WIREs
Wiley Interdisciplinary Reviews

Article Title: An Update of the Development of Motor Behavior

Article Category: Primer

Authors:

John M. Franchak* University of California, Riverside franchak@ucr.edu ORCID: 0000-0002-0751-2864
Karen E. Adolph New York University karen.adolph@nyu.edu ORCID: 0000-0003-2819-134X

Abstract

This primer describes research on the development of motor behavior. We focus on infancy when basic action systems are acquired—posture, locomotion, manual actions, and facial actions—and we adopt a developmental systems perspective to understand the causes and consequences of developmental change. Experience facilitates improvements in motor behavior and infants accumulate immense amounts of varied everyday experience with all the basic action systems. At every point in development, perception guides behavior by providing feedback about the results of just prior movements and information about what to do next. Across development, new motor behaviors provide new inputs for perception. Thus, motor development opens up new opportunities for acquiring knowledge and acting on the world, instigating cascades of developmental changes in perceptual, cognitive, and social domains.

1 INTRODUCTION

Motor behavior includes every kind of movement from involuntary twitches to goal-directed actions, in every part of the body from head to toe, and in every physical and social context from alone in a crib to a raucous playground. Although movements depend on generating, controlling, and exploiting physical forces, doing so requires more than muscles and biomechanics. At every point in development, adaptive control of movement requires core psychological functions—perception, cognition, motivation, and so on (Bernstein, 1996; Gibson, 1994).

As in our original primer (Adolph & Franchak, 2016), this article is organized around the development of four basic action systems in infancy—posture, locomotion, manual actions, and movements of the eyes, face, and head (Figure 1). Although we review each action system separately, they are inter-related: Movements of the eyes, head, and hands are nested in a body that sits, stands, crawls, and walks, so changes in one skill can affect the expression of another. Moreover, motor development has both short-term and long-term consequences. Movements generate immediate perceptual information, provide the means for acquiring knowledge about the world, and make social interactions possible. Over longer time periods, developmental changes in motor skills can have cascading effects on development in other domains.

From a developmental systems view (Blumberg et al., 2016), motor behaviors—even in the fetus and neonate—cannot be understood as purely reflexive and hardwired. Motor behaviors can never be divorced from the body, environment, and sociocultural context in which they occur. Movements are inextricably embodied, embedded, and enculturated (Adolph & Hoch, 2019; Adolph & Robinson, 2015). The body and environment develop in tandem such that new or improved motor skills make new parts of the environment accessible and thereby provide new or enhanced opportunities for learning and doing. New motor behaviors emerge from a mix of interacting factors, some obvious (e.g., muscle strength), some so pervasive that we take them for granted (like gravity), and some so subtle or non-obvious that we fail to recognize their role (e.g., how caregivers hold or dress infants). Indeed, social and cultural differences in the way caregivers structure the environment and interact with their infants affect the form of new motor skills, the ages when they

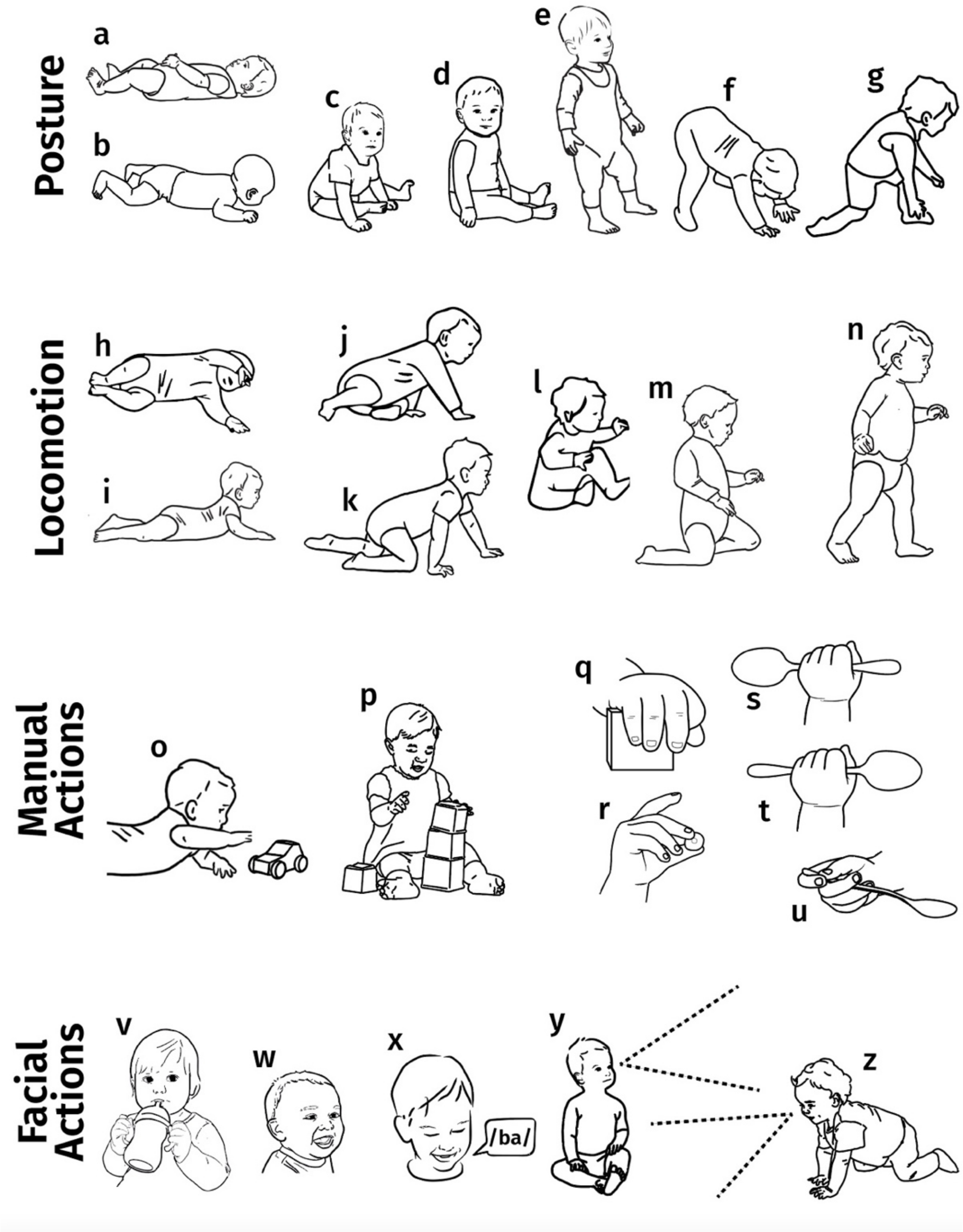

Figure 1. Motor development from A to Z across four action systems—posture, locomotion, manual actions, and facial actions. All movements of the extremities are nested within postures, including: supine (A), prone (B), tripod sitting (C), independent sitting (D), and standing (E). Transitions between postures (F, G) allow infants the freedom to choose how to move from moment to moment. Infants employ creative means to locomote before they learn to walk, such as log rolling (H), belly crawling (I), hitching (J), hands-and-knees crawling (K), bum-shuffling (L), and knee walking (M). Upright walking (N), like all movements, is refined through practice. Compared to when prone (O) or supine (A), sitting (P) provides a stable base of support for reaching and manual exploration. Infants refine their ability to grasp objects from palmar (Q) to fingertip grips (R), and they learn to hold tools with grips that become increasingly functional (S, T, U). Facial action involves coordinating movements to eat and drink (V), smile (W), and vocalize (X). Infants' ability to look and visually explore their surroundings depends on movements of the eyes and head nested within the body, meaning that while sitting (Y) infants can see farther and higher compared to while prone (Z). Drawings are reprinted with permission from the NIH Baby Toolbox (A-O, Q-U, X, Y) and by Kelsey West (P, V, W, Z).

appear, and the trajectory of their development (Adolph et al., 2010; Adolph & Robinson, 2015). Thus, individual developmental trajectories do not invariably follow the age-related sequences pictured in traditional milestone charts as in Figure 2. Rather each infant finds their own solutions for moving and thus developmental trajectories can vary from infant to infant (Box 1).

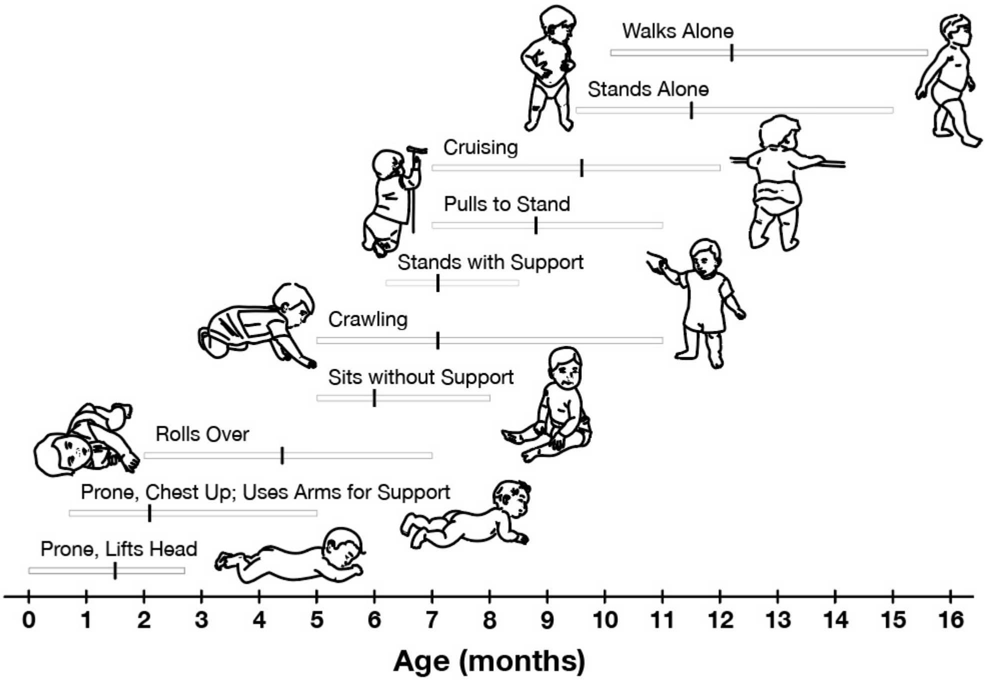

Figure 2. Typical milestone chart illustrating age-related changes in motor development. Age runs along the x-axis, and skills become increasingly mature from bottom to top. Open bars show the 10th to 90th percentiles, and vertical lines denote the 50th percentile. Data are based on World Health Organization standards, the Bayley scales of infant development, and the Denver II Screening Manual. Reprinted with permission from Adolph et al. (2010). Copyright 2010 Taylor and Francis.

