Pulling to Stand: Common Trajectories and Individual Differences in Development

ABSTRACT: This longitudinal study of 27 infants examined the development of pulling-to-stand (PTS). In general, infants began PTS using a two-leg strategy and transitioned to a half-kneel strategy. As a group, infants showed no preference for either strategy at the onset of PTS, switching between strategies until half-kneeling became the dominant pattern about 1 month after the onset of PTS. Examination of individual developmental trajectories revealed variability in age at PTS onset, time between PTS onset and half-kneel strategy onset, duration of the two-leg strategy as the dominant pattern, time until the half-kneel strategy became the dominant pattern, shape of the transition between strategies (gradual vs. abrupt), and timing of PTS relative to onset of other motor milestones. We discuss variation in developmental trajectory in terms of adaptive behavior during the acquisition of new skills and as a process shaped by infants’ unique experiences prior to and during the acquisition period. © 2011 Wiley Periodicals, Inc. Developmental Psychobiology

Keywords: motor development; individual differences; infancy; pulling-to-stand; pattern preference index; motor coordination

INTRODUCTION

Pulling-to-stand (PTS) is one of the most memorable motor achievements in infancy. Parents experience surprise and delight the first morning they enter their infants’ rooms to find them upright holding onto the railing of the crib (Alexander, Boehme, & Cupps, 1993). When asked to remember important motor milestones, 98% of parents reported when their infants first pulled to a standing position, the highest report of any motor milestone on a 12-item checklist (Capute, Shapiro, Palmer, Ross, & Wachtel, 1985). For all of its salience with parents, however, compared to other motor milestones, PTS has been relatively overlooked in the research literature.

The primary focus on PTS has been documenting age of attainment, but there has been inconsistency in the literature depending on the definition used to operationalize PTS, the age at which infants were observed, and whether documentation was for assessment or descriptive purposes (Bayley, 1993; Capute et al., 1985; Frankenburg & Dodds, 1975; Largo et al., 1985; Piper & Darrah, 1994; Wijnhoven et al., 2004). When PTS has been included in empirical studies it is usually as the anchoring milestone in the transition to independent standing and walking, after infants already know how to PTS, but not a focus of study per se (e.g., Sundermier & Woollacott, 1998; Woollacott & Sveistrup, 1992). For example, infants use less force to hold onto a surface of support after they learn to stand alone than they did when they could only PTS (Barela, Jeka, & Clark, 1999) and muscle activation in the ankle, knee, and hip was less coordinated in infants who could only PTS than in infants who could stand independently (e.g., Sveistrup & Woollacott, 1996; Woollacott and Sveistrup, 1992). In the few studies to document the process by which infants move through the sub-sequences of PTS, the focus has been on atypical development in children with Down syndrome (Lauteslager, 1995; Lauteslager, Vermeer, & Helders, 1998).
It takes infants several months to proceed through the typical sequence of upright postures that precede independent mobility. This sequence of milestones starts between 7 and 10 months of age (8 months on average) with infants using furniture or another object for support to help them pull up to a standing position and continues with infants cruising along a surface of support, keeping balance without holding on, taking their first independent steps, and, finally, between 11 and 15 months of age, independent walking (Capute et al., 1985; Frankenburg & Dodds, 1975; Piper & Darrah, 1994). Summaries of this sequence typically describe PTS briefly as a transitional milestone that launches the subsequent events (Adolph & Berger, 2006; Piek, 2006; Trettien, 1900) and the sequence as a whole reflects a protracted period during which leg strength and balance control increase (Thelen & Ulrich, 1991).

