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Coping with asymmetry: How infants and adults walk with one elongated leg

Whitney G. Cole[a], Simone V. Gill[a], Beatrix Vereijken[b], Karen E. Adolph[a,*]

[a] New York University, United States
[b] Norwegian University of Science and Technology, Norway

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ABSTRACT

The stability of a system affects how it will handle a perturbation: The system may compensate for the perturbation or not. This study examined how 14-month-old infants—notoriously unstable walkers—and adults cope with a perturbation to walking. We attached a platform to one of participants' shoes, forcing them to walk with one elongated leg. At first, the platform shoe caused both age groups to slow down and limp, and caused infants to misstep and fall. But after a few trials, infants altered their gait to compensate for the platform shoe whereas adults did not; infants recovered symmetrical gait whereas adults continued to limp. Apparently, adult walking was stable enough to cope with the perturbation, but infants risked falling if they did not compensate. Compensation depends on the interplay of multiple factors: The availability of a compensatory response, the cost of compensation, and the stability of the system being perturbed.

1. Introduction

In this study, we examined how the stability of a system affects accommodation to a novel perturbation: We compared infant walkers—whose balance is notoriously unstable and whose gait is variable under the best of conditions—with adult walkers, whose balance and gait are highly stable. The perturbation was a sudden change in leg length introduced with a platform shoe on one foot. We indexed accommodation to the potential upset by observing the frequency of gait disruptions and falls, and the asymmetry and variability of gait.

1.1. Symmetry in walking

Walking is a highly symmetrical activity. Each leg's movement roughly mirrors the other, shifted in time: Weight shifts off of one foot as it shifts onto the other, and each foot touches down about halfway through the opposite leg's stride. Walking is automatized and rhythmical. But what if the symmetry in walking were broken so that the rhythm is perturbed? With a heavy bag over one shoulder or a cast on one leg, the forces acting on the body become asymmetrical. Uncorrected, walkers limp—their gait becomes uneven and halting because the distance and timing of each step is no longer the same for each foot. To return to normal gait, walkers must compensate for the asymmetrical forces. In many situations (such as a painful blister

* Corresponding author. Tel.: +1 212 998 9058.
E-mail addresses: wgcole@nyu.edu (W.G. Cole), karen.adolph@nyu.edu (K.E. Adolph).

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on one foot or a broken high heeled shoe), limping is the typical response. In other situations (carrying a heavy shoulder bag), walkers actively redress asymmetrical forces (by leaning) to return gait to greater symmetry.

Walkers can either compensate for the induced perturbation (i.e., correct for the perturbation to restore the symmetry of gait) or not. Whether to compensate depends on the interplay between the stability of the walking system, the size of the perturbation, and the cost and availability of compensation. A stable system can absorb a perturbation without compensation; an unstable one cannot. Skilled adult walkers are stable. Although capable of compensating, adults may not need to; coping with the effects of a slight perturbation may be preferable to a costly correction. Novice walkers, in contrast, are unstable. Their gait is variable and poorly controlled and new walkers may be less able to accommodate unusual forces, and simultaneously less equipped to compensate for them. Indeed, novice walking may be so intrinsically variable that the effects of the perturbation go unnoticed. Breaking the natural symmetry of walking provides an ideal test case for understanding how stable and unstable systems handle perturbations; well-coordinated walking is naturally symmetrical, but symmetry is not obligatory at any level of walking stability.

1.2. Breaking symmetry in walking

One way to break the symmetry of walking is to add weight to one side of the body. Adults immediately compensate for a heavy weight attached to one side of the torso. The load pulls the body to one side; in response, adults immediately lean away from the weight, pulling the center of mass back over the base of support (Fowler, Rodacki, & Rodacki, 2006; Goh, Thambyah, & Bose, 1998; P. E. Martin & Nelson, 1986). Fourteen-month-old infants do not compensate for a load on one side of the torso (e.g., lead-weighted shoulder-pack). Instead of leaning away from the weight like adults, infants lean *into* the load by tipping their bodies in the direction of the weight (Garciaguirre, Adolph, & Shrout, 2007). As a consequence, infants take quicker steps on the side with the weight and slower steps on the unweighted leg, and they incur more frequent gait disruptions such as trips, double-steps, and falls. Thus, stable adult walkers cope with a perturbation induced by an asymmetrical load with compensatory postural strategies. Novice walkers do not, but lack of compensation could be a result of the additional weight.

