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Effects of support surface and optic flow on step-like movements in pre-crawling and crawling infants

David I. Anderson[a,*], Yuka Kobayashi[a], Kate Hamel[a], Monica Rivera[b], Joseph J. Campos[c], Marianne Barbu-Roth[d]

[a] Department of Kinesiology, San Francisco State University, San Francisco, CA, United States
[b] Department of Physical Therapy, California State University, Fresno, CA, United States
[c] Institute of Human Development, University of California, Berkeley, CA, United States
[d] Laboratoire Psychologie de la Perception—UMR 8242 CNRS—Université Paris Descartes, Paris, France

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ABSTRACT

Step-like movements were examined in pre-crawling ($n = 9$) and crawling ($n = 9$) 6–13 month-old infants in the air and on a surface in response to a static pattern or optic flows that moved toward or away from the infant. Infants completed six 60-s trials. A significant interaction between locomotor status and support condition revealed that pre-crawling infants made more step-like movements in the air than on a rigid surface. In contrast, crawling infants made an equivalent number of step-like movements in the air and on the surface. Optic flow did not influence the number of step-like movements made by infants. The pre-crawling infant finding is consistent with a finding in a previous study in which two month-old infants were shown to step more in the air than on the ground. This finding is discussed relative to the idea that the infant stepping pattern disappears because the legs become too heavy to lift.

1. Introduction

The disappearance of the newborn stepping pattern at approximately two months of age has attracted considerable scientific interest. Though originally attributed to the suppression of sub-cortically controlled reflex patterns by the maturing cortex (Fiorentino, 1981; Forssberg, 1985; McGraw, 1940; McGraw, 1945; Peiper, 1963), the favored explanation over the last 30 years for the disappearance of the stepping pattern has been Thelen's *heavy legs hypothesis* (e.g., Thelen, Fisher, & Ridley-Johnson, 1984). The hypothesis argues that stepping disappears because rapid weight gain on the legs during the early weeks of life, particularly in fat mass relative to muscle mass, makes the legs difficult to lift in the upright position. The hypothesis was initially formulated following the observation that infants continued to kick in the supine position when they had stopped stepping in upright position, even though kicking and stepping looked like identical behaviors in terms of joint kinematics and underlying muscle activation patterns (Thelen & Fisher, 1982). The hypothesis gained widespread acceptance following three experiments by Thelen et al. (1984). The first showed that increases in body weight and ponderal index between two and four weeks of age were significant predictors of a decline in stepping at four weeks of age. The

* Corresponding author. Tel.: +1 415 338 1559; fax: +1 415 338 7566.
E-mail address: danders@sfsu.edu (D.I. Anderson).

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second showed that adding mass to the legs of four week-old infants significantly depressed stepping and the third showed that making the legs easier to lift by submerging them in a tank of water resulted in significant increases in stepping.

Despite the convincing nature of the evidence provided by Thelen and colleagues to support the heavy legs hypothesis, recent findings reported by Barbu-Roth et al. (2015) suggest the hypothesis may need modification. Barbu-Roth et al. found that two month-old infants stepped significantly more when held upright in the air than when supported upright on a rigid surface. They argued that inability to lift the legs couldn't be the only explanation for the greater amounts of stepping observed in the air than on the surface because if the legs were too heavy to lift on the surface they must have been too heavy to lift in the air. While acknowledging that heavy legs may have helped to depress stepping on the surface, Barbu-Roth et al. (2015) argued that the primary reason stepping was inhibited on the surface was not because the infants could not lift the legs, though heavy legs certainly could have factored into the explanation, but because the infants had a tendency to collapse their legs (flex the hips and knees) when lowered in the upright position onto the surface. In other words, the infants were either unable or unwilling to support their body weight on the surface and stepping was not seen because the infants didn't adopt a posture from which stepping could be initiated.

