill and body proportions to these judgments. Four predetermined slopes were presented in both ascending and descending order for counterbalanced groups. For the ascending slopes, walking skill was the better predictor for the abilities of the 14-month-old toddlers. For the descending slopes, none of the variables investigated were useful as predictors. Unlike the ascending slopes, however, only two of the four descending slopes presented were perceived as walkable by the children. Alternative methods (e.g., sliding) of descent were used for the two slopes perceived as un-walkable. Because of the greatly reduced data set for the descending slopes, the researchers argue that their finding is exploratory at best. Neither crawling experience nor skill were useful as predictors for the behavior of the younger group.

In a follow-up study, Adolph (1995) used a psychophysical staircasing procedure to specifically determine the walking boundaries of 14-month-old toddlers. Using this procedure, toddlers were presented with increasingly steep slopes until an angle was reached where they either failed or refused to walk up it. The process was then repeated in reverse, with the angle of

the slope becoming less steep, until the toddlers could once again successfully walk down the slope (Adolph, 1995). Walking boundaries were defined as the steepest slope that children could, on average, successfully walk up while failing to walk up the next steepest increment (see Adolph, 1995 for details). One advantage of the psychophysical staircasing procedure is that researchers can more closely approximate children's true abilities (Adolph, 1995). Using this procedure, Adolph (1995) found walking skill to be the best predictor overall for both ascent and descent boundaries.

The purpose of this study was to investigate the roles of walking experience and walking skill in determining the action choices of 18- and 24-month-old toddlers in crossing barriers of varying heights. Such an investigation was of interest for a number of reasons. First, as previously mentioned, few researchers have looked at these two concepts separately in their investigations of the affordances of locomoting children (Adolph, 1995; Adolph et al., 1993a); walking skill, rather than walking experience, appears to be a more powerful predictor of the action capabilities of young children. Second, although walking patterns are still not mature, toddlers in this age range may show more variability in kinematic and anthropomorphic variables, as well as greater walking skill than the younger ages previously investigated. For example, Schmuckler (1996) found that 18- and 24-month-old toddlers were more accurate in their perceptual judgments of impassable barriers than 12-month-old toddlers. This finding suggests a developmental trend with the accuracy of our perceptual judgments improving with age. A similar trend has also been found for measures of walking skill — with improvements in walking skill positively correlated with days of walking experience (Adolph, Vereijken, Byrne & Ilustre, 1996).

Moreover, studies of barrier crossing create an ideal situation for investigating perceptual-motor behavior and its impact on the perception of affordances. Both physical and

perceptual constraints determine an individual's ability to successfully cross a barrier. In choosing the best course of action, an actor must be able to accurately perceive the height and width of the barrier and take into account his/her physical capabilities and limitations in executing the movements needed to cross (Schmuckler, 1996).

Although the act of crossing a barrier can be accomplished in more than one way (see Heinrichs, 1994), the primary interest in this study includes the movement patterns involved in stepping over a barrier. For very low barriers, successfully stepping over simply entails taking a higher step than normal. For somewhat higher barriers, the actor must approach the barrier and plant one foot close to it, lift the other leg over and plant it on the other side. The actor must then shift his weight to the other side of the barrier in order to bring the lagging leg across. Crossing barriers of even greater heights presents further difficulties, with strength, flexibility and balance playing a more significant role. For example, depending on the height of the barrier, it may be necessary for the actor to balance on her toes, and/or on the ball of her foot, in order to achieve the height needed to cross.

Based on this description of the movement patterns involved in barrier crossing, as well as previous research, there are a number of variables that are of interest in examining the abilities of toddlers in stepping over barriers. Such measures include walking skill, walking experience, and various indices of body proportion. Previous investigations of walking skill in toddlers have used a global measure in which measures of stride length, step length, step width, foot rotation and dynamic base are derived from the inked footprint sequences of each child's walking pattern and compared to the mature pattern of adults (Adolph, 1995; Adolph et al., 1993a; Adolph et al., 1996; Boenig, 1977). The more closely a child's walking pattern resembles that of a mature adult, the more skilled he/she is at walking. In general, improvements in walking skill are associated with longer steps, longer strides and smaller step

widths when walking. Small foot rotations, indicating a straight path of progression when walking, are also associated with greater walking skill (Adolph, 1995; Adolph et al., 1996). In her work on affordances in locomotion, Adolph (1995) found this global measure of walking skill to be a powerful and useful tool for predicting the walking boundaries of toddlers for going up and down slopes. Finally, a general questionnaire will attempt to assess previous experience with barriers and related surfaces.

Method

Participants

Thirty-two toddlers participated in this study, 16 toddlers each at 18 months (7 boys and 9 girls) and 24 months (11 boys and 5 girls) of age. The mean age of each group was 18.0-months and 24.8-months respectively. An additional 24 children (17 18-month-olds and 7 24-month-olds) participated in the study but were not included in the data analysis. Of these children, they either ran on both walking trials (12), refused to walk (1), did not reach their crossing limit as a consequence of refusing to cross the barrier, kicking the barrier or becoming too upset to participate (10) or, were too overexcited to participate (1). All infants were recruited from the Scarborough, Ontario, community and received a toy and certificate for their participation.

Experimental Apparatus

The barrier created for Schmuckler (1996) was used in this study. The barrier consisted of two grey, hollow vertical poles, each supported by a steel base. Each of the poles had notches cut into them in 1 inch increments from top to bottom. A grey, plastic dowel, approximately 1.4 m long and 2 cm thick, stretched horizontally between these two poles, supported by the notches. The notches allowed the horizontal dowel to be positioned from 0 inches off the ground up to 18 inches high.