Box 1: Individual Developmental Trajectories

The developmental systems perspective eschews the idea of a universal blueprint. There is no central plan that dictates which motor skills develop or how and when they appear (Thelen & Ulrich, 1991). Rather, each behavior emerges through the interaction of multiple subsystems operating at different time scales within the lifetime of the individual (e.g., genetic, anatomical, experiential, environmental, social, cultural). As illustrated in Figure 1, action systems develop concurrently. *Equifinality* refers to various developmental trajectories that converge on the same endpoint. Highly energetic infants, for example, need to dampen down their overactive arm “flaps” when learning to reach, whereas lethargic, quiet infants need to power up their “floppy” stationary arms to initiate reaching movements (Thelen et al., 1993). *Multifinality* refers to numerous developmental trajectories that diverge from the same starting point. For example, most infants learn to prop on their forearms while lying belly down on the floor, but only some infants will "army crawl" on their bellies using their forearms to pull their body forward. Others will discover alternative forms of belly crawling and inchworming, and many infants never crawl with their bellies on the floor. The pervasiveness of equifinality and multifinality across development means that traditional milestone charts (Figure 2)—which depict motor development as an orderly series of increasingly mature, obligatory forms of movement—fail to capture individual differences in developmental trajectories. Motor development—both within and across infants—is far messier and more complex than a simple sequence of age-normed milestones. Moreover, the skills selected for the milestone charts reflect the cultural and historical biases of the initial researchers and samples rather than anything fundamental about human development (Adolph et al., 2010). In some cultures and time periods, for example, many infants do not crawl, or they crawl after they begin walking (Hopkins & Westra, 1990).

2 POSTURE

Posture is the foundation on which other actions are built (Reed, 1982). The instant that any part of the body breaks from the support surface—merely lifting the head while prone or raising an arm while supine—torque acting on that body part creates disequilibrium. This is why newly sitting and standing infants lose balance just from turning their heads or lifting their arms. Posture must be sufficiently stable to allow movements of the extremities and to set up the necessary conditions for looking around, handling objects, holding conversations, or going somewhere (Bertenthal & von Hofsten, 1998). As such, the emergence of motor skills—including those not obviously related to posture—awaits the development of sufficient postural control.

Postural development is the attainment of increasingly erect postures poised over an increasingly small base of support. Think of a newborn lying supine (Figure 1A) or struggling to lift their head while prone (Figure 1B), a toddler's wide walking stance, and an older child dancing en pointe. Indeed, the most common images of motor development are milestone charts of postural and locomotor development (Figure 2). The charts suggest an orderly, age-related series of obligatory, universal stages, but developmental trajectories in individual infants often diverge from the normative sequence. Infants acquire skills in various orders, skip stages, and revert to earlier forms (Adolph et al., 2011; Atun-Einy et al., 2012; Gesell, 1946); see Box 1.

2.1 Overcoming Gravity

Gravity and the surrounding media (air, water, ground) are so quietly pervasive, so hidden in plain sight, that these factors are often overlooked as causal forces in development. But they are central for motor development. Before birth, the buoyant uterine environment supports a variety of postures. Large body movements—whole body flexion and extension, stretching and writhing, leg kicks that somersault the fetus through the amniotic fluid—peak at 14 to 16 weeks of gestation (D'Elia et al., 2001; de Vries & Hopkins, 2005). As the growing fetus fills the uterus, the propensity for movement is masked due to lack of space to extend the limbs. Many movements practiced in utero (leg kicks, hand-to-mouth movements, finger wiggles) are also displayed by newborns (de Vries & Hopkins, 2005), but after birth, infants face new challenges from gravity and ground surfaces.

Infants' triumph over gravity generally proceeds from head to toe. The top-down progression is especially striking in the development of sitting. At first, head and trunk control is so poor that unsupported infants fall chest to legs or topple backwards. With experience fighting gravity, postural control progresses slowly down the spine—neck, shoulders, waist, hips (Saavedra et al., 2012). Differences in childrearing practices affect the timing and trajectory of sitting skill. In cultures where caregivers hold infants without supporting their head and torso against gravity, and encourage practice with independent sitting (Adolph et al., 2010), babies sit independently before 5 months of age, and they do so with such assured stability that caregivers regularly perch them on high furniture and leave the room to do chores (Karasik et al., 2015).

Infants eventually "tripod sit" by supporting their torso with arms propped between their legs (Figure 1C). Around 6 months of age, infants sit independently on the ground with legs outstretched and hands free (Martorell et al., 2006) (Figure 1D). They gradually gain sufficient control to manage swaying movements of the trunk and destabilizing forces from turning the head, twisting the torso, or moving the arms to play (Claxton et al., 2014; Dusing et al., 2016). Likewise, infants learn to adjust their trunk position to cope with variable ground surfaces or a smaller base of support to sit on a chair or ledge. They lean opposite to the direction of a sloping surface (Rachwani et al., 2017), and they refuse to lean forward with their legs dangling over the edge of a high drop-off (Adolph, 2000).

Sitting skill improves via immense amounts of everyday practice. Although pre-sitters can sit with support from a caregiver (Kretch, Marcinowski, et al., 2022) or device (Franchak et al., 2024; Karasik et al., 2022), 3-month-olds rarely sit (Franchak, 2019a). At 6 months, independent sitters spend twice as much time per day sitting compared with same-age pre-sitters (Franchak, 2019a). And typically-developing infants sit more than infants with neuromotor disorders—even when matched for sitting skill (Kretch et al., in press). Caregivers decide where to place pre-sitters for play, but sitters choose for themselves where to sit and play—typically at right angles to their caregiver (Schneider et al., 2022). By 12 months, sitting is infants' most common posture (Franchak et al., in press).

Like sitting, standing typically begins with manual support of balance. Infants pull up to a stand and hold onto furniture for support of upright balance (Atun-Einy et al., 2012). Toward the end of the first year, infants stand freely (Figure 1E) and "cruise" sideways holding furniture for support (Martorell et al., 2006), coordinating arms and legs in different configurations to suit the nature of the supports (Ossmy & Adolph, 2020). Independent walking typically appears after infants can keep balance standing in place. Transitions to upright positions, such as sitting, kneeling or squatting to stand (Figure 1F-G), typically emerge later (Thurman & Corbetta, 2020).

2.2 Basis for Action

A stable postural base opens up new possibilities for acquiring knowledge and acting on the world. While lying supine, infants see the ceiling overhead and faces that pop into their view (Fausey et al., 2016). While lying prone or in a crawling position, view of the world is limited mostly to the floor in front of infants' hands (Kretch et al., 2014) (Figure 1Z). Upright sitting (Figure 1Y) and standing provide a new vantage point for visual exploration—objects, other people's hands, and the whole room come into view (Kretch et al., 2014; Luo & Franchak, 2020).

Moreover, sitting frees the arms for reaching and the hands for manual exploration (Harbourne et al., 2013; Marcinowski et al., 2019; Rachwani et al., 2013; Soska & Adolph, 2014). Indeed, reaching and object exploration have different developmental trajectories for prone, supine, and sitting postures (Carvalho et al., 2008; Soska & Adolph, 2014). While prone, bimanual exploration is difficult because one arm supports the trunk (Figure 1O). While supine, visual exploration is difficult due to lifting the arms to hold objects overhead. But while sitting, infants can engage in sophisticated visual-manual object exploration (Figure 1P), such as fingering, transferring, and rotating, which in turn, facilitates learning about the three-dimensionality of objects (Soska et al., 2010). As sitting skill improves, infants spend longer periods interacting with objects (Mlincek et al., 2020)—about 45% of their waking day (Franchak et al., 2024).

Supported sitting is less conducive for learning than independent sitting. Infants hear less caregiver speech when constrained in a device because caregivers stray farther away to do household chores (Malachowski et al., 2023), and sitting with caregiver support makes caregivers' faces less likely to be in infants' view (Kretch, Marcinowski, et al., 2022). Enhanced visual-manual exploration might explain why independent sitting is linked with improvements in figure-ground perception (Ross-Sheehy et al., 2016) and spatial memory (Oudgenoeg-Paz et al., 2015). Likewise, the benefits of sitting for exploration and social interaction may underlie links with later vocabulary growth (Libertus & Violi, 2016; Oudgenoeg-Paz et al., 2012).

2.3 Summary: Posture

Posture is the foundation for motor skill. Without postural control, most motor behaviors are impossible. Postural control emerges from the interaction of a growing body dealing with the constraints of the physical environment—gravity, properties of the support surface, and so on—over immense amounts of experience during daily activities. Everyday caregiving practices can speed up or delay postural control. The development of postural control instigates a cascade of new skills and opens up new possibilities for looking, social interactions, manual actions, and locomotion.

3 LOCOMOTION

Precursory locomotor movements, such as stepping, are exhibited during fetal and neonatal periods, but locomotion, like any action, is not reflexive or hardwired. Rather, locomotion, like every action, is creative. As with every action system, each infant finds their own solutions for mobility given the current status of their body and environment, and they must learn to control locomotion adaptively to cope with changes in their bodies and environments. Many solutions converge because some forms of locomotion are more efficient or highly constrained than others. Locomotion improves with practice, and practice can lead to extraordinary performance (Adolph et al., 2010; Adolph & Robinson, 2013, 2015).

3.1 Newborn Stepping

When newborns are held upright with their feet on a hard surface, they move their legs in an alternating pattern that resembles walking—the so-called "newborn stepping reflex" (Andre-Thomas & Autgaerden, 1966). Stepping typically disappears by 2 months of age and reappears at 8-10 months when infants begin walking with support. The fact that newborns can produce alternating, upright leg movements led researchers to believe that walking is hardwired in the nervous system (Dominici et al., 2011; McGraw, 1945). Similarly, the curious disappearance and reappearance of stepping was attributed to cortical maturation.

However, newborn stepping is not, in fact, reflexive, and alternating leg movements do not, in fact, disappear. Contra-reflex: Newborns "air-step" without an eliciting physical stimulus and they also do so in response to optic flow (Barbu-Roth et al., 2009; Barbu-Roth et al., 2014). And infants can deliberately modify their leg movements (Angulo-Kinzler et al., 2002) in various configurations of alternating, simultaneous, and single-leg kicks (Rovee-Collier et al., 1978; Thelen, 1994). Contra-disappearance: Infants kick their limbs in alternation while lying supine throughout the time period when upright stepping disappears. Moreover, upright steps instantly reappear when infants are held on a motorized treadmill (Thelen, 1986; Yang et al., 2004), with their legs are submerged in water (Thelen et al., 1984), or when they are held upright off the ground (Barbu-Roth et al., 2014). The disappearance and reappearance of upright stepping on a hard surface is likely due to lifting heavy legs against gravity (Thelen et al., 1984) and supporting weight on a single, weak leg (Anderson et al., 2016; Barbu-Roth et al., 2015).

3.2 Creative Solutions

Individual infants find different ways to solve the problem of moving. Their first success at mobility typically involves a prone position with minimal balance constraints—log rolling (Figure 1H) (Trettien, 1900), pivoting in circles (van der Meer et al., 2008), pushing backward, or belly crawling (Figure 1I) where the belly rests continually on the floor or bumps up and down during each cycle (Adolph et al., 1998; Patrick et al., 2012). Every form of precursory prone movement helps: Infants who pivot, belly crawl, and so on are twice as proficient when they begin crawling on hands and knees compared with infants who don't display the earlier forms (Adolph et al., 1998). In fact, simply spending a few minutes a day in a prone position accelerates the onset of rolling and crawling (Majnemer & Barr, 2005).