PTS represents an important achievement in the development of postural control, including upward displacement in the body’s center of gravity and narrowing the base of support (Alexander et al., 1993). Standard behavioral assessment tools (e.g., Bayley, 1993; Frankenburg & Dodds, 1975; Piper & Darrah, 1994) and guidelines for practitioners (e.g., Alexander et al., 1993; Bly, 1994) provide good qualitative descriptions of the endpoints of the development of PTS and the ages at which the intra-task sub-sequences are achieved. For example, the Alberta Infant Motor Scale (AIMS; Piper & Darrah, 1994) includes a 16-item subscale for standing, that has three items regarding the transition to stand: PTS with support, PTS as a way to assume independent standing, and a half-kneel posture as a position to play. In the beginning, infants pull-to-stand supporting most of their weight with their arms, and with their legs extended symmetrically behind them (Fig. 1A). Gradually, infants use the lower extremities more actively when pulling up against gravity to supported standing (Vander Linden & Wilhelm, 1991). As greater control of the hips develops, infants progress to PTS from a half-kneeling position. Half-kneeling is a qualitatively different movement pattern than PTS from two feet because it requires a dissociation of the lower extremities while in a weight-bearing position (Alexander et al., 1993). To pull to a stand from a half-kneel, infants start with both legs flexed towards the trunk, with one or both rotated to one side. Then, one leg is flexed forward and pushes into extension as the other leg extends from kneeling and moves forward (Fig. 1B). In the AIMS, the only

![Schematic drawing of (A) two-leg and (B) half-kneel strategies for pulling to stand.](image)
assessments tool that has half-kneeling as an independent item, infants receive credit for half-kneeling as a transitional posture used for PTS or a permanent posture in which they play. Fifty percent of infants demonstrate half-kneeling by 8.5 months of age and 90% by 11 months of age (Piper & Darrah, 1994).

Traditionally, the transitions to sitting, crawling, and walking have been a well-studied part of motor development research because of the psychological changes that accompany dramatic change from prone to upright postures or from immobility to independent locomotion (e.g., Adolph, Vereijken, & Denney, 1998; Adolph, Vereijken, & Shront, 2003; Deffeyes et al., 2009). The onset of crawling, for example, is related to increased conflict between parents and infants, infants’ sense of mastery at their newfound independence, and cognitive changes as infants explore more of their environment (Acredolo, Adams, & Goodwyn, 1984; Campos, Kerboian, & Zumbohalen, 1992; Campos et al., 2000; Koterba and Iverson, 2005). Like crawling, PTS may also mark a significant psychological change in infancy. PTS provides infants with a new upright vantage point or a position to play (Alexander et al., 1993; Bly, 1994; Piper & Darrah, 1994), new opportunities for different exploratory behaviors, the ability to get upright under their own volition, and when they do, new visual, vestibular, and proprioceptive information (Adolph, 1997; Chen, Metcalfe, Jeka, & Clark, 2007; Metcalfe et al., 2005). Learning to pull to a stand is associated with emotional changes, such as self-awareness, pride, and joy (Trettien, 1900).

OBJECTIVES

Studying the naturalistic, spontaneous transition as infants learn to pull to a stand has important theoretical and clinical implications. First, PTS marks a meaningful postural change from quadruped to biped (Barela et al., 1999; Sveistrup & Woollacott, 1996; Woollacott & Sveistrup, 1992). Second, disturbances in motor development may be indicated by stereotyped and invariant behaviors during the acquisition of PTS (Alexander et al., 1993; Bly, 1994; Lauteslager et al., 1998; Winders, 1997), but to know what is truly invariant or atypical, we must first examine and understand the normative range of development. Thus, the first aim of this study was to describe in detail the typical acquisition and developmental trajectory of PTS.

Our second aim was to examine individual differences in the acquisition of PTS. We examined both within- and between-posture variability, specifically individual differences in the timing of the sub-components comprising the pull-to-stand posture, and variability in timing of PTS relative to other motor milestones (Adolph, Berger, & Leo, 2011; Berger, Theuring, & Adolph, 2007). Because PTS is a closed task with a clear starting and ending position and minimal variability in the environment over the course of executing the motor skill, we expected to see fewer patterns of movement than typically observed in open motor tasks, such as crawling, walking, and reaching, in which actors respond to a constantly changing environment as the task is executed (Adolph et al., 1998, 2003; Thelen et al., 1993). Akin to the pattern of transitioning between two strategies over the course of learning to stand up from a chair independently (a closed task; McMillan & Scholz, 2000), we predicted that infants would first pull to a stand using both legs simultaneously before eventually pulling to a stand from a half-kneeling position. We also had the opportunity to examine individual patterns of timing as infants learned to pull to a stand, previously done only with open-task skills. We expected to find variation in the amount of time that infants spent in each sub-posture and in the time it took them to move from one to the other.