Procedure

Testing took place in a long hallway with separate areas designated for two of the measures: walking skill and barrier crossing. A video camera resting on a tripod at one end of the hallway recorded the experimental session. All trials for both measures began at the experimenter's end of the hallway; consequently, the children's movements were all filmed from behind. Each test session began with the assessment of walking skill followed by the assessment of barrier crossing abilities.

In the area of the hallway designated for the assessment of walking skill, the floor was lined with a 6m long strip of paper and a chair was placed at the beginning of the paper. Lines demarcating the starting line (i.e., the beginning of the paper) and the finishing line were drawn at either end of the paper (i.e., the end of the paper). The parent of the child was instructed to stand at the finishing line and the child was placed at the starting line. Once the two experimenters had positioned themselves on either side of the length of the paper, the child was encouraged to walk along the paper to the waiting parent. For each test session, several practice trials took place to ensure that children would walk along the length of the paper and would not stray from the paper during the process. If a child ran on the paper, the task was modeled by either the parent or the experimenter in order to demonstrate that walking was the desired behavior.

Following the practice trials, the child was seated in the chair in order for the inkpads to be placed on his/her feet. For ease of application, the inkpads were placed on pieces of cardboard that could easily be taped to the bottoms of a child's shoes; the bottom edge of each card was always placed such that it was in line with the edge of the child's heel. Each inkpad card consisted of a strip of cardboard, measuring 10.2 x 3.8 cm, and two pieces of moleskin, one piece cut into the shape of a triangle (2.5 x 3.0 x 3.0 cm) and one, cut into the shape of a square

(2.5 x 2.5 cm). The moleskin was placed on the card such that the tip of the triangle touched the top edge of the card and the bottom edge of the square touched the bottom edge of the card. Liquid ink was applied to the moleskin immediately prior to the cards being placed on the child's shoes. Once the inkpad cards were in place, the child was taken out of the chair, positioned at the starting line and again encouraged to walk towards his parent. At the end of the test trial, the parent picked up the child and the experimenters removed the inkpad cards. The trial was repeated with a fresh strip of paper if the child happened to run along the paper, stop halfway or turn around during the test trial.

Once walking skill had been assessed, both parent and child moved to the second area of the hallway for the barrier crossing component of the study. The barrier was set up such that it was in line with a recessed doorway in the hallway. To protect a toddler from falls, gymnastic mats lined the floor. Again, two experimenters were responsible for running the experiment. Positioned at opposite ends of the hallway, the first experimenter and one of the child's parents were responsible for encouraging the child to approach and cross the barrier. The second experimenter, positioned in the recessed doorway and hidden from view, was responsible for adjusting the barrier's height.

Prior to testing, both parent and child had a chance to settle in and play with a pile of toys at the parent's end of the walkway in order to become accustomed to the new setup. Following this, the child was brought to the experimenter's end of the walkway. Once the barrier had been adjusted to the appropriate height, the child was encouraged to walk towards the barrier and to cross it in order to get a toy from the parent to bring back to the experimenter. Receiving a toy at the end of each trial is in contrast to the Schmuckler (1996) study in which children carried toys to their parents. One concern with Schmuckler's (1996) methodology is that a child's balance may have been affected by not having her hands free when crossing the barrier;

moreover, children in the study often took as many or even more toys than they could easily handle.

For each trial, parents could provide verbal encouragement to their child but were discouraged from both physically helping their child and from sitting too close to the barrier such that the child did not need to cross the barrier in order to get a toy. Because of the age of these participants and the possibility that they could trip and fall if they were unaware of the barrier's presence, the necessary movement needed to cross the barrier was modeled during the first few trials of the test session. Following the completion of a trial, the barrier was removed by the second experimenter and the child was induced back to the starting point. The second experimenter then replaced the barrier, adjusted its height accordingly, and the process was repeated.

At the end of the session, a number of physical measures were taken to assess the child's body size. These measures included the child's standing and sitting height, body weight, as well as waist, hip and shoulder width. Parents were also asked various questions related to their child's walking experience. The entire session lasted approximately 45 to 60 minutes.

Testing

A modified psychophysical staircase procedure was used to determine the barrier crossing thresholds of the toddlers. With this procedure, subjects are presented with stimuli in increasing increments until a change in behavior or response occurs. The process is then repeated in reverse, with the stimuli presented in decreasing order until a change in responding again occurs. This pattern of alternating between increasing and decreasing increments is continued with each change in response until a predetermined criterion has been met; at which point, a measure of threshold is taken (Adolph, 1995; Schmuckler, 1996).

Adapting this procedure to barrier crossing, infants were initially presented with a low barrier height (three inches). Their crossing behavior was coded as a success (e.g., able to step over), a failure (e.g., falls down when crossing) or a refusal (e.g., no attempt was made). Special notations were used if the child attempted to crawl over the barrier or if the child held on to the side of the barrier while crossing; the success or failure of these attempts were also recorded. If a child was able to successfully cross a specific barrier height twice in a row, the height was increased by two inches. Increases in height continued until a failure or refusal to cross occurred. Following this change in behavior, the barrier height was decreased by one inch. If the child was still unable to cross, the barrier height was dropped again by one inch. Increases in barrier height once again occurred if the infant could successfully cross the barrier two times in a row; subsequent unsuccessful crosses caused a decrease. Barrier heights that a child failed to cross on two trials while still able to cross the next lowest height were coded on-line as a crossing threshold.