On hands and knees, demands for balance increase because the belly is off the floor. As a consequence, infants mostly settle into a relatively stable, near-trot pattern (Adolph et al., 1998; Cole et al., 2019; Patrick et al., 2009). But they also display other coordination patterns. And they crawl on hands and feet and combine hands, knees, feet, and buttocks into various forms of hitching and bum-shuffling that blur the line between sitting and crawling (Figure 1J-M) (Adolph & Robinson, 2013;

Patrick et al., 2012). Indeed, the rampant variability in early forms of locomotion and the inconsistency of crawling across cultures and time periods led the U.S. Center for Disease Control to remove crawling from its checklist of developmental milestones (Kretch, Willett, et al., 2022; Zubler et al., 2022).

Balance constraints are more severe while upright, but learning to walk (Figure 1N) is likewise an exercise in creative problem solving. Infants display various falling, twisting, and stepping strategies to induce enough disequilibrium to take steps but not so much to induce a fall (McCollum et al., 1995; McGraw, 1945; Snapp-Childs & Corbetta, 2009).

Generating new forms of locomotion can involve cognitive skills such as means-ends problem solving, representing goals and spatial locations, and tool use. When confronted with challenging obstacles such as steep slopes, cliffs, and stairs, infants search for alternative means of descent—scooting, crawling, sliding, and backing (Adolph, 1997; Karasik et al., 2016; Kretch & Adolph, 2013). On narrow bridges, infants use a sturdy wooden handrail as a tool to augment their balance, but they reject the handrail if it is too far from the bridge (Berger & Adolph, 2003; Berger et al., 2010; Berger et al., 2005). With only a wobbly rubber handrail for support, they test the potential utility of the rail, and invent various strategies for distributing body weight over the bridge and handrail.

3.3 Learning to Walk

Infants take their first walking steps at 12 months, on average (Martorell et al., 2006), but like all motor milestones, walk onset has a wide range (8-18 months) because it awaits sufficient strength and balance to support the body on one leg as the other leg swings forward (Bril & Ledebt, 1998; McGraw, 1945). Infants' first steps are wobbly and uneven, with a wide side-to-side distance between feet, a small front-to-back distance between steps, long periods with both feet on the floor, and short periods with one foot is in the air (Adolph et al., 2003; Bril & Breniere, 1992; Hospodar et al., 2021; Lee et al., 2018). But soon the base of support narrows, step length increases, double support periods decrease, and infants are racing across the floor. In particular, longer steps allow infants to move faster without increasing their step rate (Bisi & Stagni, 2015). The steep developmental trajectory for walking resembles the negatively accelerated performance curves characteristic of most motor learning. Initial rapid improvements in the first 3-6 months of walking reflect infants' discovery of the relevant parameters that control upright balance and propulsion (Adolph et al., 2003; Bril &

Breniere, 1993; Bril et al., 2015; Ivanenko et al., 2005). A protracted tapering-off period (between 5-7 years) reflects subtle fine-tuning of gait parameters (Bril & Ledebt, 1998; Sutherland et al., 1988).

Practice, not merely maturation, underlies infants' age at walk onset and improvements in walking skill (Adolph et al., 2003; Hospodar et al., 2021). Typically, infants accumulate immense amount of practice. In one hour of free play, the average toddler takes about 2400 steps, travels the length of 8 American football fields, and falls 17 times (Adolph et al., 2012; Han & Adolph, 2021). Practice is time distributed, with short bouts of walking interspersed with longer periods of rest (Cole et al., 2016; Lee et al., 2018). Infants take steps in place and in every direction (forward, backward, and sideways), and they walk along curved and twisting paths (Hoch et al., 2019; Hoch et al., 2020). Bout length, step direction, and path shape are unrelated to walking skill, meaning that infants do not stop walking, step backward, or walk in curved paths because they lose balance—it is just the way babies walk. Moreover, walking changes how infants spend their time in daily life. Walkers spend 2 more hours per day upright compared to same-aged pre-walkers (Franchak, et al., 2024).

Both experimental and cross-cultural studies show that experience standing, stepping, and moving upright facilitates strength and balance and accelerates walk onset (Adolph & Hoch, 2019; Adolph et al., 2010; Adolph & Robinson, 2013, 2015). A few minutes of daily practice with upright stepping causes infants to begin walking weeks earlier than infants who receive only passive exercise (Wu et al., 2007; Zelazo et al., 1972). Similarly, in cultures where caregivers deliberately exercise infants' upright skills, babies walk sooner than those from the same ethnic backgrounds who do not receive exercise (Hopkins & Westra, 1990). Extensive practice can lead to improvements in endurance, strength, coordination, and balance far beyond the norm for Western walkers (Adolph & Hoch, 2019; Adolph et al., 2010; Adolph & Robinson, 2013, 2015). Tarahumaran children engage in long-distance running as part of daily activity. As a consequence, their endurance exceeds the abilities of most Western ultra-marathoners: Tarahumaran children routinely run 10-40 km and adults race 150-300 km (Bennett & Zingg, 1935).

Conversely, reduced practice hinders improvements in walking skill and delays walk onset. Infants who are bound in a traditional "gahvora" cradle learn to crawl, stand, and walk at later ages compared with World Health Organization standards (Karasik et al., 2023). More hours bound in a traditional "gahvora" cradle predict slower walking speed and shorter steps among Tajik infants (Karasik et al., 2023).

Learning to walk alters infants' exploratory behaviors and social interactions, resulting in cascading effects on other aspects of development (Iverson, 2022). Compared with crawling, walking helps infants to travel farther, transport objects (Heiman et al., 2019; Karasik et al., 2011), and to see distant objects and places (Franchak et al., 2018; Kretch et al., 2014; Luo & Franchak, 2020). Walking infants move farther away from their caregivers (Chen et al., 2023), but when they return, they more often bring objects to share (Karasik et al., 2011) and can more easily look at caregivers' faces and make eye contact (Franchak et al., 2018; Yamamoto et al., 2020). Walkers increasingly vocalize while moving (West & Iverson, 2021) and caregivers provide different language input when speaking about actions and objects to walking infants compared with crawlers (Karasik et al., 2014; West et al., 2023). Learning to walk cascades into long-term improvements in visual attention (Mulder et al., 2022), spatial cognition (Oudgenoeg-Paz et al., 2015), and language development (Oudgenoeg-Paz et al., 2012; Schneider & Iverson, 2022; Walle & Campos, 2014; West & Iverson, 2021).

3.4 Obstacle Navigation

To navigate the everyday environment—replete with obstacles and variations in ground surfaces—infants must select the appropriate actions and modify them accordingly. Infants generate the requisite perceptual information through exploratory movements—looking, touching, and testing various options (Adolph, 1997; Adolph & Robinson, 2015; Kretch & Adolph, 2017). The first studies of obstacle navigation tested infants on a "visual cliff," a drop-off covered in safety glass (Gibson & Walk, 1960). But infants can feel the glass, so after one trial, they learn that the drop-off is only illusory and cross (Campos et al., 1978). Subsequent researchers used real cliffs, bridges, waterbeds, foam pits, water pits, slippery surfaces, barriers, apertures, and other obstacles to test infants' prospective control of locomotion (for a review, see Adolph et al., 2021). Because visual and haptic information are not in conflict on apparatuses with no safety glass, infants can be tested in dozens of trials (an experimenter follows alongside to ensure their safety). Many apparatuses are adjustable, allowing precise assessment of infants' ability to gauge possibilities for locomotion.

Prelocomotor infants are sensitive to visual flow for heading (Gilmore et al., 2004) and depth information for a drop-off (Campos et al., 1992), but sensitivity is not enough. Mobile infants must learn to navigate. In their first weeks of independent mobility, infants plunge repeatedly over the edge of impossibly steep slopes, high cliffs, and wide gaps. Over weeks of everyday experience, judgments improve so that infants attempt safe increments within their ability and avoid risky obstacles beyond their ability (Adolph & Robinson, 2013, 2015). But despite these early improvements, learning to make accurate motor decisions is a protracted process—months to years to achieve adult-like levels of accuracy. For example, infants and children adapt their judgments to accommodate shoulder-packs that make them top-heavy (Adolph & Avolio, 2000) or backpacks that make them thicker through the torso (Franchak, 2019b), but adults more readily accommodate their new abilities following practice. Even 7- and 8-year-olds make larger errors than adults when gauging whether they can walk through apertures (Franchak, 2019b).

3.5 Summary: Locomotion

Fetuses and neonates can produce leg and arm movements that grossly resemble locomotion, but locomotion is not hardwired or reflexive. Instead, locomotor development is tremendously plastic and responsive to caregiving practices and experience. And locomotion is wildly creative. Infants discover their own solutions for their first rolling, crawling, bum shuffling, and walking steps. And then they must learn to generate information for perception and cognition to find appropriate solutions to navigate the continually-changing everyday environment.

4 MANUAL ACTIONS

Manual actions begin prenatally, but outside the womb, infants require a stable postural base to support arm movements and perceptual information to guide movements adaptively. Tools extend manual abilities, but children must learn to use tools effectively (Adolph & Robinson, 2015; Lockman & Kahrs, 2014; Smitsman & Bongers, 2003).

4.1 Spontaneous Movement

Like all movements, manual actions appear long before birth. Ten-week-old fetuses flex and extend their arms, wiggle their fingers, and clench their fists (Prechtl, 1985, 1986). By 14 weeks, fetuses manually explore their bodies, the umbilical cord, and the surface of the uterine wall (Sparling et al., 1999). By 16 weeks, fetuses bring hand to mouth to suck their thumbs (Hepper et al., 1991). Even these early actions are perceptually guided and planned: Fetuses open their mouths in anticipation of, not in reaction to, the arrival of their thumb (Reissland et al., 2014). By 22 weeks, acceleration/deceleration of the hand is controlled with respect to the target: Hand movements aimed towards a delicate target (the eyes) are smoother compared with movements directed towards the mouth (Zoia et al., 2007).

Self-directed manual movements continue after birth. During the first two postnatal months, infants frequently (~13 times/minute) touch their own heads and bodies (DiMercurio et al., 2018), generating tactile and proprioceptive information. By 7 months, infants localize and reach toward vibrating targets placed on their mouths, hands, and forearms (Leed et al., 2019). Retrieving targets placed on ears, forehead, and elbows becomes more successful as infants learn to integrate visual and proprioceptive information. Self-directed actions may provide a basis for later-developing object-directed actions (Babik et al., 2022).

4.2 Reaching and Grasping

Reaching to external targets (Figure 1O-P) requires perceptual information about the location of the object vis-a-vis the hand. Given appropriate postural support, neonates and young infants extend their arms more frequently while looking at a toy than while looking away (Lee et al., 2008; Lee et al., 2011). Successful contact appears between 11 and 24 weeks of age (Berthier & Keen, 2006; Clifton et al., 1993), but early reaches are jerky and crooked; the arm speeds up, slows down, and changes direction multiple times prior to contact. It takes years before children's reaches become as smooth and straight as those of adults (Berthier & Keen, 2006; Schneiberg et al., 2002).