METHOD

Participants

Twenty-seven infants (17 male; 10 female) participated from the time they were 7 months old until they were 12 months. We chose 7 months to begin observation because the average age at which infants first pull to stand is around 8 months and we wanted to capture the onset (Capute et al., 1985; Piper & Darrah, 1994). One boy began contributing data at 6 months of age because he had earlier motor milestone onsets than the rest of the sample. Three infants continued to be studied after they were 12 months until we obtained a minimum of 3 sessions where we observed them PTS. No infants could pull-to-stand when the study began. By the time the study ended, 7 infants had begun to walk.

Families were recruited to participate in the study by posting fliers about the research around the university where the research was being conducted and by leaving fliers at health care centers. Participants were also recruited via a “snowball” technique where participants were asked to mention the research to friends or contacts via word of mouth. All infants were born at full term and were in good health. All families but one were urban, Caucasian, and of middle to upper-middle socio-economic status. Mothers’ average age at the start of the study was 33 years; fathers’ average age was 35 years. Average years of education for both mothers and fathers was 17 years. Families received disks with the movies from each observation session and a children’s book as thank you gifts.

Procedures

Naturalistic Observation. Infants were videotaped for 20–30 min in their own homes every 3 weeks. Infants were
observed at least seven times. Due to individual differences in timing of PTS onset, some infants had 3–4 additional observation sessions. The number of total home observations for each infant ranged from 7 to 11 (M = 8.5; SD = .89). The number of times infants pulled to a stand at each session ranged from 3 to 8 (M = 6). From the videotapes of each session, a primary coder rated infants’ PTS ability: no attempt to get upright, attempt to get upright, success at getting upright with two legs, success at PTS from a half-kneel posture. After infants achieved success at PTS using either strategy, a primary coder rated subsequent sessions to determine when infants were skilled at PTS, which was defined as PTS with minimum effort and concentration, with the ability to change positions quickly.

**Motor Milestone Checklist.** Parents documented the onsets of getting to sit, pulling to stand, hands-and-knees crawling, and cruising. Parents were given an illustrated checklist of motor milestones based on Scher and Cohen’s (2005) motor diary. They were instructed to use the checklist to monitor changes in their infants’ motor skills between observation sessions. The onset of getting to sit was when the infant could get into a sitting position independently and hold the position. The onset of PTS was defined as the day when infants first successfully used furniture or another object as support to pull themselves up and maintain an upright position without falling. When infants met the attempt criteria, parents were instructed to pay special attention to infants’ behavior and to contact the researcher as soon as infants first met either of the success criteria. The onset of crawling was when infants could execute two full cycles of forward movement on hands and knees with their belly off the ground. The onset of cruising was when infants could support an upright posture by holding onto a surface of support with their hands and execute two full cycles of movement using hands and feet. Infants’ acquisition of motor milestones according to checklist criteria was confirmed via video coding.

**Pattern Preference Index.** A primary coder calculated infants’ PTS pattern preference at each observation point by identifying whether infants preferred to pull to a stand using two legs or from a half-kneeling position. Coders used the index \( \frac{(B-U)}{(B+U)} \) which is frequently used for calculating right or left hand/leg preferences or uni- or bi-manual reaching preferences (e.g., Armitage & Larkin, 1993; Corbetta & Thelen, 1999; Corbetta, Williams, & Snapp-Childs, 2006; Cornwell, Harris, & Fitzgerald, 1991; Fagard, 1998; McCormick & Maurer, 1988; Michel, Sheu, & Brumley, 2002). For this study, \( B \) stands for the number of times that infants used two legs to PTS (“bipedal”) and \( U \) stands for the number of times infants PTS from a half-kneel (“unipedal”). This index generates a continuous measure of preference enabling researchers to describe how strong a preference is, rather than create a possibly artificial, dichotomous forced choice (Bryden & Sprott, 1981; Michel et al., 2002). The limited range from 1 to −1 makes it possible to compare preferences between infants. We defined dominance for PTS with two legs as an index between .5 and 1.0, for PTS with a half-kneel as between −.5 and −1.0, and no pattern preference around 0. For each infant, a preference index was calculated for each observation and for the overall study.