To avoid frustration at repeated failures, trials at a very low height were interspersed throughout the experiment (Schmuckler, 1996). Trials at a very low height were also used to break up a pattern of supported crossing (i.e., successfully stepping over the barrier while holding on to the side). The number of trials completed by a child was variable and depended to a great deal on how quickly the child walked back and forth during the test session; all children, however, completed a minimum of 17 trials for inclusion in the study.

Measures

Body Size Variables

Measures of body weight, standing and sitting height, and shoulder, waist, and hip widths were taken for each child. A standard bathroom scale with a digital readout was used to measure the child's weight. A measuring tape placed on a wall allowed for recordings of height to be

easily made when a child was standing with her back against the wall and when she was seated on the floor in the same manner. Width measurements were obtained by wrapping a measuring tape around the child's shoulder bones, the area around her navel and, the area above her pelvic bone, for shoulder, waist and hip measures, respectively.

From these measures, a number of additional measures could be derived, including leg length (sitting height - standing height), the Ponderal Index ($\text{weight}/(\text{standing height})^3 \times 100$) and a ratio of shoulder width/waist width. In children, small values of the Ponderal Index and the shoulder-to-waist ratio are associated with more mature body proportions (Adolph, 1995).

Walking Skill

Walking skill was assessed using information derived from the inked footprint sequences of each toddler's walking pattern (Adolph, 1995; Boenig, 1977). A transparent grid (0.25 cm) was used to obtain XY coordinates for the middle portion of each child's walking pattern, where it is believed that children hit their stride (Brenière, Bril & Fontaine, 1989). For each footprint, XY coordinates of the tip of the toe print and the midpoint of the heel print were obtained. For each child, a minimum of three footprints per foot were coded.

A specially designed computer program was used to derive the relevant measures of interest from the XY coordinates of the footprint sequences; these measures included stride and step length, step width, foot rotation, and dynamic base. Stride length is defined as the distance between the heel prints of the same foot. Step length is the distance between the heel strike of one foot and the heel strike of the other foot. Step width is a measure of the lateral distance between the heel strike of one foot and the heel strike of the other foot. The angle of a child's toe print relative to their heel print is given by the measure of foot rotation (i.e., toe-in or toe-out); children who are more skilled at walking point their feet straight ahead (Adolph, 1995; Adolph et al., 1996). And finally, dynamic base is a measure of the "angle between the stride of

one foot and the step on the other foot” (Adolph, 1995); this angle can be obtained from three [dynamic base (3)] or four steps [dynamic base (4)].

More specifically, dynamic base reflects how well children are able to control their path of progression; as walking skill improves, dynamic base approaches angles of 180 degrees. This relatively new measure of walking skill is designed to provide information about step length, step width and the relation between them (Adolph, 1995). Of the types of information provided by this global measure (i.e., the footprint method) of walking skill, dynamic base was found to be the greatest predictor of the children’s walking boundaries for both ascending and descending slopes in Adolph’s (1995) study.

Locomotor Experience

Parents were encouraged to consult their personal records prior to their visit as they would be asked to provide information concerning the onset of crawling, independent standing, and upright locomotion for their child. Upright locomotion was defined as the age at which children can stand on their own, without any help, and walk 10 steps across a room (Schmuckler, 1996). To obtain additional information about more individual experiences with walking, parents were asked about their child’s experience with stairs, gates, and playground equipment. Parents were also asked whether their child had ever experienced a serious fall or whether he/she displayed any fear of heights.

Results

To examine whether the walking skill measures obtained varied as a function of left versus right foot within the two age groups, a series of preliminary two-way analyses of variance (ANOVAs) were conducted. Walking skill measures included stride length, step length, step width, foot rotation, dynamic base (3) and dynamic base (4). None of these measures produced a significant main effect for foot (right vs. left), or any interaction between foot and age (all p s >

0.05); consequently, all walking skill measures were averaged across left and right feet. The first primary series of analyses examined the anthropomorphic, walking skill and locomotor experience measures, as well as the subsequent crossing thresholds, as a function of age (18 vs. 24 months), using one-way ANOVAs. The next series of analyses examined the relation between crossing thresholds and the variables of interest, body size, walking skill, age and locomotor experience (normalization analyses). And finally, the correlations within and between crossing thresholds, body size variables, walking skill and locomotor experience were examined.

Age Differences

In terms of body size, children in the two age groups differed on a number of physical parameters. Significant differences between the ages were found for standing height [$F(1, 30) = 21.64$, $MSE = 39.38$, $p < .001$], sitting height [$F(1, 30) = 9.20$, $MSE = 6.35$, $p < .01$], body weight [$F(1, 30) = 24.29$, $MSE = 220.50$, $p < .001$], leg length [$F(1, 30) = 16.79$, $MSE = 14.11$, $p < .001$] and hip width [$F(1, 30) = 5.38$, $MSE = 8.00$, $p < .05$]. Generally, the older children were taller and heavier than the younger children. Not all anthropomorphic measures varied as a function of age, however. Specifically, there were no differences in measures of waist width [$F(1, 30) = 0.31$, $MSE = 0.50$], shoulder width [$F(1, 30) = 3.79$, $MSE = 5.91$], Ponderal Index [$F(1, 30) = 0.11$, $MSE = 0.00$], or shoulder-to-waist ratio [$F(1, 30) = 1.27$, $MSE = 0.01$] as a function of age. Mean values for the 18- and 24-month-old toddlers for all of these measures are given in Table 1.