Older children and adults rely on view of the hand as well as view of the target to guide reaching (Churchill et al., 2000; Kuhtz-Buschbeck et al., 1998). However, young infants do not benefit from seeing their moving hand. Researchers can measure the importance of visual feedback by turning off the lights after a reach begins (toy glows to mark its location) or by occluding sight of the hand and arm with a barrier. Infants begin reaching for objects in the light and dark at the same age and are equally successful in both conditions (Clifton et al., 1993). Moreover, infants' reaching trajectories in the light and dark are indistinguishable (Clifton et al., 1994), with and without sight of the hand (Lee & Newell, 2012). In other words, infants' zigzag reach trajectories do not imply that they visually track their hand because infants display equally jerky reaches when they cannot see their hand. Jerky trajectories may result in part from postural constraints (Hopkins & Ronnqvist, 2002) and unanticipated reactive forces (Berthier & Keen, 2006).

Much to infants' frustration, getting the hand to the right place is only part of the problem. Reaching precedes grasping because control of the arms precedes control of the hands. With increased hand/finger control, infants adapt their grip configuration to object properties (Figure 1Q-R), but they do so after contacting the object, not prospectively during the reach (Vollmer & Forssberg, 2009). Prospective control of grasping based on visual information for object size, shape, and orientation appears months after infants begin reaching (Barrett et al., 2008; Fagard, 2000; von Hofsten & Johansson, 2009).

4.3 Exploring Objects

An object in hand opens up new opportunities for visual, manual, and oral exploration, and with increasing skill, object exploration becomes increasingly multi-modal and specific (Lockman & Tamis-LeMonda, 2021; Needham, 2000; Rochat, 1989). At first, infants use their hands only to bring objects to the face for looking and mouthing (Norris & Smith, 2002). Increased grip strength allows infants to alternate between looking and mouthing, providing multimodal information about object properties. Soon, manual skills progress beyond mere holding. Infants heft, rub, squeeze, finger, and rotate objects (Eppler, 1995; Palmer, 1989; Rochat, 1989; Soska & Adolph, 2014). Hands begin to serve complementary functions, one supporting the object and keeping it in view, the other generating information about object properties by fingering or palpating (Babik & Michel, 2016; Kotwica et al., 2008).

Infants' daily experiences with objects are tremendous in scale and diversity, generating a wealth of information to support perceptual, cognitive, and language learning. By 12 months of age, infants interact with objects 40%-60% of their waking day, encountering dozens of different objects each hour (Franchaket al., 2024; Herzberg et al., 2022; Karasik et al., 2011). Infants learn the names of objects that they frequently see and act on (Clerkin et al., 2017; Suarez-Rivera et al., 2022). Moreover, how infants hold and rotate objects for visual exploration predicts their later vocabulary size (Slone et al., 2019). Improvements in manual exploration are also linked with shifts in infants' attention to changes in object appearance (Baumgartner & Oakes, 2013), object size (Libertus et al., 2013), multimodal information about objects (Eppler, 1995), and other people's intentions to grasp objects (Daum et al., 2011; Loucks & Sommerville, 2012).

4.4 Extending Abilities with Tools

Tool use has its roots in early motor actions and relies on motor actions for its execution (Kahrs et al., 2013; Lockman & Kahrs, 2014; Smitsman & Bongers, 2003). Young infants' spontaneous banging and rubbing become preschoolers' hammering and drawing. Fetal hand-to-mouth behaviors become self-feeding with a spoon. Exploring relations between objects and surfaces sets the stage for using objects as effective tools.

Tool use requires infants to perceive that a goal is beyond their abilities, recognize that an object can serve as a means to augment their abilities, and execute the necessary movements to use the tool. Each step in real time must first be acquired in development. For example, very young infants perceive when an object is out of reach (Yonas & Hartman, 1993). Months later, they use hooks, canes, and rakes to acquire out-of-reach objects, but only if the target object is already placed inside the crook of the tool (Chen & Siegler, 2000; Rat-Fischer et al., 2012). And still later they perceive the full implications of the spatial relations by orienting the tools to place the target in the crook. Observing caregivers or other adults use a tool effectively provides a powerful impetus for learning (Rat-Fischer et al., 2012)

Implementation is the last step in functional tool use. Nine-month-olds grasp a spoon filled with applesauce by the bowl end rather than by the handle (getting a handful of applesauce), or with a grip that points the food away from the mouth so that they cannot eat (Figure 1S). Although 12- to 24-month-olds correctly choose to strike an object with the hard rather than soft side of a hammer, 12-month-olds often miss the target, so even well-planned strikes may not be functional (Fragaszy et al., 2014). Eighteen-month-olds perceive the optimal grasp for delivering food to their own mouth and plan their grasp prospectively (Figure 1T), but their planning is less efficient when feeding a doll (Claxton et al., 2009; McCarty et al., 1999, 2001). Two-year-olds adapt their grasp to use a spoon with a bent handle (Steenbergen et al., 1997). But even 4-year-olds fail to realize that they must use an underhand grip (Figure 1U) to grasp a spoon or hammer pointing away from their dominant hand (Comalli et al., 2016; Keen et al., 2014). Planning improves with age, as preschoolers increasingly look at a hammer and decide how to grasp it before moving their hands (Ossmy et al., 2022).

4.5 Summary: Manual Actions

Beginning prenatally, manual actions are perceptually guided and serve exploratory functions. Many of infants' spontaneous arm and hand movements are co-opted for goal-directed manual actions and tool use. Infants use vision to locate the target of a reach and to preshape their hand for grasping, but they do not require sight of their hand to get it to a target. Exploring objects is a multimodal activity involving eyes, hands, fingers, and mouth. Manual skills instigate a cascade of new opportunities for learning.

5 FACIAL ACTIONS

All the parts of the face begin moving prenatally, including the eyes with eyelids still fused shut. After birth, infants continue to produce spontaneous facial movements, but facial actions become integral to everyday function. The simple ability to swallow is critical for suckling, eating, and talking. Vocalizations and facial expressions are fundamental for communication. Head and eye movements provide the basis for visual exploration of the environment.

5.1 Swallowing, Sucking, and Chewing

Actions like swallowing (Figure 1V) are normally so innocuous that we fail to recognize the tremendous coordination required. Fetuses make swallowing, sucking, and breathing movements, but since they do not breathe air or eat, the movements are not coordinated (Miller et al., 2003). However, to nurse without choking or swallowing air, newborns must coordinate movements of tongue, jaws, and lips to create suction, draw liquid into the mouth, pull the liquid into the pharynx, and divert the liquid to the esophagus while pulling air into the trachea (Burton et al., 2013; Geddes et al., 2012; Wilson et al., 2008). Infants solve the timing problem by coordinating when to suck, swallow, and breathe (Barlow, 2009; Fucile et al., 2012; van der Meer et al., 2005).

Chewing solid food is more complicated than nursing because the food must be masticated before it can be swallowed. Newborns can mush up a small piece of banana and move it around the mouth with jaws and tongue (Sheppard & Mysak, 1984). However, infants rely on lateral jaw movements to do most of the work of chewing, whereas older children and adults use rotary jaw movements and incorporate more prospective actions of the lips and tongue (Wilson & Green, 2009). Infants produce the same chewing movements regardless of the type of food, whereas older children select appropriate jaw movements and muscle forces based on the food consistency (Wilson & Green, 2009).

5.2 Facial Gestures and Speech

Facial expressions and vocalizations appear long before infants can convey feelings and communicate ideas. Fetuses produce smiles (Figure 1W), grimaces, and facial movements that resemble adult-like expressions of laughter, crying, and pain (Reissland et al., 2013; Reissland et al., 2011). Neonates produce characteristic facial gestures to strong stimuli such as nose wrinkling and furrowed brows to noxious smells (Loos et al., 2014). Newborns smile most while asleep, about one smile every five minutes (Messinger, 2002, 2008). Awake infants display social smiles and laughter by 2 to 5 months of age while gazing at caregivers or in response to positive stimulation (Messinger, 2006). Perhaps because they are so critical for social interaction, facial expressions are highly redundant so that muscles distributed throughout the face work in concert; eyebrows can convey basic facial expressions as effectively as the mouth. In fact, infants who lack the ability to move specific parts of their faces due to craniofacial anomalies, cleft lip/palate, or hemangiomas produce recognizable smiles, cries, and interested expressions (Oster, 2003).

The movements needed for speech production (Figure 1X) are perhaps the most complex movements children learn (Green & Nip, 2010). The jaws, lips, and tongue must be precisely positioned to shape each sound as air travels through the oral and nasal cavities. Both speed and accuracy are major challenges in speech development. Adult-like speech is incredibly fast, encompassing up to 15 sounds per second (Green & Nip, 2010). As in the development of chewing, infants discover functional strategies to produce speech sounds, but their movements are not adult-like. For example, adults use quick simultaneous movements of jaws and lips to babble ("baba," "mama"), whereas infants rely primarily on jaw movements, which are easier to control (Green et al., 2000). Between 2-6 years of age, children gain better control over their lips and incorporate those movements into the previously established jaw movements, allowing them to produce a greater variety of speech sounds (Wilson et al., 2008).

5.3 Looking

Although it is tempting to think of looking as merely perception, moving gaze from one location to another is an action that requires control. Like all actions, looking is nested within a postural base: The orientation of the eyes within the head, the head on the body, and the body in space determine what is in view (Figure 1Y-Z). Eye movements are fast and require little energy, but larger shifts of gaze require head and body rotations that are slow and effortful. Adults coordinate eye and head movements to efficiently gather information in all directions (Franchak et al., 2021; Luo & Franchak, 2022). But newborns, who can barely turn their heads, look at whatever is in front of them. By 6 months, eye and head movements are tightly coupled: Like adults, infants use a combination of eye and head rotations to orient to targets in different directions (Daniel & Lee, 1990; Schmitow et al., 2013). By 12 months, infants hold their eyes and head still while looking at objects, presumably to stabilize gaze for exploration (Borjon et al., 2021). Toddlers' looking becomes more efficient by switching gaze with the eyes before moving the head (Nakagawa & Sukigara, 2013).

Task-specific visual guidance becomes increasingly efficient with development. Although young infants struggle to disengage from one target to shift their gaze to the next (Rosander, 2020), toddlers seamlessly distribute visual attention among multiple motor tasks, looking at obstacles to guide locomotion and fixating objects to guide the hand while reaching (Franchak et al., 2011). Quick glances to obstacles from a distance elicit more costly types of exploration such as touching (Kretch & Adolph, 2017). While copying letters, children shift gaze between examining the to-be-copied letters and monitoring their current handwriting (Fears & Lockman, 2018).

Wearable eye trackers and head cameras capture what infants see during naturalistic activities, providing a window into how visual exploration supports learning and development in daily life. Younger infants, who spend more time held and reclined, see faces more frequently than older infants, who spend more time on the ground sitting and crawling (Fausey et al., 2016). The same effect holds for real-time changes in posture. Faces are more likely in view while sitting (Figure 1Y) and standing compared to prone (Figure 1Z) (Kretch et al., 2014; Long et al., 2022)—although both seated and mobile infants and toddlers rarely look at their caregiver's face during play (Franchak et al., 2018; Yu & Smith, 2013; Yurkovic-Harding et al., 2022). Raising infants off the floor (e.g., in an infant carrier) increases the availability of faces in view (Kretch & Adolph, 2015). Thus, moment-to-moment changes in posture have consequences for what infants can see.

