

The ecology of infants' perceptual-motor exploration

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Abstract

The first goal of this article is to review recent advances in understanding how new motor skills facilitate infants' exploration—the active acquisition of information about their environments. New postural abilities, such as sitting and walking, qualitatively change how infants can learn about objects, places, and people with with potential downstream effects on infants' later cognitive and linguistic development. What's missing, however, is a characterization of how new exploratory abilities change infants' everyday experiences. Presumably, changes in opportunities for learning mediate the downstream effects of posture on other developmental achievements. Accordingly, the second goal of this article is to discuss the importance of measuring the ecology of infants' everyday experiences and how they vary.

Keywords: Ecological psychology, exploration, perceptual-motor development, posture

1. Introduction

Ecological and systems theories emphasize the interdependence between individual and environment [1–5]. For example, James Gibson's concept of affordances considers how an individual's motor capabilities with respect to physical characteristics of the environment co-determine whether actions are possible [2]. The Gibsonian concept of *exploration*—how observers' motor actions support

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actively acquiring information about the environment—also reflects individual-environment interdependence [6, 7]. Eleanor Gibson extended this idea to infant development, wherein the acquisition of new motor abilities fundamentally changes how infants can explore—and thus learn about—their environments [3]. Gibson’s claim has been borne out: The acquisition of motor skills, such as sitting, crawling, and walking, predicts developmental changes in perception, cognition, and language [e.g., 8–10].

The first goal of this article is to review recent work documenting how motor development—more specifically, the acquisition of new postures—augments exploration and effects broader changes on cognitive and language development. However, I will argue that despite a solid foundational understanding in how exploratory *abilities* change, we know relatively little about how exploratory *experiences* change. The degree to which exploratory abilities influence later development—so-called downstream effects—are presumably mediated by the everyday exercise of exploration. Just as affordances are co-determined by the individual-environment relation, I contend that infants’ everyday opportunities for learning are co-determined by their exploratory abilities relative to what their environments offer. Environments vary between infants (e.g., cultural and material factors) and over time (e.g., changes in caregiving). Thus, the second goal of this article is to discuss the importance of characterizing everyday exploration, identify the challenges of studying those experiences, and review encouraging steps taken to address this gap.

2. Postural development alters exploration

Without the ability to control posture, young infants can only lie supine on their backs or prone on their stomachs unless they are held by caregivers, and they must rely on caregivers to switch between different positions. Over the first two years, infants master static postures (sitting and standing) and dynamic postures (crawling and walking) that dramatically expand exploratory abilities [11].

Infants learn about objects through coordinated visual, manual, and oral exploration. Although the ability to grasp and acquire objects spurs object exploration [12], further developments depend on infants' ability to sit. Coordinating the hands to rotate, transfer, and manipulate objects—especially while simultaneously looking at objects—is facilitated by sitting compared to prone and supine postures [9, 13]. Using the hands to support the body when prone hinders coordinated visual-manual exploration. Sitting frees both hands to manipulate objects, and the stability of sitting allows infants to better control their heads to look at objects [9, 14].

Posture not only influences exploration of near objects, but also constrains visual exploration of distant targets. Recent advances in mobile eye tracking technology have allowed researchers to measure where infants look in naturalistic settings [15-17]. Whereas more commonly-used methods, such as measuring looking towards stimuli on a screen, preclude studying visual attention as an embodied process, mobile eye tracking captures how every turn of the head and body alter what infants see (Figure 1). Results reveal that when sitting and upright, 13-month-olds see farther in the distance compared to when prone [18]. Prone infants' view is dominated by the floor, as they must struggle to lift up their heads to glimpse distant locations. This impacts how often infants look at important visual targets. For example, posture influences social looking (Figure 2): 12-month-olds rarely look at caregivers' faces when prone compared with sitting and upright postures [19]. However, face looking is still quite rare (~5% of the time) when sitting and upright, in part because caregivers' faces are too high up to be seen by infants playing on the floor. Instead, infants look at caregivers' bodies (~15% of the time)—their hands, legs, and torsos—which are easier to view from infants' low vantage point. A higher vantage point (such as when carried) allows infants to more frequently look at faces (~18% of the time) [20].