In contrast to the body size measures, assessments of walking skill showed few differences as a function of age. Only marginally significant differences were found for stride length and step length, $F(1, 30) = 3.60$, $MSE = 147.86$, $p = .068$ and $F(1, 30) = 3.51$, $MSE = 33.15$, $p = .071$, respectively. A comparison of the mean values given in Table 1 for these

measures of walking skill show that 24-month-old toddlers have slightly longer strides and steps than 18-month-old toddlers. No significant differences in step width [$F(1, 30) = 0.03$, $MSE = 0.07$], foot rotations [$F(1, 30) = 0.002$, $MSE = 0.33$], dynamic base (3) [$F(1, 30) = 0.95$, $MSE = 224.46$] and dynamic base (4) [$F(1, 30) = 0.03$, $MS = 2.48$], however, were found between the two age groups. Mean values for these measures are also listed in Table 1.

Significant differences, though, in crawling [$F(1, 28) = 154.10$, $MSE = 271.50$, $p < .001$], standing [$F(1, 30) = 90.77$, $MSE = 277.60$, $p < .001$] and walking [$F(1, 30) = 109.90$, $MSE = 304.74$, $p < .001$] experience were found between the age groups. The degrees of freedom for crawling experience differs from the remaining two forms of locomotor experience as two children in the study were reported to never have crawled. Overall, and not surprisingly, older children were found to have had more locomotor experience than younger children. Again, mean values for the various experiential variables as a function of age are given in Table 1.

Similarly, crossing thresholds were also found to vary as a function of age [$F(1, 30) = 36.15$, $MSE = 112.50$, $p < .001$]. Older children were successfully able to cross barriers much higher in height than younger children. The mean crossing threshold for the 24-month-old children was 9.31 in. ($SD = 1.78$ in.) and 5.56 in. ($SD = 1.75$ in.) for the 18-month-old children.

Normalization Analyses

The next step in the analysis involved examining the relation between crossing thresholds and the various body size, walking skill, and locomotor experience measures. To accomplish this goal, each child's crossing threshold was divided by each of the various measures; the resulting normalized crossing thresholds were then compared as a function of age in a series of one-way ANOVAs. This procedure, developed by Schmuckler (1996), was adapted from Warren (1984), who found that differences in the maximum height of perceived stair

climbability between short and tall participants were eliminated once these judgments were divided by the participants' leg length. In the current context, factors that are most strongly related to crossing thresholds will eliminate differences in threshold values, both within an age group as well as between age groups. In contrast, variables that are less strongly related to crossing thresholds, although reducing differences within and between age groups, will not eliminate these differences (Schmuckler, 1996).

Table 2 presents the results of the 1-way ANOVAs, with the factor of age (18 vs. 24 months), on the normalized crossing thresholds. Replicating Schmuckler (1996), none of the body size variables removed the differences in crossing thresholds as a function of age. Interestingly, and in contrast to Adolph's (1995; Adolph et al., 1993a) findings, measures of walking skill were similarly ineffective in removing threshold differences across the ages. Alternatively, and again replicating Schmuckler (1996), all of the experiential variables successfully eliminated the threshold differences as a function of age.

Correlational Analyses

An alternative way of further examining the relation between crossing thresholds and the various body size, skill and experiential variables involves calculating the correlation between these variables, both across and within each age group; these correlation coefficients are presented in Table 3. For the analyses combining the two age groups, it is worth noting that the largest correlations were found between crossing thresholds and the three types of locomotor experience; this finding is also in keeping with the earlier findings obtained from the normalized data. Also of interest are the large correlations between crossing thresholds and standing height and between, crossing thresholds and leg length for the combined age groups.

Looking at the individual age groups, a significant correlation between crossing thresholds and leg length was also found for the 24-month-olds. This finding, in conjunction

with the correlation for the combined age group, suggests that the physical parameter of leg length is influencing crossing thresholds. A significant negative correlation was also evident between the angle of the foot rotations of 24-month-old children and their crossing thresholds. Smaller foot rotations were associated with higher crossing thresholds; they are also associated with greater walking skill (Adolph, 1995; Adolph et al., 1996).

The inter-correlations among the walking skill variables assessed also show strong correlations; these values are presented in Table 4. Not surprisingly, stride length and step length, were almost perfectly correlated with another. Large correlations were also found between measures of dynamic base and stride length, step length, and step width. Again this is not surprising as the measure of dynamic base is designed to reflect the relation between these three variables. Similar patterns are seen in the correlations among the walking skill variables for the individual age groups. Unexpectedly, step width was only weakly correlated with stride and step length for the combined age group; moreover, a significant positive correlation was found for the 24-month-old toddlers. This is in contrast to previous findings on changes in walking skill, where step widths have been found to decrease as stride and step length increase (Adolph, 1995); with a larger sample size, however, the pattern seen here may change.

Looking at the correlation between measures of walking skill and locomotor experience for the combined ages, stride and step length were positively correlated with length of crawling and walking experience. Thus, longer steps and strides were seen in children with greater amounts of crawling and walking experience. Adolph et al. (1996) also found a large correlation between days of walking experience and measures of walking skill. Standing experience, however, was only weakly correlated with step and stride length. No significant correlations were found between the measures of step width, foot rotation, dynamic base (3) and dynamic base (4) and, locomotor experience for the combined ages. For the individual age groups,

dynamic base (4) was significantly correlated with standing experience for the 24-month-old children. However, no other significant correlations between the measures of walking skill and locomotor experience were found for the individual age groups. All of these correlation coefficients are presented in Table 5.