Everyday visual exploration in a rich, multimodal, social environment shapes cognitive development. Head-camera recordings reveal that the objects in infants' view correspond to early-learned nouns (Clerkin et al., 2017). Infants' views are cluttered with multiple objects, but repeated day-to-day experiences help infants map what they hear to what they see. For toddlers, coordination of visual and manual action predicts language learning: Object names are most likely to be learned when infants hold an object and look at it when it is named by a caregiver (Schroer & Yu, 2022). Simultaneously holding and looking at an object makes it dominate the visual field, helping to remove distraction from competing visual targets (Suanda et al., 2019). Infants amass huge amounts of daily experience observing others' actions, and individual differences in action observation predict infants' vocabulary for mental states (Ruffman et al., 2022).

5.4 Summary: Facial Actions

Facial actions include many of our most prized and basic social skills—talking, facial gestures, eating and drinking, and looking at others and at the environment. And each of these skills sets off a new cascade of interactions. Infants' solutions for moving the various parts of their face often differ from those of adults, but they get the job done in that developmental niche.

6 CONCLUSION

The study of motor development is really the study of behavioral development. As such, it can provide a useful window into general processes of development because the topic of study—movement—is directly observable. Researchers in motor development have always recognized the importance of the body (Adolph & Robinson, 2015). How could they do otherwise? Movements depend on physical forces, and the moment-to-moment changes and developmental status of the body affect those forces. The developmental systems perspective encourages researchers to consider a larger context that includes the physical and social/cultural environment, and to view motor behaviors as potentially both cause and consequence of developmental change in other psychological domains. Although prominent developmental theorists have long recognized the importance of motor development for psychological development more generally (Gibson, 1988; Piaget, 1954), only recently have researchers begun to systematically map out developmental cascades.

References

Adolph, K. E. (1997). Learning in the development of infant locomotion. *Monographs of the Society for Research in Child Development*, *62*(3, Serial No. 251). https://doi.org/10.2307/1166199

Adolph, K. E. (2000). Specificity of learning: Why infants fall over a veritable cliff. *PsychologicaL Science*, *11*, 290-295.

Adolph, K. E., & Avolio, A. M. (2000). Walking infants adapt locomotion to changing body dimensions. *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 1148-1166.

Adolph, K. E., Berger, S. E., & Leo, A. J. (2011). Developmental continuity? Crawling, cruising, and walking. *Developmental Science*, *14*, 306-318.

Adolph, K. E., Cole, W. G., Komati, M., Garciaguirre, J. S., Badaly, D., Lingeman, J. M., Chan, G., & Sotsky, R. B. (2012). How do you learn to walk? Thousands of steps and dozens of falls per day. *PsychologicaL Science*, *23*, 1387-1394.

Adolph, K. E., & Franchak, J. M. (2016). The development of motor behavior. *Wiley Interdisciplinary Reviews: Cognitive Science (WIREs)*. https://doi.org/10.1002/wcs.1430

Adolph, K. E., & Hoch, J. E. (2019). Motor development: Embodied, embedded, enculturated, and enabling. *Annual Review of Psychology*, *70*, 141-164.

Adolph, K. E., Kaplan, B. E., & Kretch, K. S. (2021). Infants on the edge: Beyond the visual cliff. In A. Slater & P. Quinn (Eds.), *Developmental psychology: Revisiting the classic studies, 2nd ed* (2 ed., pp. 51-72). Sage Publications.

Adolph, K. E., Karasik, L. B., & Tamis-LeMonda, C. S. (2010). Motor skills. In M. H. Bornstein (Ed.), *Handbook of cultural development science. Vol. 1. Domains of development across cultures* (pp. 61-88). Taylor and Francis.

Adolph, K. E., & Robinson, S. R. (2013). The road to walking: What learning to walk tells us about development. In P. Zelazo (Ed.), *Oxford handbook of developmental psychology* (pp. 403-443). Oxford University Press.

Adolph, K. E., & Robinson, S. R. (2015). Motor development. In R. M. Lerner, L. Liben, & U. Muller (Eds.), *Handbook of child psychology and developmental science* (7th ed., Vol. 2 Cognitive Processes, pp. 113-157). Wiley. https://doi.org/10.1002/9781118963418.childpsy204

Adolph, K. E., Vereijken, B., & Denny, M. A. (1998). Learning to crawl. *Child Development*, *69*, 1299-1312.

Adolph, K. E., Vereijken, B., & Shrout, P. E. (2003). What changes in infant walking and why. *Child Development*, *74*, 474-497.

Anderson, D. I., Kobayashi, Y., Hamel, K., Rivera, M., Campos, J. J., & Barbu-Roth, M. (2016). Effects of support surface and optic flow on step-like movements in pre-crawling and crawling infants. *Infant Behavior and Development*, *42*, 104-110.

Andre-Thomas, M., & Autgaerden, S. (1966). *Locomotion from pre- to post-natal life*. Spastics Society Medical Education and Information Unit in association with William Heinemann Medical Books, Ltd.

Angulo-Kinzler, R. M., Ulrich, B. D., & Thelen, E. (2002). Three-month-old infants can select specific leg motor solutions. *Motor Control*, *6*, 52-68.

Atun-Einy, O., Berger, S. E., & Scher, A. (2012). Pulling to stand: Common trajectories and individual differences. *Developmental Psychobiology*, *54*, 187-198.

Babik, I., Galloway, J. C., & Lobo, M. (2022). Early exploration of one's own body, exploration of objects, and motor, language, and cognitive development relate dynamically across the first two years of life. *Developmental Psychology*, *58*(2), 222-235.

Babik, I., & Michel, G. F. (2016). Development of role-differentiated bimanual manipulation in infancy: Part 1. The emergence of the skill. *Developental Psychobiology*, *58*(2), 243-256.

Barbu-Roth, M., Anderson, D. I., Despres, A., Provasi, J., Cabrol, D., & Campos, J. J. (2009). Neonatal stepping in relation to terrestrial optic flow. *Child Development*, *80*, 8-14.

Barbu-Roth, M., Anderson, D. I., Despres, A., Streeter, R. J., Caborl, D., Trukillo, M., Campos, J. J., & Provasi, J. (2014). Air stepping in response to optic flows that move toward and away from the neonate. *Developmental Psychobiology*, *56*, 1142-1149.

Barbu-Roth, M., Anderson, D. I., Streeter, R. J., Combrouze, M., Park, J., Schultz, B., Campos, J. J., Goffinet, F., & Provasi, J. (2015). Why does infant stepping disappear and can it be stimulated by optic flow? *Child Development*, *86*, 441-455.

Barlow, S. M. (2009). Oral and respiratory control for preterm feeding. *Current Opinion in Otolaryngology and Head and Neck Surgery*, *17*, 179-186.

Barrett, T. M., Traupman, E., & Needham, A. W. (2008). Infants' visual anticipation of object structure in grasp planning. *Infant Behavior and Development*, *31*, 1-9.

Baumgartner, H. A., & Oakes, L. M. (2013). Investigating the relation between infants' manual activity with objects and their perception of dynamic events. *Infancy*, *18*, 983-1006.

Bennett, W. C., & Zingg, R. M. (1935). *The Tarahumara, an Indian tribe of northern Mexico*. University of Chicago Press.

Berger, S. E., & Adolph, K. E. (2003). Infants use handrails as tools in a locomotor task. *Developmental Psychology*, *39*, 594-605.

Berger, S. E., Adolph, K. E., & Kavookjian, A. E. (2010). Bridging the gap: Solving spatial means-ends relations in a locomotor task. *Child Development*, *81*, 1367-1375.

Berger, S. E., Adolph, K. E., & Lobo, S. A. (2005). Out of the toolbox: Toddlers differentiate wobbly and wooden handrails. *Child Development*, *76*, 1294-1307.

Bernstein, N. A. (1996). Dexterity and its development. In M. L. Latash & M. T. Turvey (Eds.), *Dexterity and its development* (pp. 3-244). Erlbaum.

Bertenthal, B. I., & von Hofsten, C. (1998). Eye, head and trunk control: The foundation for manual development. *Neuroscience and Biobehavioral Review*, *22*, 515-520. https://doi.org/10.1016/S0149-7634(97)00038-9

Berthier, N. E., & Keen, R. E. (2006). Development of reaching in infancy. *Experimental Brain Research*, *169*, 507-518. https://doi.org/10.1007/s00221-005-0169-9

Bisi, M. C., & Stagni, R. (2015). Evaluation of toddler different strategies during the first six-months of independent walking: A longitudinal study. *Gait and Posture*, *41*, 574-579.

Blumberg, M. S., Spencer, J. P., & Shenk, D. (2016). Introduction to the collection “How we develop—developmental systems and the emergence of complex behaviors”. *Wiley interdisciplinary reviews. Cognitive science*, *8*, e1413.

Borjon, J. I., Abney, D. H., Yu, C., & Smith, L. B. (2021). Head and eyes: Looking behavior in 12- to 24-month-old infants. *Journal of vision*, *21*(8), 18.

Bril, B., & Breniere, Y. (1992). Postural requirements and progression velocity in young walkers. *Journal of Motor Behavior*, *24*, 105-116.

Bril, B., & Breniere, Y. (1993). Posture and independent locomotion in early childhood: Learning to walk or learning dynamic postural control? In G. J. P. Savelsbergh (Ed.), *The development of coordination in infancy* (pp. 337-358). Elsevier.

Bril, B., Dupuy, L., Dietrich, G., & Corbetta, D. (2015). Learning to tune the antero-posterior propulsive forces during walking: A necessary skill for mastering upright locomotion in toddlers. *Experimental Brain Research*, *233*, 2903-2912.

Bril, B., & Ledebt, A. (1998). Head coordination as a means to assist sensory integration in learning to walk. *Neuroscience and Biobehavioral Reviews*, *22*, 555-563.

Burton, P., Deng, J., McDonald, D., & Fewtrell, M. S. (2013). Real-time 3D ultrasound imaging of infant tongue movements during breastfeeding. *Early Human Development*, *89*, 635-641.

Campos, J. J., Bertenthal, B. I., & Kermoian, R. (1992). Early experience and emotional development: The emergence of wariness of heights. *PsychologicaL Science*, *3*, 61-64.

Campos, J. J., Hiatt, S., Ramsay, D., Henderson, C., & Svejda, M. (1978). The emergence of fear on the visual cliff. In M. Lewis & L. Rosenblum (Eds.), *The development of affect* (pp. 149-182). Plenum.

Carvalho, R. P., Tudella, E., Calijouw, S. R., & Savelsbergh, G. J. P. (2008). Early control of reaching: Effects of experience and body orientation. *Infant Behavior and Development*, *31*, 23-33.

Chen, Q., Schneider, J. L., West, K. L., & Iverson, J. M. (2023). Infant locomotion shapes proximity to adults during everyday play in the U.S. *Infancy*, *28*(2), 190-205.