**Motor Development Screening.** To ensure that participants fell in the normal range of motor development, infants were screened in two ways. Trained pediatric physical therapists rated videotapes using the Alberta Infant Motor Scale (AIMS; Piper & Darrah, 1994) for each home observation of each infant. The AIMS is an assessment tool used to identify motor delay and evaluate motor performance from birth to independent walking. The scale was normed on a cross-sectional, random sample of over 2000 infants, has high inter-rater and test–retest reliability and validity, and has been cross-culturally validated (Darrah, Piper, & Watt, 1998; Darrah, Redfern, Maguire, Beaulne, & Watt, 1998; Jeng, Yau, Chen, & Hsiao, 2000; Manacero & Nunes, 2008; Piper & Darrah, 1994; Syrengelas et al., 2010). In addition, a trained pediatric physical therapist manually evaluated infants’ muscle tone and range of motion in the hip, knee, and ankle joints in the lower and shoulder, elbow, and wrist joints in the upper limbs, during one session via passive limb movement. If infants were evaluated to have relatively excessive range of motion in more than five joints, then they were classified as having hypermobility.

**Inter-Rater Reliability.** To ensure reliability, a second coder recoded 30% of observations making sure to choose samples so that all ages were represented. Interrater reliability for both the naturalistic observations of PTS and the AIMS was greater than 90%. Disagreements were resolved through discussion.

**RESULTS**

**Preliminary Data Analysis**

The distribution of infants’ scores on the AIMS was close to a normal distribution (skewness = .11, \( SD = .44 \); kurtosis = −.18, \( SD = .87 \), with all scores falling within the normal range. The physical exam identified hypermobility in 6 of the 27 participants. For an additional two infants, the physical exam revealed hypermobility and muscle tone at the low end of the normal range. Nonparametric Mann–Whitney analyses tested whether the eight participants with excessive range of motion were different from infants with normal muscle tone and normal range of motion. Analyses revealed no differences based on physical examination for age of attainment for standing, crawling, half-kneeling, cruising, or AIMS score. Therefore, subsequent analyses make no distinction between participants based on the results of the physical exam.
Onset of Pulling to Stand

Figure 2 shows individual differences in the age and timing of PTS onset and strategies. All infants learned to pull to a stand over the course of the study. As indicated by the end of the dark gray sections of Figure 2, the age of onset of PTS ranged from 5.92 to 11.89 months (M = 8.66 months; SD = 1.26 months), which fell within the expected normal developmental range (Bayley, 1993; Piper & Darrah, 1994). At onset, only 2 infants (7%) used half-kneeling exclusively to PTS, 10 infants (37%) used 2 legs exclusively to PTS, and 15 (55%) infants PTS using both strategies in the same session.

The start of the light gray sections of Figure 2 indicate the age of onset of PTS using the half-kneel pattern (range = 6.56–11.89 months; M = 9.23 months; SD = 1.26 months). All infants except one (who used two legs to PTS throughout the entire study) used the half-kneel pattern during the study. The half-kneeling strategy was observed within a week of the onset of PTS in 34.6% of participants, between 1 and 2 weeks after the onset of PTS in 15.4% of participants, and greater than 2 weeks after the onset of PTS in 50% of participants (range = 0–1.51 months).

The endpoint of each individual graph in Figure 2 marks the age at which skilled half-kneel PTS was attained. The time from PTS onset to skilled half-kneel PTS ranged from 1.11 to 2.89 months (M = 1.91 months, SD = .41 months).

We examined when infants achieved the PTS milestone relative to other locomotor milestones (getting into a sitting position independently, crawling on hands and knees, cruising). On average, infants pulled to a stand after the onset of hands and knees crawling and getting into a sitting position and before cruising. There were no gender differences for onset ages for any of the motor milestones. An examination of individual patterns of motor milestone achievement revealed a variety of motor milestone orders that were not apparent when ages of onset were averaged across the whole sample. Only seven infants (26%) matched the average group pattern. The rest of the sample achieved their motor milestones in three different additional orders (Fig. 3).

In addition to variability in the order in which milestones were achieved, we also observed variability in the timing in which milestones were achieved relative to each other. Close to half of the sample achieved at least two milestones within a week of each other. Seven infants (26%) began PTS and hands-and-knees crawling in the same week, four (15%) began getting to sit and PTS in the same week, and two (7.5%) began hands-and-knees crawling, getting to sit, and PTS all in the same week.