The explanation put forward by Barbu-Roth and colleagues is consistent with the idea that the limbs become progressively more relaxed over the first months of life as the strength of the upright righting response decreases (e.g., Amiel-Tison, Gosselin, & Kurjak, 2006; Dargassies, 1987) and it suggests that changes in body weight and ponderal index may predict the decline in stepping not because of asynchronous development of fat and muscle in the legs, but because an increase in body weight will make it more difficult to support the body weight on one leg and potentially accentuate the tendency to collapse the legs when the infant is lowered toward a surface. Thus, body weight and ponderal index may still predict whether or not infants will step, but these variables may influence whether the infant can support its weight rather than whether it can lift its legs. Alternately, these variables may influence whether the infant can support its weight *and* whether it can lift its legs.

Barbu-Roth et al. (2015) also examined whether air stepping in their two month-olds was influenced by approaching and receding optic flows, following earlier studies that showed newborns engaged in more air stepping in response to terrestrial optic flows than to a static pattern (Barbu-Roth et al., 2009, 2013). Their findings on two month-olds were difficult to interpret. No differences in the amount of stepping were seen in the approaching and receding optic flow conditions relative to the static condition, suggesting a lack of responsiveness to optic flow; however, significantly more air stepping was seen in the receding optic flow condition than in the approaching optic flow condition. Curiously, the amount of air stepping in the approaching optic flow condition was the lowest in the three air stepping conditions, just the opposite of what was observed in newborns (Barbu-Roth et al., 2009, 2013), and seemingly inconsistent with recent reports of enhanced tactile stepping frequency and quality in infants as young as two months of age (with and without disabilities) when optic flow is added to the treadmill on which they are stepping (Pantall, Teulier, Smith, Moerchen, & Ulrich, 2011; Pantall, Teulier, & Ulrich, 2012; Teulier, Barbu-Roth, & Anderson, 2014). Barbu-Roth et al. (2015) did not have a tenable explanation for the effects of optic flow they observed in their two month-olds.

The current exploratory study sought to extend the methodology used by Barbu-Roth et al. (2015) to older infants with and without hands-and-knees crawling experience using a balanced design in which two levels of postural support (Air and Surface) were crossed with three levels of optic flow (Static, Approaching, and Receding). We were interested in whether older infants would continue to make more step-like movements in the air than on a surface and whether the infant's locomotor status would influence their behavior in the two contexts. We were also interested in whether the infant's responsiveness to approaching and receding optic flows, relative to a static pattern, would be more clear-cut than those of two month-olds, particularly in infants with crawling experience. We predicted that infants without crawling experience would make more step-like movements in the air than on the surface and that they would respond more to the receding optic flow than the approaching optic flow (consistent with the Barbu-Roth et al., 2015 findings). We predicted that the infants with crawling experience would make equivalent numbers of step-like movements in the air and on the surface because they were more likely to have the capacity to lift one leg while supporting the body weight on the other leg when they were positioned upright on the surface. Crawling experience likely would have contributed to improved strength in the lower limbs and torso (Adolph, Vereijken, & Denny, 1998) and reinforced the pattern of alternation between the legs. In addition, we speculated that crawling infants would step more in response to the approaching optic flow than to the receding optic flow and static condition because they would have had more experience coupling approaching optic flow with forward locomotion during crawling. We were not sure whether the responsiveness to optic flow would be more apparent in the air or on the surface in the crawling infants.

2. Methods

2.1. Participants

A total of 33 infants were originally tested. However the data were not analyzed if the infant was too fussy to complete all six experimental trials (6 infants) or cried for more than 30 s during a single trial (5 infants) or did not look at the optic flow pattern for more than 30 s during a single trial (4 infants). Consequently, the final sample consisted of eighteen 6- to 13-month-old infants (13 females and 5 males, 9 were Caucasian, 2 were Asian, 1 was Hispanic, and 6 were of mixed heritage). Infants were classified into prelocomotor ($n = 9$; Mean Age = 8.5 months, SD = 1.09 months) and locomotor ($n = 9$; Mean Age = 11 months, SD = 1.9 months) groups. All of the infants classified as locomotor were reported to be crawlers by