Discussion

To summarize the main findings of this experiment, a number of parameters were examined, including measures of walking skill, body size, and locomotor experience, as well as the barrier crossing abilities for a group of 18- and 24-month-old toddlers. Walking skill was assessed using the footprint method of gait analysis; few significant differences however were found between the two ages. On all other measures though, 24-month-old children were found to differ in several ways from 18-month-old children. In addition to being larger and heavier, the older children also had more crawling, standing and walking experience than did the younger children. The older group of toddlers were also able to cross barriers much higher in height than the younger group of toddlers. Of the variables investigated (body size, walking skill and locomotor experience) as possible predictors of children's barrier crossing abilities, walking experience was found to be the best predictor of crossing thresholds for 18- and 24-month-old children.

Although previous work, addressing the conceptual difference between walking skill and walking experience, found walking skill to be a stronger predictor of children's abilities to walk up and down slopes than walking experience (Adolph, 1995; Adolph et al., 1993a), the findings of the current study paint a somewhat different picture. Rather the action capabilities of 18- and 24-month-old toddlers for crossing a barrier varying in height were strongly predicted by the length of time a child had been independently mobile. This finding is consistent with previous

work by Schmuckler (1996) in which barrier crossing thresholds were most strongly related to the amount of walking experience a child had had.

There are several possible explanations for the apparent dichotomy in findings seen here with respect to the roles of walking experience and walking skill in predicting the abilities of newly locomoting children. First of all, the actions involved in walking up and down slopes are dramatically different from those required to cross over a barrier. The key actions involved in barrier crossing depend to a certain degree on the height of the barrier. As previously discussed (see Heinrichs, 1994), stepping over very low barriers simply involves taking a slightly higher step than when normally walking. High barriers, on the other hand, involve an interplay of balance, strength and flexibility and a more complicated series of movements (e.g., balancing on one foot, swinging a leg across the barrier). As the height of the barrier continues to increase, so too, does the level of difficulty involved; eventually, a height will be reached where it is no longer physically possible for an individual to step over the barrier. Thus, the act of successfully crossing over a barrier depends to a large degree on the actor recognizing the correct pattern of actions needed to cross.

In contrast, successfully walking up and down slopes involves repeating a similar set of actions over and over. Although the basic leg actions are the same as those used to walk across a flat surface, the direction and angle of the slope can put different physical demands on these familiar actions. For instance, when walking up a slope, the actor leans forward, an action that aids in his acceleration up the slope; however, when walking down a slope, the actor must lean backwards to avoid increasing his forward momentum and toppling forwards (Adolph et al., 1993a).

Given these different demands, the walking skill assessment used (Adolph, 1995; Adolph et al., 1996; Boenig, 1977), although thought of as a global measure of walking skill, is more

closely attuned to the motor demands of walking up and down slopes than to the motor demands of barrier crossing. For example, walking on flat ground does not require the actor to balance on one foot while swinging a leg across an obstacle. Thus, although, intended as a general measure of skill, the footprint method of gait analysis may in fact be much more specific to particular locomotor activities. Adolph's (1995) own findings would seem to support this very idea. Although Adolph (1995) found dynamic base to be the best predictor of the abilities of 14-month-old toddlers to walk up and down slopes, the strength of this relation was affected by the direction of the slope. Larger correlations were found between measures of dynamic base and walking boundaries for ascending than for descending slopes.

Walking up and down slopes also differ in terms of the physical demands and the level of control required to maneuver oneself. Whereas walking up a slope may be more physically tiring, it requires less physical control than walking down a slope; one consequence of this difference is that there is less danger of seriously hurting oneself when going up a slope than when going down a slope (Adolph, 1995). With respect to the amount of control required, walking on flat ground would be similar to walking up a slope, in that it too, would require lower levels of physical control than walking down a slope. It may be that as the amount of control required in a physical task increases (thereby moving further away from the levels required for walking on flat ground), this global measure of walking skill is no longer of use. The pattern of correlations found by Adolph (1995) would certainly seem to support the hypothesis that the strength of the relation between this global measure of walking skill and the physical task being predicted is dependent on how similar the two are in makeup.

Also consistent with this suggestion are the findings of Bril and Brenière (1992) from a two-year study in which a number of gait parameters were assessed in a group of children following their first steps. According to these researchers, the development of walking in young

children occurs in two phases. The first phase, lasting between 3 to 6 months after the onset of walking, is a learning period in which a child learns to integrate the necessary physical components needed to initiate her first steps (Brenière et al., 1989). During this time period, dramatic visible changes in a child's gait occur. The second phase is a period in which a child's abilities become more finely tuned; it is characterized by a stabilizing of the gait parameters and takes place during the 18 months following the end of the first phase (Bril & Brenière, 1992). Unfortunately, the researchers only observed children for a period of two years following the onset of walking (i.e., until roughly their third birthday). As it has been suggested that children do not have mature pattern of walking until they are around six years of age (Pufall & Dunbar, 1992), it is conceivable that the length of this second phase is much longer than originally suggested. Alternatively, the development of walking may be more complicated than a two phase process.