Changes in Pattern Preference

A repeated measures ANOVA on Pattern Preference Index score at the first four observations after onset of PTS revealed a main effect for session, $F(3, 72) = 17.50, p < .00, \eta^2 = .41$ (Fig. 4). As expected, the preference for PTS using half kneel increased over the course of the study. A series of post hoc, least significant difference, pairwise comparisons revealed that the preference for half kneeling was significantly lower in session 1 than in sessions 2, 3, and 4 ($p$'s < .04); and lower in session 2 than in session 3 ($p < .01$).

Relationship Between Skill and Pattern Dominance

To test the relationship between skilled PTS and pattern preference, we identified for each infant the session at which skilled half kneel PTS was first achieved. A repeated measures ANOVA comparing infants’ Pattern Preference Index score at the “skilled” session with the sessions immediately before and after revealed a main effect for session, $F(2, 50) = 11.56, p < .00, \eta^2 = .32$. Infants showed a significant increase in preference for the half-kneel strategy from the session prior to skilled half-kneeling to the session where they were skilled at using it. Infants’ preference for the half-kneel strategy remained unchanged between the session where skill was first observed and the subsequent session.

Pulling to Stand Trajectory Profiles

To address our aim of examining the developmental trajectory of PTS and individual differences, trajectory profiles for individual infants were determined by

![FIGURE 2](image-url)
examining the shape of change of infants’ Pattern Preference Index over the course of the study. By examining the shape of the trajectory, rather than only a static index, profiles contained additional information about the time from the first day of PTS onset until the first day the half-kneel pattern was attained, and time until the half-kneel pattern was the dominant pattern.

We first sorted participants into groups based on whether their individual trajectory fit the overall group pattern preference. Sorting continued with profiles of individuals who did not fit the overall pattern based on how long infants spent in each PTS pattern. Three distinct profiles emerged: gradual transition to half-kneel preference (group pattern), prolonged use of two legs, and rapid transition to half-kneeling.

**Profile 1: Gradual Transition to Half-Kneel Preference.** Forty-four percent of infants ($n = 12$) fit the profile of having a gradual change in PTS strategies before exclusively using half-kneeling to PTS (Fig. 5A). Infants in this profile began PTS either with a two-leg...
preference or without a preference and then gradually acquired a preference for the half-kneel strategy. By the last observation session, all infants were using the half-kneel strategy exclusively. The physical examination revealed hypermobility in only two infants fitting Profile 1.

Profile 2: Prolonged Use of Two Legs to PTS. Twenty-six percent of the infants in the sample \((n = 7)\) fit the profile of prolonged use of two legs to PTS as their dominant pattern (Fig. 5B). Infants in this profile typically did not begin to use half-kneel to PTS as their dominant strategy until the 5th or 6th session. Of the seven infants fitting Profile 2, the physical examination revealed one with low tone and hypermobility, three with hypermobility, and two with excessive range of motion in the legs but not the arms.

Figure 5D shows an extreme case of prolonged exclusive use of two legs to PTS. Infant GK’s trajectory was so unusual that we describe it in detail here as a case study, but his data were not included in the group statistical analyses. In 8 observations in which GK pulled to stand 53 times, he did not use the half-kneel strategy once. PTS using the half-kneel strategy was observed only in follow-up observation sessions when he was 14 months and 21 days—after cruising and close to the onset of walking. Because of the unusual timing, we observed GK closely and noted that he used the “w-sit” pattern exclusively for the first month after he began to sit independently. W-sitting may indicate insufficient muscle control around the hip compensated for with a symmetrical sitting posture. GK also demonstrated excessive range of motion during the physical exam but only in the lower limbs. Despite the unusual developmental trajectory for PTS, GK was within the normal range on the AIMS, and his locomotor milestone onsets were in the normal range. Onset of sitting may have been delayed—his parents sat him passively at around 9 months of age and he got into a sitting position independently at 11 months.