A split-belt treadmill is another classic method for inducing gait asymmetry. One treadmill belt runs at a higher speed, initially forcing walkers to limp by taking longer, quicker steps with the leg on the fast-belt side while maintaining alternating steps. Even when the fast-moving belt moves at four times the speed of the slow-moving belt, adults require only 10–20 strides to alter the timing and size of their steps to compensate for the asymmetry induced by the treadmill (Dietz, Zijlstra, & Duysens, 1994; Prokop, Berger, Zijlstra, & Dietz, 1995; Reisman, Block, & Bastian, 2005). Less stable walkers—8 to 36-month old infants, 4- to 11-year old children, and adult clinical populations—show less robust compensation. Adaptation in infants and children is slower (Musselman, Patrick, Vasudevan, Bastian, & Yang, 2011) and more variable (Zijlstra, Prokop, & Berger, 1996), and they do not display the full suite of compensatory mechanisms used by typical adults (Choi, Vining, Reisman, & Bastian, 2009; Morton & Bastian, 2006; Musselman et al., 2011; Vasudevan, Torres-Oviedo, Morton, Yang, & Bastian, 2011). Compensation can be reflected in a host of different measures, but always includes changes in step length at every age. Moreover, infants are unpredictable: Although some infants eventually correct for asymmetry, some infants never do, and others show no initial asymmetry to correct (Musselman et al., 2011; Thelen, Ulrich, & Niles, 1987).

Neither paradigm is ideal for studying the effects of an asymmetrical perturbation in infant walkers. Load carriage—even a symmetrical load—disrupts infant walking because of the additional weight (Garciaguirre et al., 2007; Vereijken, Pedersen, & Storksen, 2009). An asymmetrical load breaks the symmetry of infants' bodies, but it compounds the already substantial problem of load carriage. Thus, we cannot know whether the lack of adult-like compensation in infants results from carrying the load, from the asymmetrical nature of the perturbation, or both. The split-belt paradigm is also not ideal because participants are forced to compensate for the perturbation: Walkers who do not compensate for the faster moving belt will find themselves abruptly without a limb beneath them. What's needed is a perturbation that breaks the symmetry of walking while leaving participants free to compensate or not. Walking with uneven leg lengths is such a perturbation.

Without compensation, when forced to walk on legs of different lengths (either experimentally induced or naturally occurring) the longer leg takes larger, slower steps and the shorter leg takes smaller, quicker steps—causing asymmetry in step length and timing. Accordingly, a large lift (>3 cm) in one shoe causes significant gait asymmetries in otherwise healthy adults, indicating that they failed to compensate for the perturbation (Brand & Yack, 1996); however, smaller lifts do not create gait asymmetry (Goel, Loudon, Nazare, Rondinelli, & Hassanein, 1997). In cases of naturally occurring leg length discrepancies, some adults show gait asymmetries even after years of practice (Kaufman, Miller, & Sutherland, 1996; Liu & Fabry, 1998; Seeley, Umberger, Clasey, & Shapiro, 2010); but others maintain symmetry inside the normal range (Kaufman et al., 1996; Liu & Fabry, 1998; Siffert, 1987), indicating that they compensate for the asymmetry induced by their uneven legs.

1.3. Current study

In the current study, we assessed effects of stability on walkers' responses to a perturbation by comparing changes in gait patterns in infants and adults. We studied 14-month-olds to allow comparisons with previous work (Garciaguirre et al., 2007) and because at that age, infants are novice walkers and their gait is variable and precarious compared with adults' (Adolph, Vereijken, & Shrout, 2003). We broke the natural symmetry of walking by elongating one of walkers' legs with