Acquiring locomotor abilities—crawling and walking—provides new ways to explore. Before crawling, infants must rely on caregivers to move them from place to place: A sitting infant may glimpse a distant toy, but a crawling infant

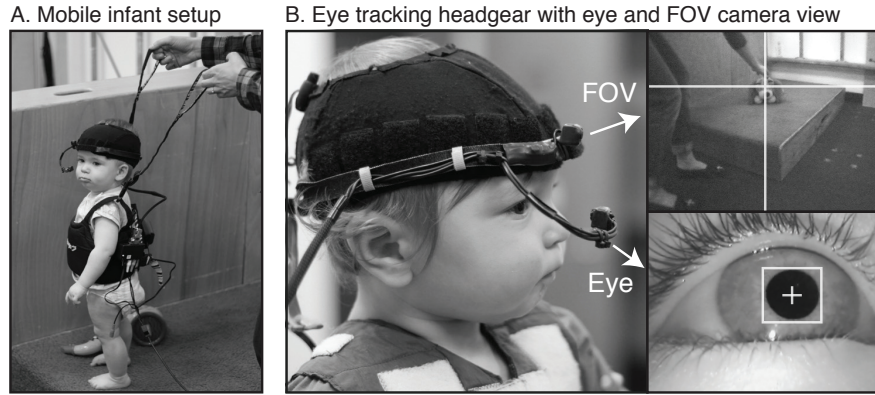


Figure 1: Mobile eye-tracking method. A) Infant wearing mobile eye tracker in a laboratory playroom. B) Close-up of infant eye-tracking headgear, which houses two cameras to capture the infant's eye and the approximate field of view (FOV). Calibration of eye and field of view videos allows tracking of gaze position within the field of view, indicated by a crosshair.

can go retrieve it. With greater crawling experience, infants gain autonomy and travel farther from their caregivers. The acquisition of walking provides even more advantages over crawling: Walking entails greater speed of movement [21, 22], allows infants to travel greater distances [21, 23], facilitates carrying objects [24, 25], and provides a better viewpoint of distant locations [18]. Both crawling and walking alter social interactions with caregivers [8, 23, 26]. For example, walking compared with crawling allows infants to bring distant objects

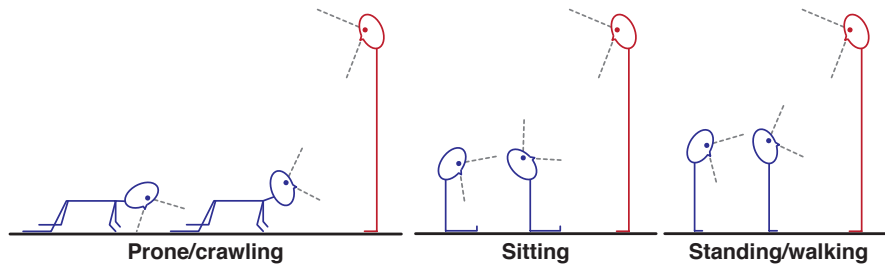


Figure 2: Infant viewpoint of a standing caregiver from prone, sitting, and upright postures. Infant head angles are drawn to approximate the ranges reported in [18].

to share with caregivers [24].

3. Changes in exploratory abilities have downstream effects

The varied ways by which posture alters exploration suggests multiple pathways through which posture may influence other areas of development. For brevity, I will review how postural attainment facilitates later spatial and linguistic abilities. However, it is important to consider that acquiring new motor skills may not always be facilitative, especially in the short term. Crawling interferes with new crawlers' vocalizations [27] and carrying objects disrupts new walkers' balance [28].

The attainment of sitting, crawling, and walking have downstream effects on object perception [9] and spatial cognition [8, 29]. Infants' ability to sit independently facilitates visual-manual exploration of objects [13, 14], which, in turn, facilitates object perception [9]. Downstream effects can be far-reaching: Earlier sitting onsets predict better spatial memory at 24 months [29]. Although object exploration at 20 months failed to mediate this effect, exploratory differences earlier in infancy might account for it. Independent crawling and walking predict earlier achievement in spatial cognition tasks [8, 29]. Infants who walked earlier engaged in more exploratory locomotion at 20 months, which predicted better performance on a standardized block-copying task at 32 months [29]. Other exploratory benefits of walking over crawling, such as a better viewpoint for distant locations [18] and the ability to carry objects [24, 25], have yet to be tested as potential mediators in downstream effects on spatial abilities.

Earlier attainment of both sitting [29, 30] and walking [29, 31, 32] predict receptive and productive vocabulary between 1 and 4 years. Unlike spatial-cognitive abilities, downstream effects of sitting on language were not mediated by object exploration [29, 30]. Other, untested aspects of object exploration may be more relevant. Recent work indicates that infants' self-generated visual experiences (greater variability of object views when holding and moving objects) predict vocabulary growth [33], but whether sitting ability facilitates

variability in object experiences is unknown. Furthermore, sitting facilitates shared visual attention to objects between infants and caregivers [19] and might enhance opportunities for language learning. Similarly, joint attention partially mediates the effect between walking onset and vocabulary development [31]. Most likely, sitting and walking have cascading effects on later language development through multiple pathways, such as changes in caregivers' behaviors in response to infants' motor development. Caregivers provide more complex language input to 13-month-old walkers compared with crawlers [34]. Moreover, caregivers' perception of infants as individuals increases after infants begin to walk, which predicts later vocabulary development [31].