Profile 3: Rapid Transition to Half-Kneeling. Thirty percent of the infants in the sample \((n = 8)\) fit the profile of a rapid transition to PTS using a half-kneeling strategy (Fig. 5C). Infants in this profile typically began using half-kneeling as a strategy for PTS immediately after the onset of PTS and began using it almost exclusively. One infant demonstrated hypermobility during the physical examination and another infant demonstrated hypermobility and low tone.

Figure 5E shows an extreme case of rapid and exclusive use of PTS using a half-kneeling strategy. Infant

![Figure 5](image)

**FIGURE 5** Representative individual trajectories for PTS fitting (A) Profile 1, (B) Profile 2, and (C) Profile 3. Dashed vertical lines in graphs (D)–(F) indicate the onset of key motor milestones for the three case studies. For (D), the last three observation sessions fell during the follow-up period after the formal period of study had ended. Scores from .50 to 1.00 indicate a dominant preference for PTS with two legs. Scores from −1.00 to −.50 indicate dominant preference for PTS with half-kneel. Scores around 0 indicate no preference.
AB was observed 11 times, but only pulled to stand in 5 observations. During the first observation session where PTS was observed, it occurred only once. AB was the last infant in the study to attain PTS and he demonstrated the half-kneel pattern exclusively. Despite the unusual developmental trajectory for PTS, AB was within the normal range on the AIMS.

Kruskal–Wallis tests comparing the three profiles confirmed significant differences between the groups for Overall Pattern Preference Index score and time until the half-kneel pattern became a dominant pattern ($\chi^2 = 16.79$, $p < .01$ and $\chi^2 = 11.27$, $p < .01$, respectively), as well as the Pattern Preference Index scores at each of the first three observation sessions, all $p$’s $< .02$. Mann–Whitney tests revealed that each profile was significantly different from the other two on all measures (all $p$’s $< .02$), except for Profiles 1 and 2 on time until half-kneel pattern dominance. There were no differences between the groups for age of onset for PTS, crawling on hands and knees, cruising, or AIMS scores. A chi-square test revealed no significant relationship between PTS trajectory profile and physical examination results.

**Microgenetic Case Study**

We had the opportunity to observe 1 infant, GE, at least once per week, but sometimes more frequently, from the age of 8.5 months until the age of 13 months, for a total of 32 observation sessions. The most striking characteristic of the development of PTS was an almost exclusive use of the half-kneel strategy from the onset (Fig. 5F). On only three observations did GE pull to a stand with two legs, and on those occasions PTS with two legs was sporadic and GE still showed a half-kneel preference at those sessions. GE’s motor development was typical on all measures, with the only noteworthy event being a modified crawl on one knee and one foot as her typical crawling pattern immediately prior to the onset of PTS.

**DISCUSSION**

This study longitudinally examined the development of PTS in infancy. On average, infants learned to pull to a stand at 8.75 months of age using two legs before eventually starting to use the half-kneel strategy about 2 weeks later. The Pattern Preference Index showed that, in general, infants showed no pattern preference at the onset of PTS, but typically switched between strategies within and between sessions until half-kneeling became the dominant pattern about 1 month after the onset of PTS. Our findings about the development of PTS at the group level showed that the traditional ways of describing this transition were accurate in the aggregate (Alexander et al., 1993; Bly, 1994). However, observing the development of PTS at the individual level revealed that traditional methods of observation were unable to capture the nuances of variability within and between participants. As with other well-documented motor milestones, the development of PTS is characterized by individual variation in trajectory, timing relative to other motor milestones, and strategy preference.

To address our first aim of describing the acquisition and developmental trajectory of PTS, we documented the change over time of the strategies that infants used as they were learning to pull to stand. As expected, infants transitioned from the two-leg strategy to the half-kneel strategy for PTS. PTS with two legs requires the legs to move simultaneously as one unit in two dimensions. The half-kneeling pattern requires a lateral weight shift to the supporting leg, greater coordination between the flexors and extensors to keep balance around the relevant joints (i.e., hip, knees), dissociation between the legs, and movement in three dimensions (Bly, 1994; Meade, 1998). When infants first learn to pull to a stand, with minimal strength and balance control for getting upright, stability takes the form of limiting the movement of some joints and muscles (“freezing” the degrees of freedom) and shifting the center of mass upward until the initial sub-tasks of the skill are mastered (Bernstein, 1967; Vereijken, van Emmerik, Whiting, & Newell, 1992). Later, as strength and coordination increase, infants are free to introduce more complexity into the solution, such as shifting the center of mass laterally and upward (e.g., Harbourne & Stergiou, 2003; McMillan & Scholz, 2000; Vereijken & Waardenburg, 1996). Variability in pattern dominance over the course of skill acquisition resulted from fluctuating motor abilities as infants acquired expertise about keeping balance in their new upright posture (Piek, 2002).