Bril and Brenière (1992) further suggest that during the first developmental phase of walking, a child's primary goal is twofold: not only must the child learn how to maintain sufficient postural control to remain upright but he must also do so while attempting to propel his body forward. Until a child has adequately mastered this process, upright locomotion is limited. Thus, the process of maintaining postural control while walking is a complicated one that can only be successfully achieved through the integration of a number of interdependent elements. One consequence of the complexity of this process is that the abilities of a child displayed during this first phase are very sensitive to external influences. As a result, situations that are posturally demanding for a child may lead to a visible regression in the child's ability to maintain her balance. Manipulations, then, that stress the child's postural control system can be seen to either reject or support predictions of a causal relation between characteristics of gait displayed early on and balance control (Bril & Brenière, 1992).

This hypothesis may in fact be a key factor in the task related pattern of findings seen here. Following the ideas put forth by Bril & Brenière (1992), the act of crossing a barrier would easily qualify as a very posturally demanding task, particularly in the case of a very young child. Thus, measures of a child's walking skill on flat ground (a task that is presumably less posturally demanding than barrier crossing and consequently, would not disturb postural control to the same degree) may not be strongly related to crossing thresholds.

Perhaps then what is needed is a different measure of skill; one that more accurately assesses the elements involved in crossing a barrier. For instance, although the footprint method of gait analysis provides a global measure of walking skill, this ability can also be assessed through measures of various kinematic parameters, such as balance, flexibility and strength. A number of different tests can be used to measure each of these parameters independently (see Heinrichs, 1994). One limitation of these tests however, is that little information is available concerning how such variables change as a function of increasing age (and presumably) walking skill; the absence of such comparison data may be due to the difficulty in testing these variables in young children. In spite of the lack of such information, an attempt was made to assess these three kinematic parameters in the two age groups of interest in the current study. Unfortunately, these attempts had to be abandoned as the physical demands of the task were either too great, especially for the younger age group, or the children were simply too young to complete the task on demand putting into question the reliability of the measure obtained.

Alternatively, it may be that the importance of skill itself changes with age. For instance, it may be useful to think of skill in an abstract way. Early in life, skill may be of a global form; over time, the basic elements making up this global form of skill become increasingly differentiated and refined. Thus, it may be that once a basic (although not yet mature) level of skill has been achieved, experiential factors take on a greater role in predicting a child's motor

abilities. Perhaps then the difference in findings between Adolph's (1995) study and the current study is reflective of a developmental change such as this, with walking skill more important than walking experience in the very early days of walking. A comparison of the amount of walking experienced by the age groups in question does reveal large differences. The 14-month-old toddlers who participated in Adolph's (1995) study had an average of 76.87 days of walking experience. In contrast, the 18- and 24-month-old toddlers in the current study had approximately 199 days (6.64 months) and 384 days (12.81 months) of walking experience, respectively. Children in the current study then, had almost two and a half to five times as much walking experience than the children in Adolph's (1995) study. Although Schmuckler (1996) found a scaling of action to walking experience in the 12-month-old children who participated in his study, walking skill, itself, was not assessed. Had it been, a very different pattern of results may have been found, for instance, with a scaling of barrier crossing abilities to skill in the youngest age group (12-months), and to experiential variables in the older two age groups (18 and 24 months).

It may be that the action capabilities of children are initially related to skill variables, then to experiential factors and finally, to physical measures. A pattern of changes such as this is not unheard of in the literature on affordances. Certainly work with older adults has shown a movement away from a direct scaling of action to anthropomorphic measures, to a combination of anthropomorphic and kinematic variables as these individuals experience constraints on their movements as a consequence of aging (Konczak et al., 1992). In order to determine whether children show similar changes in scaling factors, walking skill, walking experience, and the barrier crossing thresholds of 14-month-old children need to be examined. Assessing the abilities of 14-month-old children is important for a number of reasons. Not only will it allow for a more accurate comparison to Adolph's (1995; Adolph et al., 1993a) findings on the role of

walking skill in predicting children's abilities in walking up and down slopes but, it will also help to chart the developmental changes involved in the scaling of the action capabilities of children in a variety of physical tasks. Moreover, it will provide information as to whether the physical demands of barrier crossing and those involved in walking on flat ground are similar enough to make direct comparisons.

In addition to examining the abilities of even younger age groups, attention also needs to be directed towards the abilities of older children. Previous work examining the scaling of action choices in barrier crossing has found crossing thresholds to be strongly related to leg length in children as young as five (Heinrichs, 1994). The large correlation coefficient found between leg length and crossing thresholds for 24-month-old children in the current study, however, suggests that a scaling of action to a physical measure may be seen in children younger than 5 years of age. Future studies examining the abilities of children falling between 2 and 5 years of age will allow researchers to determine the age at which the scaling of a child's action capabilities switches from experiential factors to physical factors.

In spite of the differences found in action capabilities for crossing a barrier varying in height, few differences were found in the measures of walking skill between the 18- and 24-month-old toddlers in this study. Overall, only slight differences in step length and stride length were found, with older children taking longer steps and strides than the younger children. Although greater differences were expected, this pattern is consistent with improvements in walking skill. Children who are more skilled at walking take both longer strides and steps, their feet are also more closely positioned to one another and point straight ahead when walking than children who are less skilled (Adolph, 1995; Adolph et al., 1996).

A comparison of the range of values for the skill measures assessed in the current study with those obtained in Adolph's (1995) study does indicate a very large difference in walking

skill between children in the two studies (see Table 6). Thus, it would appear that between the ages of 14 and 18 months that walking skill dramatically improves. Minimum and maximum values for the measures of stride and step length are much larger for the older two age groups. Likewise, the range of values of step width is also smaller for the 18- and 24-month-old toddlers. All of these differences are consistent with improvements in walking skill. Moreover, the maximum values of the step widths reported are less than 5 cm for both of the older ages; similarly small step widths have been reported for the mature patterns of walking found in adults (Adolph, 1995).