Chen, Z., & Siegler, R. S. (2000). Across the great divide: Bridging the gap between understanding of toddlers' and older children's thinking. *Monographs of the Society for Research in Child Development*, *65*(2, Serial No. 261).

Churchill, A., Hopkins, B., Ronnqvist, L., & Vogt, S. (2000). Vision of the hand and environmental context in human prehension. *Experimental Brain Research*, *134*, 81-89.

Claxton, L. J., McCarty, M. E., & Keen, R. (2009). Self-directed action affects planning in tool-use tasks with toddlers. *Infant Behavior and Development*, *32*, 230-233.

Claxton, L. J., Strasser, J. M., Leung, E. J., Ryu, J. H., & O’Brien, K. M. (2014). Sitting infants alter the magnitude and structure of postural sway when performing a manual goal directed task. *Developmental Psychobiology*, *56*, 1416-1422.

Clerkin, E. M., Hart, E., Rehg, J. M., Yu, C., & Smith, L. B. (2017). Real-world visual statistics and infants' first-learned object names. *Philosophical Transactions of the Royal Society. B: Biological Sciences*, *372*, 20160055. https://doi.org/10.1098/rstb.2016.0055

Clifton, R. K., Muir, D. W., Ashmead, D. H., & Clarkson, M. G. (1993). Is visually guided reaching in early infancy a myth? *Child Development*, *64*, 1099-1110. https://doi.org/10.1111/j.1467-8624.1993.tb04189.x

Clifton, R. K., Rochat, P., Robin, D. J., & Berthier, N. E. (1994). Multimodal perception in the control of infant reaching. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 876-886.

Cole, W. G., Robinson, S. R., & Adolph, K. E. (2016). Bouts of steps: The organization of infant exploration. *Developmental Psychobiology*, *58*, 341-354.

Cole, W. G., Vereijken, B., Young, J. W., Robinson, S. R., & Adolph, K. E. (2019). Use it or lose it? Effects of age, experience, and disuse on quadrupedal gait. *Developmental Psychobiology*, *61*, 29-42.

Comalli, D. M., Keen, R., Abraham, E., Foo, V. J., Lee, M. H., & Adolph, K. E. (2016). The development of tool use: Planning for end-state comfort. *Developmental Psychology*, *52*, 1878-1892.

D'Elia, A., Pighetti, M., Moccia, G., & Santangelo, N. (2001). Spontaneous motor activity in normal fetuses. *Early Human Development*, *65*, 139-147.

Daniel, B. M., & Lee, D. N. (1990). Development of looking with head and eyes. *Journal of Experimental Child Psychology*, *50*, 200-216.

Daum, M. M., Prinz, W., & Aschersleben, G. (2011). Perception and production of object-related grasping in 6-month-olds. *Journal of Experimental Child Psychology*, *108*, 810-818.

de Vries, J. I. P., & Hopkins, B. (2005). Fetal movements and postures: What do they mean for postnatal development? In B. Hopkins & S. P. Johnson (Eds.), *Prenatal development of postnatal functions* (pp. 177-220). Praeger.

DiMercurio, A., Connell, J. P., Clark, M., & Corbetta, D. (2018). A naturalistic observation of spontaneous touches to the body and environment in the first 2 months of life. *Frontiers in Psychology*, *9*, 2613.

Dominici, N., Ivanenko, Y. P., Cappellini, G., d'Avella, A., Mondi, V., Cicchese, M., Fabiano, A., Silei, T., Di Paolo, A., Giannini, C., Poppele, R. E., & Lacquaniti, F. (2011). Locomotor primitives in newborn babies and their development. *Science*, *334*, 997-999.

Dusing, S. C., Thacker, L. R., & Galloway, J. C. (2016). Infant born preterm have delayed development of adaptive postural control in the first 5 months of life. *Infant Behavior and Development*, *44*, 49-58.

Eppler, M. A. (1995). Development of manipulatory skills and the deployment of attention. *Infant Behavior and Development*, *18*, 391-405.

Fagard, J. (2000). Linked proximal and distal changes in the reaching behavior of 5- to 12-month-old human infants grasping objects of different sizes. *Infant Behavior and Development*, *23*, 317-329.

Fausey, C. M., Jayaraman, S., & Smith, L. B. (2016). From faces to hands: Changing visual input in the first two years. *Cognition*, *152*, 101-107. https://doi.org/10.1016/j.cognition.2016.03.005

Fears, N. E., & Lockman, J. J. (2018). Variable coordination of eye and head movements during the early development of attention: A longitudinal study of infants aged 12–36 months. *Journal of Experimental Child Psychology*, *171*, 55-70.

Fragaszy, D., Simpson, K., Cummins-Sebree, S., & Brakke, K. (2014). Ontogeny of tool use: How do toddlers use hammers? *Developmental Psychobiology*, *58*, 759-772.

Franchak, J. M. (2019a). Changing opportunities for learning in everyday life: Infant body position over the first year. *Infancy*, *24*(2), 187-209.

Franchak, J. M. (2019b). Development of affordance perception and recalibration in children and adults. *Journal of Experimental Child Psychology*, *183*, 100-114.

Franchak, J. M., Kadooka, K., & Fausey, C. (2024). Longitudinal relations between independent walking, body position, and object experiences in home life. *Developmental Psychology*, *62(2)*, 228-242.

Franchak, J. M., Kretch, K. S., & Adolph, K. E. (2018). See and be seen: Infant-caregiver social looking during freely mobile play. *Developmental Science*, *21*, e12626.

Franchak, J. M., Kretch, K. S., Soska, K. C., & Adolph, K. E. (2011). Head-mounted eye tracking: A new method to describe infant looking. *Child Development*, *82*, 1738-1750.

Franchak, J. M., McGee, B., & Blanch, G. (2021). Adapting the coordination of eyes and head to differences in task and environment during fully-mobile visual exploration. *PLoS ONE*, *16*(8), e0256463.
Franchak, J. M., Tang, M., Rousey, H., & Luo, C. (in press). Long-form recording of infant body position in the home using wearable inertial sensors. *Behavior Research Methods*.
Fucile, S., MacFarland, D. H., Gisel, E. G., & Lau, C. (2012). Oral and nonoral sensorimotor interventions facilitate suck-swallow-respiration functions and their coordination in preterm infants. *Early Human Development*, *88*, 345-350.
Geddes, D. T., Sakalidis, V. S., Hepworth, A. R., McClellan, H. L., Kent, J. C., Lai, C. T., & Hartmann, P. E. (2012). Tongue movement and intra-oral vacuum of term infants during breastfeeding and feeding from an experimental teat that released milk under vacuum only. *Early Human Development*, *88*, 443-449.
Gesell, A. (1946). The ontogenesis of infant behavior. In L. Carmichael (Ed.), *Manual of child psychology* (pp. 295-331). John Wiley. https://doi.org/10.1037/10756-006
Gibson, E. J. (1988). Exploratory behavior in the development of perceiving, acting, and the acquiring of knowledge. *Annual Review of Psychology*, *39*, 1-41. https://doi.org/10.1146/annurev.ps.39.020188.000245
Gibson, E. J. (1994). Has psychology a future? *PsychologicaL Science*, *5*, 69-76.
Gibson, E. J., & Walk, R. D. (1960). The "visual cliff". *Scientific American*, *202*, 64-71.
Gilmore, R. O., Baker, T. J., & Grobman, K. H. (2004). Stability in young infants' discrimination of optic flow. *Developmental Psychology*, *40*, 259-270.
Green, J. R., Moore, C. A., Higashikawa, M., & Steeve, R. W. (2000). The physiologic development of speech motor control: Lip and jaw coordination. *Journal of Speech, Language, and Hearing Research*, *43*, 239-255.
Green, J. R., & Nip, I. S. B. (2010). Some organization principles in early speech development. In B. Maaseen & P. H. H. M. van Lieshout (Eds.), *Speech motor control: New development in basic and applied research* (pp. 171-188). Oxford University Press.
Han, D., & Adolph, K. E. (2021). The impact of errors in infant development: Falling like a baby. *Developmental Science*, *24*, e13069.
Harbourne, R. T., Lobo, M. A., Karst, G. M., & Galloway, J. C. (2013). Sit happens: Does sitting development perturb reaching development, or vice versa? *Infant Behavior and Development*, *36*, 438-450.
Heiman, C. M., Cole, W. G., Lee, D. K., & Adolph, K. E. (2019). Object interaction and walking: Integration of old and new skills in infant development. *Infancy*, *24*, 547-569.
Hepper, P. G., Shahidullah, S., & White, R. (1991). Handedness in the human fetus. *Neuropsychologia*, *29*, 1107-1111.
Herzberg, O., Fletcher, K. K., Schatz, J. L., Adolph, K. E., & Tamis-LeMonda, C. (2022). Infant exuberant object play at home: Immense amounts of time-distributed, variable practice. *Child Development*, *93*, 150-164.
Hoch, J. E., O'Grady, S. M., & Adolph, K. E. (2019). It's the journey, not the destination: Locomotor exploration in infants. *Developmental Science*, *22*, e12740.
Hoch, J. E., Rachwani, J., & Adolph, K. E. (2020). Where infants go: Real-time dynamics of locomotor exploration in crawling and walking infants. *Child Development*, *91*, 1001-1020.
Hopkins, B., & Ronnqvist, L. (2002). Facilitating postural control: Effects on the reaching behavior of 6-month-old infants. *Developmental Psychobiology*, *40*, 168-182.
Hopkins, B., & Westra, T. (1990). Motor development, maternal expectations, and the role of handling. *Infant Behavior and Development*, *13*, 117-122.
Hospodar, C. M., Hoch, J. E., Lee, D. K., Shrout, P. E., & Adolph, K. E. (2021). Practice and proficiency: Factors that facilitate infant walking skill. *Developmental Psychobiology*, *63*, e22187.
Ivanenko, Y. P., Dominici, N., Cappellini, G., & Lacquaniti, F. (2005). Kinematics in newly walking toddlers does not depend upon postural stability. *Journal of Neurophysiology*, *94*, 754-763. https://doi.org/10.1152/jn.00088.2004
Iverson, J. M. (2022). Developing language in a developing body, revisited: The cascading effects of motor development on the acquisition of language. *Wiley interdisciplinary reviews. Cognitive science*, *13*(6), e1626.
Kahrs, B. A., Jung, W. P., & Lockman, J. J. (2013). Motor origins of tool use. *Child Development*, *84*, 810-816. https://doi.org/10.1111/cdev.12000