4. What's missing: The ecology of everyday exploratory experiences

A key assumption in linking exploratory abilities to downstream effects is that they are mediated by changes in everyday experiences. But direct measurements of daily experiences are rare [35], and inferences based on laboratory observations might not generalize well to daily life. Brief laboratory play tasks cannot capture infants' full daily routines, which contain both play and non-play activities (e.g., feeding, bathing, errands) that may provide different opportunities for exploration. For example, in a mobile play task infants may be unrestrained [19, 23], but in everyday feeding and travel activities infants are restrained in high chairs, strollers, and car seats. Infants' and caregivers' behaviors may also be biased by researchers' observation. For example, caregivers spoke up to four times more during audio-video recordings compared with audio-only recordings [36].

Recent advances in wearable devices—lightweight “headcams” that record infant-perspective visual experiences and audio recorders that can capture day-long recordings of infant and adult speech—provide researchers with new ways to capture home experiences at scale [36–38]. Headcam recordings over the first two years of life show that the frequency of faces in infants' views decreases with age while that the presence of hands increases in frequency [37]. The differential

quality and frequency of visual experiences of objects in the home may shed light on why and how infants learn specific words [39, 40].

Given the hypothesized downstream effects of sitting, crawling, and walking, it will be important in future work to characterize everyday motor experiences throughout the day. But whereas infants' language and visual experiences can be profitably measured with audio recorders and headcams, the gold standard for measuring infants' naturalistic motor activity is third-person video in the home [41] or laboratory [19, 23], which suffers from the limitations mentioned above. One alternative is to use ecological momentary assessment (EMA). Changes in infants' posture over the first year of life [42] were captured through caregiver reports in response to 35 text message notifications over a week. These full-day recordings differed from brief laboratory observations: 12-month-olds were upright 50-70% of the time in laboratory play [19, 23] compared with 30% of the time in the home. A future alternative may be to use lightweight inertial sensors [38]: Posture has been accurately classified in small samples of infants in controlled tasks [43], but soon these methods may be suitable for home recordings.

Several open questions remain. First, how does the frequency of exploratory experiences change after acquiring a new exploratory ability? For example, both EMA [42] and video [41] recordings indicate that 5- to 6-month-old independent sitters sit (with or without support from caregivers or furniture) twice as often as same-aged non-sitters. More sitting time could increase opportunities for object exploration or shared attention with caregivers, but these opportunities—and whether they mediate downstream effects on cognition and language—have yet to be tested. Similarly, postural effects on visual exploration in the lab have yet to be extended to measurement of everyday visual experiences—simultaneous headcam and EMA/inertial measurement could address this question and potentially contribute to our understanding of word learning [e.g., 33].

Second, what does the environment offer for exploration—how do environments vary and how do they change? Future work should characterize the everyday motor opportunities afforded by infants' environments, how they vary, and what factors (e.g., caregiving, material, and/or cultural) account for vari-

ations. For example, use of infant equipment to restrain infants is common in the US, and individual differences in use depend on factors such as family size [44]. But cross-cultural studies show that infants' experiences with motor restraint can exceed what is typical for US infants. In Tajikistan, 12-month-olds spend between as many as 18.5 hours each day restrained on their backs [45, 46]. Future research should determine whether individual differences in restraint (depending on caregiving and cultural factors) constrain infants' opportunities to explore, with potential downstream effects on cognition and language.

A second source of variation is the home environment. Infants' access to material resources relevant for perceptual-motor exploration vary widely by socioeconomic and cultural factors [47]. The Affordances in the Home Environment for Motor Development scale (AHEMD) characterizes variability in the physical environment related to motor development and predict standard measures of motor skill acquisition [48]. In particular, the number of objects for promoting fine and gross motor skills and the total amount of space in the home are linked with motor development [49, 50]. More work, however, is needed to determine whether perceptual-motor *exploration* is also facilitated by these variations in the physical environment.

5. Conclusion

There is little doubt from the prevailing literature that changing motor abilities alter opportunities for learning. But the extent to which infants actualize those opportunities in daily life is largely unknown, particularly with regard to postural activities and their potential consequences on visual, manual, and social experiences. New recording methods show promise for describing the ecology of infants' everyday experiences and how they are shaped by environmental variation.

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