These findings are consistent with Bril and Brenière's (1992) hypothesis concerning the development of walking. According to these researchers, the first developmental phase of walking ends when children are approximately 15- to 18 months of age and the second phase, when they are between 33- to 36-months of age. Based on these age breakdowns, the children in Adolph's (1995) study clearly fall in the first phase of walking development while the majority of those in the current study fall in the second phase of development (only 5 toddlers fell in the first developmental phase). Thus, it may be that in order to find significantly large differences in walking skill in toddlers 18 months of age and older, a much greater age range must be considered than that chosen in this study (i.e., more than 6 months).

Moreover, that no foot preferences were found for the 18- and 24-month-old children in the current study further suggests that walking skill has dramatically improved from assessments done at 14 months of age. On measures of walking skill, 14-month-old children show a right foot preference; measures obtained from their right feet are more reliable than those from their left feet (Adolph, 1995; Adolph et al, 1993a; Adolph et al., 1996). The disappearance of this foot preference by 18 months of age is in keeping with the findings of Clark and Philip (1993). Looking specifically at the development of intralimb (e.g., between the legs) and interlimb (e.g.,

within a leg) coordination, the researchers found that children achieved an adult-like relation between these two elements after three months of walking. In Adolph's (1995) study, the mean length of walking experience for the children involved was approximately 2.5 months ($M = 76.87$ days); a period of time falling short of Clark and Philip's (1993) three-month mark. In contrast, this three-month mark is clearly surpassed even by the youngest age group in the current study who had on average 6.64 months of walking experience. The lack of a difference in skill measures between children's feet in the current study further illustrates an increasingly synchronized, and thus, more consistent pattern of walking in children 18 months of age and older.

Thus, the results of the current study suggest that little change in walking skill occurs between the ages of 18 and 24 months; however, large changes indicative of improvements do seem to take place between the ages of 14 and 18 months (see Adolph, 1995; Adolph et al., 1996). These findings are consistent with the two-phase theory of walking development put forth by Bril and Brenière (1992); one limitation to this theory however, is that little is known about changes in walking skill that may occur past this second phase. As a mature pattern of walking is not achieved until the age of six (Pufall & Dunbar, 1992), there is a strong possibility that more than two phases are involved in this developmental process. More information is thus needed to determine exactly how the gait parameters assessed by the footprint method change as a function of age. Additionally, the limitations of this assessment technique as a predictor for different forms of visually-guided locomotion also needs to be addressed.

Not only is future research critical for charting the developmental changes that occur in walking skill but much is also needed to determine the changes that take place in the scaling of action capabilities in young children. This study, in conjunction with the work of Adolph (1995), Schmuckler (1996) and Heinrichs (1994) suggests that the scaling of action in young

children follows a specific developmental path. Early on, walking skill appears to play an important role in predicting a child's physical capabilities. Once a certain level of walking skill is achieved however, these skill factors are displaced in favor of locomotor experience as the strongest predictor of children's abilities. And finally, once a mature pattern of walking is achieved, a scaling of action to anthropomorphic factors, similar to that found for adults, is seen. Thus, children's ability to successfully navigate themselves through the world depends to a large degree on their sensitivity to, and ability to adapt to the series of changes occurring in the fit between themselves and their environment.

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Table 1

Mean Values and Standard Deviations for Measures of Body Size, Walking Skill, Locomotor Experience, and Crossing Thresholds

Variable	18 Months		24 Months	
	Mean	SD	Mean	SD
Body Size				
Standing height (in.)	32.53	1.69	34.75	0.88
Sitting height (in.)	19.03	0.85	19.92	0.82
Weight (lb)	22.06	3.17	27.31	2.85
Leg length (in.)	13.50	1.06	14.83	0.75
Waist width (in.)	19.47	1.28	19.72	1.25
Hip width (in.)	20.97	1.12	21.97	1.31
Shoulder width (in.)	23.02	1.31	23.88	1.19
Ponderal Index	0.06	0.01	0.07	0.01
Shoulder-to-waist ratio	1.18	0.07	1.21	0.08
Walking Skill				
Stride length (in.)	24.81	4.24	27.85	4.73
Step length (in.)	13.00	1.94	14.44	2.60
Step width (in.)	3.48	1.27	3.41	1.06
Foot rotation	13.54	7.43	13.68	18.23
Dynamic base (3) (°)	147.64	13.19	151.39	7.89
Dynamic base (4) (°)	164.00	7.37	164.40	9.39

Locomotor Experience				
Crawling (months)	11.18	1.03	17.20	1.57
Standing (months)	9.00	1.59	14.89	1.89
Walking (months)	6.64	1.66	12.81	1.67

Table 2

Results of One-way ANOVAs on Normalized Crossing Thresholds as a Function of Body Size, Walking Skill, and Locomotor Experience