To address our second aim of examining individual differences during the acquisition of PTS, we examined variability in the developmental trajectory of PTS and documented three distinct profiles: (Profile 1) a gradual change from the onset of PTS until the half-kneel strategy was dominant, (Profile 2) prolonged use of two legs to pull to stand, and (Profile 3) a rapid transition to half-kneeling to pull to stand soon after the onset of PTS. In addition, we identified infants’ unique experiences that may have contributed to which profile they fit. Most infants in the sample fit Profile 1 and it reflects the average of the groups, whereas the other two profiles describe trajectories that fall more to the extremes. Six of the seven infants who fit Profile 2 had
physical examinations revealing excessive range of motion in their joints and/or low muscle tone. Hypermobility is a benign, common (8% of the normal population) phenomenon in infants, which can affect motor development, but not necessarily (Gedalia & Brewer, 1993; Tirosh, Jaffe, Marmur, Taub, & Rosenberg, 1991). Studies of young children with Down syndrome have shown that hypermobility is associated with a lack of variability and increased symmetry as a result of having to stabilize the joints (Lauteslager, 1995). Similarly, infants’ prolonged use of two legs for PTS (relative to the other profiles) may be related to the excessive range of motion of the joints (albeit within the normal range) observed in this group as they acquired the strength they needed for stability. On average, the infants who fit Profile 3 had a PTS onset about 1 month later than the other profiles. Although it was not statistically significant, this lag may have given them more time to acquire sufficient control before attempting PTS so that once they did, they were ready to use the half-kneel strategy (Haehl, Vardaxis, & Ulrich, 2000). Although the variables capturing the developmental trajectory of PTS were not continuous themselves, variation within Profile 1 suggests a possible continuum of the developmental trajectory, with some trajectories resembling a less dramatic version of prolonged PTS with two legs (Profile 2) and other trajectories resembling a somewhat less rapid transition to half-kneeling than Profile 3.

The trajectories that infants went through during the acquisition of PTS parallel the various developmental trajectories of the acquisition of crawling. Like new crawlers who explored a variety of crawling strategies before eventually settling on a mature hands-and-knees, diagonal gait (Adolph et al., 1998; Freedland & Bertenthal, 1994), Profile 1 infants started off exploring the two different PTS patterns without showing a preference, before eventually settling on the mature half-kneel pattern. Infants in Profile 2, who initially pulled to a stand with two legs before switching to half-kneeling, resemble new crawlers who initially belly-crawl before eventually acquiring sufficient strength and balance to crawl on hands and knees (Adolph et al., 1998; Freedland & Bertenthal, 1994). Profile 3 infants, who used the half-kneel strategy to pull to a stand from the beginning, resembled new crawlers who crawled on hands-and-knees from the onset. This variation in developmental trajectory reflects infants’ adaptive behavior during the acquisition of new skills. Infants took into account their own motor ability and found a solution that was best for their unique sets of abilities and constraints (Adolph et al., 1998; Thelen et al., 1993).

As predicted, in addition to variability in profiles at the group level, we also found possible evidence for a relationship between infants’ individual differences and variation in developmental trajectory at the individual level. For example, experience in prior locomotor postures may have influenced how infants GE and AB arrived at their PTS strategies (Corbetta et al., 2006). Unusually, both infants used the half-kneel strategy almost exclusively. GE’s unique one foot/one knee crawling style may have transferred to the half-kneel strategy and AB’s considerable delay in PTS (at 11.18 months) may have resulted in the more mature manifestation of the skill at onset due to facilitative motor experience during the period prior to onset (Haehl et al., 2000). Infant GK acquired the half-kneel strategy for PTS a full 6 months after exclusively PTS using two legs—the typical order of events, but on an unusually long time scale. Although still inconclusive, this unique combination of factors suggests that his trajectory may have been shaped by instability around the pelvis girdle: recall the conflicting findings of w-sitting and excessive range of motion in the lower limbs, but AIMS scores and locomotor milestone onsets in the normal ranges.