Karasik, L. B., Adolph, K. E., Fernandes, S. N., Robinson, S. R., & Tamis-LeMonda, C. S. (2023). Gahvora cradling in Tajikistan: Cultural practices and associations with motor development. *Child Development*.
Karasik, L. B., Kuchirko, Y. A., Dodojonova, R. M., & Elison, J. T. (2022). Comparison of U.S. and Tajik infants' time in containment devices. *Infant and Child Development*, *31*(4), e2340.
Karasik, L. B., Tamis-LeMonda, C. S., & Adolph, K. E. (2011). Transition from crawling to walking and infants' actions with objects and people. *Child Development*, *82*, 1199-1209. https://doi.org/10.1111/j.1467-8624.2011.01595.x
Karasik, L. B., Tamis-LeMonda, C. S., & Adolph, K. E. (2014). Crawling and walking infants elicit different verbal responses from mothers. *Developmental Science*, *17*, 388-395. https://doi.org/10.1111/desc.12129
Karasik, L. B., Tamis-LeMonda, C. S., & Adolph, K. E. (2016). Decisions at the brink: Locomotor experience affects infants' use of social information on an adjustable drop-off. *Frontiers in Psychology*, *7*, 797.
Karasik, L. B., Tamis-LeMonda, C. S., Adolph, K. E., & Bornstein, M. H. (2015). Places and postures: A cross-cultural comparison of sitting in 5-month-olds. *Journal of Cross-Cultural Psychology*, *46*, 1023-1038.
Keen, R., Lee, M. H., & Adolph, K. E. (2014). Planning an action: A developmental progression in tool use. *Ecological Psychology, Collection to honor Herbert L. Pick, J. J. Lockman & J. Rieser, guest editors*, *26*, 96-108.
Kotwica, K. A., Ferre, C. L., & Michel, G. F. (2008). Relation of stable hand-use preferences to the development of skill for managing multiple objects from 7 to 13 months of age. *Developmental Psychobiology*, *50*, 519-529.
Kretch, K. S., & Adolph, K. E. (2013). Cliff or step? Posture-specific learning at the edge of a drop-off. *Child Development*, *84*, 226-240.
Kretch, K. S., & Adolph, K. E. (2015). Active vision in passive locomotion: Real-world free viewing in infants and adults. *Developmental Science*, *18*, 736-750.
Kretch, K. S., & Adolph, K. E. (2017). The organization of exploratory behaviors in infant locomotor planning. *Developmental Science*, *20*, e12421.
Kretch, K. S., Franchak, J. M., & Adolph, K. E. (2014). Crawling and walking infants see the world differently. *Child Development*, *85*, 1503-1518. https://doi.org/https://doi.org/10.1111/cdev.12206
Kretch, K. S., Koziol, N. A., Marcinowski, E. C., Hsu, L.-Y., Harbourne, R. T., Lobo, M. A., McCoy, S. W., Willett, S. L., & Dusing, S. C. (in press). Sitting Capacity and Performance in Infants with Typical Development and Infants with Motor Delay. *Physical & Occupational Therapy in Pediatrics*.
Kretch, K. S., Marcinowski, E. C., Hsu, L.-Y., Koziol, N. A., Harbourne, R. T., Lobo, M. A., & Dusing, S. C. (2022). Opportunities for learning and social interaction in infant sitting: Effects of sitting support, sitting skill, and gross motor delay. *Developmental Science*, *26*(3), e13318.
Kretch, K. S., Willett, S. L., Hsu, L.-Y., Sargent, B. A., Harbourne, R. T., & Dusing, S. C. (2022). ``Learn the Signs. Act Early.'': Updates and Implications for Physical Therapists. *Pediatric Physical Therapy*, *34*(4), 440-448.
Kuhtz-Buschbeck, J. P., Stolze, H., Boczek-Funcke, A., Johnk, K., Heinrichs, H., & Illert, M. (1998). Kinematic analysis of prehension movements in children. *Behavioral Brain Research*, *93*, 131-141.
Lee, D. K., Cole, W. G., Golenia, L., & Adolph, K. E. (2018). The cost of simplifying complex developmental phenomena: A new perspective on learning to walk. *Developmental Science*, *21*, e12615.
Lee, H. M., Bhat, A., Scholz, J. P., & Galloway, J. C. (2008). Toy-oriented changes during early arm movements IV: Shoulder-elbow coordination. *Infant Behavior and Development*, *31*, 447-469. https://doi.org/10.1016/j.infbeh.2007.12.018
Lee, M. H., & Newell, K. M. (2012). Visual feedback of hand trajectory and the development of infant prehension. *Infant Behavior and Development*, *35*, 273-279.
Lee, M. H., Ranganathan, R., & Newell, K. M. (2011). Changes in object-oriented arm movements that precede the transition to goal-directed reaching in infancy. *Developmental Psychobiology*, *53*(7), 685-693. https://doi.org/10.1002/dev.20541
Leed, J. E., Chinn, L. K., & Lockman, J. J. (2019). Reaching to the self: The development of infants' ability to localize targets on the body. *PsychologicaL Science*.

Libertus, K., Gibson, J., Hidayatallah, N. Z., Hirtle, J., Adcock, R. A., & Needham, A. W. (2013). Size matters: How age and reaching experience shape infants' preferences for different sized objects. *Infant Behavior and Development*, *36*, 189-198.
Libertus, K., & Violi, D. A. (2016). Sit to talk: Relation between motor skills and language development in infancy. *Frontiers in Psychology*, *7*, 475.
Lockman, J. J., & Kahrs, B. A. (2014). Tool using. *Child Development Perspectives*, *8*, 231-236.
Lockman, J. J., & Tamis-LeMonda, C. (2021). Young children s interactions with objects play as practice and practice as play. *Annual Review of Developmental Psychology*, *3*, 165-186.
Long, B. L., Sanchez, A., Kraus, A. M., Agrawal, K., & Frank, M. C. (2022). Automated detections reveal the social information in the changing infant view. *Child Development*, *93*, 101-116.
Loos, H. M., Doucet, S., Roussignan, R., Hartmann, C., Durand, K., Dittrich, R., Sagot, P., Buettner, A., & Schaal, B. (2014). Responsiveness of human neonates to the odor of 5a-Androst-16-en-3-one: A behavioral paradox? *Chemical Senses*, *39*, 693-703.
Loucks, J., & Sommerville, J. A. (2012). The role of motor experience in understanding action function: The case of the precision grasp. *Child Development*, *83*, 801-809.
Luo, C., & Franchak, J. M. (2020). Head and body structure infants' visual experiences during mobile, naturalistic play. *PLoS ONE*, *15*, e0242009.
Luo, C., & Franchak, J. M. (2022). Eye-head-body coordination in the motor-memory trade-off. *Collabra: Psychology*, *8*(1), 38821.
Majnemer, A., & Barr, R. G. (2005). Influence of supine sleep positioning on early motor milestone acquisition. *Developmental Medicine and Child Neurology*, *47*, 370-376.
Malachowski, L. G., Salo, V. C., Needham, A. W., & Humphreys, K. L. (2023). Infant placement and language exposure in daily life. *Infant and Child Development*.
Marcinowski, E. C., Tripathi, T., Hsu, L.-Y., McCoy, S. W., & Dusing, S. C. (2019). Sitting skill and the emergence of arms-free sitting affects the frequency of object looking and exploration. *Developmental Psychobiology*, *61*(7), 1035-1047.
Martorell, R., Onis, M., Martines, J., Black, M., Onyango, A., & Dewey, K. G. (2006). WHO motor development study: Windows of achievement for six gross motor development milestones. *Acta Paediatrica*, *95 (S450)*, 86-95.
McCarty, M. E., Clifton, R. K., & Collard, R. R. (1999). Problem solving in infancy: The emergence of an action plan. *Developmental Psychology*, *35*, 1091-1101.
McCarty, M. E., Clifton, R. K., & Collard, R. R. (2001). The beginnings of tool use by infants and toddlers. *Infancy*, *2*, 233-256.
McCollum, G., Holroyd, C., & Castelfranco, A. M. (1995). Forms of early walking. *Journal of Theoretical Biology*, *176*, 373-390. https://doi.org/10.1006/jtbi.1995.0206
McGraw, M. B. (1945). *The neuromuscular maturation of the human infant*. Columbia University Press.
Messinger, D. S. (2002). Positive and negative: Infant facial expressions and emotions. *Current Directions in Psychological Science*, *11*, 1-6.
Messinger, D. S. (2006). Smiling. In N. J. Salkind (Ed.), *Encyclopedia of human development* (Vol. 3, pp. 1183-1185). Sage.
Messinger, D. S. (2008). Smiling. In M. M. Haith & J. B. Benson (Eds.), *Encyclopedia of infant and early childhood development* (Vol. 3, pp. 186-198). Elsevier.
Miller, J. L., Sonies, B. C., & Macedonia, C. (2003). Emergence of oropharyngeal, laryngeal and swallowing activity in the developing fetal upper aerodigestive tract: An ultrasound evaluation. *Early Human Development*, *71*, 61-87.
Mlincek, M. M., Roemer, E. J., Kraemer, C., & Iverson, J. M. (2020). Posture matters object manipulation during the transition to arms free sitting in infants at elevated vs typical likelihood for autism spectrum disorder. *Physical & Occupational Therapy in Pediatrics*, *42*(4), 351-365.
Mulder, H., Oudgenoeg-Paz, O., Verhagen, J., van der Ham, I. J. M., & Van der Stigchel, S. (2022). Infant walking experience is related to the development of selective attention. *Journal of Experimental Child Psychology*, *220*, 105425.
Nakagawa, A., & Sukigara, M. (2013). Variable coordination of eye and head movements during the early development of attention: A longitudinal study of infants aged 12–36 months. *Infant Behavior and Development*, *36*(4), 517-525.
Needham, A. W. (2000). Improvements in object exploration skills may facilitate the development of object segregation in early infancy. *Journal of Cognition and Development*, *1*, 131-156.
Norris, B., & Smith, S. (2002). *Research into the mouthing behaviour of children up to 5 years old*.