Variable	F value
Body Size	
Standing height (in.)	$F(1, 30) = 29.41$
Sitting height (in.)	$F(1, 30) = 30.34$
Leg length (in.)	$F(1, 30) = 26.19$
Waist width (in.)	$F(1, 30) = 29.77$
Hip width (in.)	$F(1, 30) = 25.44$
Shoulder width (in.)	$F(1, 30) = 26.72$
Weight (lb)	$F(1, 30) = 9.11$
Ponderal Index	$F(1, 30) = 20.39$
Shoulder-to-waist ratio	$F(1, 30) = 29.10$
Walking Skill	
Stride length (in.)	$F(1, 30) = 16.69$
Step length (in.)	$F(1, 30) = 17.88$
Step width (in.)	$F(1, 30) = 4.00 *$
Foot rotation (°)	$F(1, 30) = 11.16$
Dynamic base 3 (°)	$F(1, 30) = 30.28$
Dynamic base 4 (°)	$F(1, 30) = 35.49$

Locomotor Experience

Crawling (months)	$\underline{F}(1, 28) = 0.37$ ***
Standing (months)	$\underline{F}(1, 30) = 0.02$ ****
Walking (months)	$\underline{F}(1, 30) = 2.28$ **

Note: Except where noted, $p < .01$

* $p = .055$, ** $p = .142$, *** $p = .551$, **** $p = .888$

Table 3

Strength of the Relation Between Crossing Thresholds and Measures of Body Size, Walking Skill, and Walking Experience

Variable	Correlation Coefficient		
	All Ages (N = 32)	18 Months (N = 16)	24 Months (N = 16)
Body Size			
Standing height (in.)	0.60**	0.28	0.19
Sitting height (in.)	0.40*	0.42	-0.29
Weight	0.43**	-0.10	-0.15
Leg length (in.)	0.60**	0.11	0.54**
Waist width (in.)	-0.02	-0.28	-0.01
Hip width (in.)	0.17	-0.33	-0.07
Shoulder width (in.)	0.10	-0.35	-0.10
Ponderal Index	-0.19	-0.40	-0.28
Shoulder-to-waist ratio	0.13	-0.02	-0.05
Walking Skill			
Stride length (in.)	0.31*	0.25	-0.03
Step length (in.)	0.29	0.24	-0.07
Step width (in.)	-0.15	-0.03	-0.25
Foot rotation	-0.26	0.001	-0.60**
Dynamic base (3) (°)	0.18	0.24	-0.20
Dynamic base (4) (°)	0.15	0.27	-0.03

Locomotor Experience			
Crawling (months)	0.71**	0.12	0.20
Standing (months)	0.60**	-0.20	-0.05
Walking (months)	0.65**	-0.23	0.17

Note: * $p < .05$ and ** $p < .01$

Table 4

Inter-correlations Between Measures of Walking Skill for Eighteen- and Twenty-four-Month-Old Toddlers

Variable	1	2	3	4	5	6
Combined Ages						
1. Stride length	—					
2. Step length	0.98**	—				
3. Step width	0.07	0.20	—			
4. Foot rotation	-0.09	-0.06	0.08	—		
5. Dynamic base (3)	0.55**	0.41**	-0.53**	0.12	—	
6. Dynamic Base (4)	0.47**	0.32*	-0.51**	0.02	0.92**	—
18 Months						
1. Stride length	—					
2. Step length	0.98**	—				
3. Step width	-0.09	0.07	—			
4. Foot rotation	0.15	0.08	-0.13	—		
5. Dynamic base (3)	0.74**	0.60**	-0.59**	0.33	—	
6. Dynamic Base (4)	0.76**	0.63**	-0.51	0.28	0.96**	—
24 Months						
1. Stride length	—					
2. Step length	0.98**	—				
3. Step width	0.49**	0.59**	—			
4. Foot rotation	-0.20	-0.12	0.28	—		

5. Dynamic base (3)	0.27	0.14	-0.29*	0.02	—	
6. Dynamic Base (4)	0.13	-0.01	0.51**	-0.20	0.84**	—

Note: * $p < .05$ and ** $p < .01$

Table 5

Strength of the Relation Between Measures of Walking Skill and Locomotor Experience

Walking Skill	Locomotor Experience		
	Crawling	Standing	Walking
All Ages			
Sample size	30	32	32
Stride length	0.32**	0.26	0.37*
Step length	0.33**	0.26	0.39*
Step width	-0.09	-0.09	-0.04
Foot rotation	-0.04	-0.06	0.004
Dynamic base (3)	0.13	0.16	0.16
Dynamic base (4)	0.06	0.14	0.05
18 Months			
Sample size	15	16	16
Stride length	0.33	-0.03	0.24
Step length	0.41	0.03	0.31
Step width	0.33	0.28	0.22
Foot rotation	0.22	0.05	0.23
Dynamic base (3)	-0.02	-0.19	-0.08
Dynamic base (4)	-0.04	-0.13	-0.09

24 Months			
Sample size	15	16	16
Stride length	-0.11	-0.07	0.15
Step length	-0.15	-0.13	0.12
Step width	-0.36	-0.42	-0.04
Foot rotation	-0.16	-0.20	-0.08
Dynamic base (3)	0.11	0.32	0.17
Dynamic base (4)	0.26	0.53*	0.06

Note: ** $p < .01$, * $p < .05$

Table 6

Mean Values of Walking Skill for Toddlers: Fourteen-Months (Adolph, 1995), Eighteen- and Twenty-four-Months (current study) of Age

	Fourteen Months		Eighteen Months		Twenty-four Months	
Walking skill	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Stride length (cm)	30.66	61.37	48.69	86.36	54.51	100.61
Step length (cm)	16.74	31.35	26.14	43.33	28.17	51.31
Step width (cm)	6.13	18.2	0.66	9.27	1.07	4.70
Foot rotation (°)	-12.12	+28.12	+5.11	+24.08	+4.16	+54.95

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