Motivation to move or get upright may also be a predictor of variation in motor milestone trajectory (Atun-Einy, Berger, & Scher, 2011; Thelen, 2005). For example, motivation may account for why belly crawlers are willing to endure the effects of dragging their bodies along the floor for the sake of independent locomotion (Adolph et al., 1998). We observed cases of infants with similar physical characteristics who arrived at different solutions in different sequences for PTS. One infant with low motor tone and excessive range of motion showed prolonged use of two-legs to pull to a stand followed by cruising and then half-kneeling to pull to a stand. In contrast, another infant with the same outcome from the physical screening showed a rapid transition to half-kneeling after a relatively delayed PTS onset followed by cruising. Individual differences in the timing of when infants pulled to a stand, relative to their other motor milestones may also indicate that attainment of an upright vantage point may be a strong motivator for some children. Thus, we observed individual differences in patterns of timing as infants learned to PTS, both within the trajectory of acquisition of the skill and relative to the onset of other motor milestones, suggesting that infants’ experiences prior to and during the acquisition of PTS, such as physical characteristics, sensorimotor experiences, or motivation, influenced the order and timing of patterns (Thelen, 1995; Haehl et al., 2000).

A general principle of human movement is that we are drawn to the most efficient, most economical motor solutions across postures (Galna & Sparrow, 2006). In this study, the half-kneel strategy eventually became
the dominant pattern for PTS for all infants, suggesting its optimality. What makes half-kneeling the optimal solution for PTS? Part of the explanation lies with the greater stability that a half-kneel provides over a two-leg solution. With one leg turned out to the side, a half-kneel stance provides a wider base of support so that infants are less susceptible to threats to balance. As with crawling, asymmetrical limb coordination stabilizes the center of mass during motion (Adolph et al., 1998). Even after they no longer need support to get upright, older children and adults often continue to use the half-kneel strategy to rise from the floor (VanSent, 1988). Another reason why the half-kneel strategy is the optimal PTS solution is the flexibility that the posture provides. By shifting some of the body’s weight to the legs and reducing the role of the arms during PTS, the half-kneel strategy allows infants to have their hands and arms free for other activities such as object exploration or play. Infants may want their hands free during the transition to a stand, prior to object play, in anticipation of manual activity (McCarty, Clifton, Ashmead, Lee, & Goubet, 2001). In addition, the half-kneel strategy is adaptive because it allows for controlled responses to events in the environment. In the half-kneel stance, infants are able to pause mid-PTS as a play position or turn their bodies in response to something that has captured their attention while maintaining stability.

A strength of this study is the different levels of analysis used to explore the development of PTS in infancy. In addition to describing the typical sequence of development, we have also been able to describe the range of developmental trajectories in the normal population. Although this study makes no claims of being able to use infants’ PTS trajectory to diagnose or detect developmental delays, these findings do have clinical implications. In practice, the timing and age of onset of PTS in infancy is often used as a marker for developmental delay. Clinicians describe extended periods of use of the two-leg strategy for PTS with asymmetrical strategies mastered relatively late (Bly, 1994; Lauteslager, 1995). However, since the developmental trajectory of PTS had never before been tracked, there was no reference for comparison in a typically developing population for how long was “too long.” Understanding the sequence and timing of development may give therapists a reference for when to intervene, perhaps keeping an eye out for periods of instability, rather than a specific landmark event. Future studies should incorporate quantitative measures of PTS at close intervals to capture instability, such as changes in the level of support provided by the upper extremities relative to the lower extremities. We now understand that variability in timing of the dominant PTS pattern, in timing of the transition between patterns, and in the way that the transition occurs (gradual vs. abrupt) is the norm. It is also apparent that, despite the appearance of a stage-like transition during the acquisition of PTS at the group level, development is not stage-like at the individual level. The timing of the sub-components of the skill do not appear in lockstep from one infant to another.

NOTES

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