Ossmy, O., & Adolph, K. E. (2020). Real-time assembly of coordination patterns in human infants. *Current Biology*, *30*, 4553-4562.
Ossmy, O., Kaplan, B. E., Han, D., Xu, M., Bianco, C., Mukamel, R., & Adolph, K. E. (2022). Real-time processes in the development of action planning. *Current Biology*, *32*, 190-199.
Oster, H. (2003). Emotion in the infant's face: Insights from the study of infants with facial anomalies. *Annals of the New York Academy of Sciences*, *1000*, 197-204.
Oudgenoeg-Paz, O., Leseman, P. P. M., & Volman, M. J. M. (2015). Exploration as a mediator of the relation between the attainment of motor milestones and the development of spatial cognition and spatial language. *Developmental Psychology*, *51*(9), 1241 - 1253. https://doi.org/10.1037/a0039572
Oudgenoeg-Paz, O., Volman, M. C. J. M., & Leseman, P. (2012). Attainment of sitting and walking predicts development of productive vocabulary between ages 16 and 28 months. *Infant Behavior and Development*, *35*, 733-736.
Palmer, C. F. (1989). The discriminating nature of infants' exploratory actions. *Developmental Psychology*, *25*, 885-893.
Patrick, S. K., Noah, J. A., & Yang, J. F. (2009). Interlimb coordination in human crawling reveals similarities in development and neural control with quadrupeds. *Journal of Neurophysiology*, *101*(2), 603-613. https://doi.org/10.1152/jn.91125.2008
Patrick, S. K., Noah, J. A., & Yang, J. F. (2012). Developmental constraints of quadrupedal coordination across crawling styles in human infants. *Journal of Neurophysiology*, *107*, 3050-3061.
Piaget, J. (1954). *The construction of reality in the child*. Basic Books.
Prechtl, H. F. R. (1985). Ultrasound studies of human fetal behaviour. *Early Human Development*, *12*, 91-98.
Prechtl, H. F. R. (1986). Prenatal motor development. In M. G. Wade & H. T. A. Whiting (Eds.), *Motor development in children: Aspects of coordination and control* (pp. 53-64). Martinus Nijhoff Publishing.
Rachwani, J., Santamaria, V., Saavedra, S. L., Wood, S., Porter, F., & Woollacott, M. H. (2013). Segmental trunk control acquisition and reaching in typically developing infants. *Experimental Brain Research*, *228*, 131-139. https://doi.org/10.1007/s00221-013-3544-y
Rachwani, J., Soska, K. C., & Adolph, K. E. (2017). Behavioral flexibility in learning to sit. *Developmental Psychobiology*, *59*, 937-948.
Rat-Fischer, L., O'Regan, J. K., & Fagard, J. (2012). The emergence of tool use during the second year of life. *Journal of Experimental Child Psychology*, *113*, 440-446.
Reed, E. S. (1982). An outline of a theory of action systems. *Journal of Motor Behavior*, *14*, 98-134.
Reissland, N., Francis, B., Aydin, E., Mason, J., & Schaal, B. (2014). The development of anticipation in the fetus: A longitudinal account of human fetal mouth movements in reaction to and anticipation of touch. *Developmental Psychobiology*, *56*, 955-963.
Reissland, N., Francis, B., & Mason, J. (2013). Can healthy fetuses show facial expressions of "pain" or "distress"? *PLoS ONE*, *8*, e65530.
Reissland, N., Francis, B., Mason, J., & Lincoln, K. (2011). Do facial expressions develop before birth? *PLoS ONE*, *6*, e24081.
Rochat, P. (1989). Object manipulation and exploration in 2- to 5-month-old infants. *Developmental Psychology*, *25*, 871-884.
Rosander, K. (2020). Development of gaze control in early infancy. *Oxford Research Encyclopedia of Psychology*. https://doi.org/10.1093/acrefore/9780190236557.013.825.
Ross-Sheehy, S., Perone, S., Vecera, S. P., & Oakes, L. M. (2016). The relationship between sitting and the use of symmetry as a cue to figure ground assignment in 6 5 month old infants. *Frontiers in Psychology*, *7*, 759.
Rovee-Collier, C. K., Morrongiello, B. A., Aron, M., & Kupersmidt, J. (1978). Topographical response differentiation and reversal in 3-month-old infants. *Infant Behavior and Development*, *1*, 323-333.
Ruffman, T., Chen, L., Lorimer, B., Vanier, S., Edgar, K., Scarf, D., & Taumoepeau, M. (2022). Exposure to behavioral regularities in everyday life predicts infants' acquisition of mental state vocabulary. *Developmental Science*, *26*(4), e13343.
Saavedra, S. L., van Donkelaar, P., & Woollacott, M. H. (2012). Learning about gravity: Segmental assessment of upright control as infants develop independent sitting. *Journal of Neurophysiology*, *108*, 2215-2229.

Schmitow, C., Stenberg, G., Billard, A., & von Hofsten, C. (2013). Using a head-mounted camera to infer attention direction. *International Journal of Behavioral Development*, *37*(5), 468-474.
Schneiberg, S., Sveistrup, H., McFadyen, B., McKinley, P., & Levin, M. F. (2002). The development of coordination of reach-to-grasp movements in children. *Experimental Brain Research*, *146*, 142-154.
Schneider, J. L., & Iverson, J. M. (2022). Cascades in action: How the transition to walking shapes caregiver communication during everyday interactions. *Developmental Psychology*, *58*, 1-16.
Schneider, J. L., Roemer, E. J., Northrup, J. B., & Iverson, J. M. (2022). Dynamics of the dyad: How mothers and infants co-construct interaction spaces during object play. *Developmental Science*, e13281.
Schroer, S. E., & Yu, C. (2022). Looking is not enough: Multimodal attention supports the real-time learning of new words. *Developmental Science*, e13290.
Sheppard, J. J., & Mysak, E. D. (1984). Ontogeny of infantile oral reflexes and emerging chewing. *Child Development*, *55*, 831-843.
Slone, L. K., Smith, L. B., & Yu, C. (2019). Self-generated variability in object images predicts vocabulary growth. *Developmental Science*, *22*, e12816.
Smitsman, A. W., & Bongers, R. M. (2003). Tool use and tool making: A developmental action perspective. In J. Valsiner & K. J. Connolly (Eds.), *Handbook of developmental psychology* (pp. 172-193). Sage.
Snapp-Childs, W., & Corbetta, D. (2009). Evidence of early strategies in learning to walk. *Infancy*, *14*, 101-116.
Soska, K. C., & Adolph, K. E. (2014). Postural position constrains multimodal object exploration in infants. *Infancy*, *19*, 138-161. https://doi.org/10.1111/infa.12039
Soska, K. C., Adolph, K. E., & Johnson, S. P. (2010). Systems in development: Motor skill acquisition facilitates three-dimensional object completion. *Developmental Psychology*, *46*, 129-138. https://doi.org/10.1037/a0014618
Sparling, J. W., van Tol, J., & Chescheir, N. C. (1999). Fetal and neonatal hand movement. *Physical Therapy*, *79*, 24-39.
Steenbergen, B., van der Kamp, J., Smitsman, A., & Carson, R. G. (1997). Spoon-handling in two- to four-year-old children. *Ecological Psychology*, *9*, 113-129.
Suanda, S. H., Barnhart, M., Smith, L. B., & Yu, C. (2019). The signal in the noise: The visual ecology of parents' object naming. *Infancy*, *24*(3), 455-476.
Suarez-Rivera, C., Linn, E., & Tamis-LeMonda, C. S. (2022). From play to language: Infants' actions on objects cascade to word learning. *Language Learning*, *72*, 1092-1127.
Sutherland, D. H., Olshen, R. A., Biden, E. N., & Wyatt, M. P. (1988). *The development of mature walking*. Mac Keith Press.
Thelen, E. (1986). Treadmill-elicited stepping in seven-month-old infants. *Child Development*, *57*, 1498-1506.
Thelen, E. (1994). Three-month-old infants can learn task-specific patterns of interlimb coordination. *PsychologicaL Science*, *5*, 280-285.
Thelen, E., Corbetta, D., Kamm, K., Spencer, J. P., Schneider, K., & Zernicke, R. F. (1993). The transition to reaching: Mapping intention and intrinsic dynamics. *Child Development*, *64*, 1058-1098.
Thelen, E., Fisher, D. M., & Ridley-Johnson, R. (1984). The relationship between physical growth and a newborn reflex. *Infant Behavior and Development*, *7*, 479-493.
Thelen, E., & Ulrich, B. D. (1991). Hidden skills: A dynamic systems analysis of treadmill stepping during the first year. *Monographs of the Society for Research in Child Development*, *56*(1, Serial No. 223), 1-103.
Thurman, S., L, & Corbetta, D. (2020). Using network analysis to capture developmental change: An illustration from infants' postural transitions. *Infancy*, *25*, 927-951.
Trettien, A. W. (1900). Creeping and walking. *American Journal of Psychology*, *12*, 1-57.
van der Meer, A. L. H., Holden, G., & van der Weel, F. R. (2005). Coordination of sucking, swallowing, and breathing in healthy newborns. *Journal of Pediatric Neonatology*, *2*, 69-72.
van der Meer, A. L. H., Ramstad, M., & van der Weel, F. R. (2008). Choosing the shortest way to mum: Auditory guided rotation in 6- to 9-moth-old infants. *Infant Behavior and Development*, *31*, 207-216.

Vollmer, B., & Forssberg, H. (2009). Development of grasping and object manipulation. In D. A. Nowak & J. Hermsdorfer (Eds.), *Sensorimotor control of grasping: Physiology and Pathophysiology* (pp. 235-249). Cambridge University Press.

von Hofsten, C., & Johansson, K. (2009). Planning to reach for a rotating rod: Developmental aspects *Zeitschrift für Entwicklungspsychologie und Pädagogische Psychologie*, *41*, 207-213.

Walle, E. A., & Campos, J. J. (2014). Infant language development is related to the acquisition of walking. *Developmental Psychology*, *50*, 336-348.

West, K. L., & Iverson, J. M. (2021). Communication changes when infants begin to walk. *Developmental Science*, *24*(5), e13102.

West, K. L., Saleh, A. N., Adolph, K. E., & Tamis-LeMonda, C. S. (2023). ``Go, go, go!'' Mothers' verbs align with infants' locomotion. *Developmental Science*, e13397.

Wilson, E. M., & Green, J. R. (2009). The development of jaw motion for mastication. *Early Human Development*, *85*, 303-311.

Wilson, E. M., Green, J. R., Yunusova, Y. Y., & Moore, C. A. (2008). Task specificity in early oral motor development. *Seminars in Speech and Language*, *29*, 257-266.

Wu, J., Looper, J., Ulrich, B. D., Ulrich, D. A., & Angulo-Barroso, R. M. (2007). Exploring effects of different treadmill interventions on walking onset and gait patterns in infants with Down syndrome. *Developmental Medicine and Child Neurology*, *49*(11), 839-945.

Yamamoto, H., Sato, A., & Itakura, S. (2020). Transition from crawling to walking changes gaze communication space in everyday infant parent interaction. *Frontiers in Psychology*, *10*, 2987.

Yang, J. F., Lam, T., Pang, M. Y. C., Lamont, E., Musselman, K., & Seinen, E. (2004). Infant stepping: A window to the behavior of the human pattern generator for walking. *Canadian Journal of Physiology and Pharmacology*, *82*, 662-674.

Yonas, A., & Hartman, B. (1993). Perceiving the affordance of contact in four- and five-month-old infants. *Child Development*, *64*, 298-308.

Yu, C., & Smith, L. B. (2013). Joint attention without gaze following: Human infants and their parents coordinate visual attention to objects through eye-hand coordination. *PLoS ONE*, *8*, e79659. https://doi.org/10.1371/journal.pone.0079659

Yurkovic-Harding, J., Lisandrelli, G., Shaffer, R. C., Dominick, K. C., Pedapati, E. V., Erickson, C. A., Yu, C., & Kennedy, D. P. (2022). Children with ASD establish joint attention during free-flowing toy play without face looks. *Current Biology*.

Zelazo, P. R., Zelazo, N. A., & Kolb, S. (1972). "Walking" in the newborn. *Science*, *176*, 314-315.

Zoia, S., Blason, L., D'Ottavio, G., Bulgheroni, M., Pezzetta, E., Scabar, A., & Castiello, U. (2007). Evidence of early development of action planning in the human foetus: A kinematic study. *Experimental Brain Research*, *176*, 217-226.

Zubler, J. M., Wiggins, L. D., Macias, M. M., Whitaker, T. M., Shaw, J. S., Squires, J. K., Pajek, J. A., Wolf, R. A., Slaughter, K. S., Broughton, A. S., Gerndt, K. L., Mlodoch, B. J., & Lipkin, P. H. (2022). Evidence-informed milestones for developmental surveillance tools. *Pediatrics*, *149*(3), e2021052138.