Acta Psychologica 161 (2015) 170–176

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Functional distance in human gait transition

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ARTICLE INFO

Article history:
Received 10 December 2014
Received in revised form 4 August 2015
Accepted 6 September 2015
Available online 24 September 2015

Keywords:
Functional distance
Gait transition
Hysteresis
Perception and action

ABSTRACT

The emerging understanding of the behavioral transitions that accompany the ascending and descending method of limits is in terms of “functional distance” — the degree to which a perceiver is disengaged from ordinary exploratory activities. Increasing functional distance results in *negative hysteresis* in contrast to the classical *positive hysteresis* more typical of ongoing activity. In the present study of human gait transitions on a treadmill, the functional distance between a perceiver and ordinary exploratory activities was manipulated in two ways: (1) “Active” participants, walking or running on a treadmill, were asked to anticipate the gait that would be required if treadmill speed were increased or decreased; and (2) “passive” participants, standing off a moving treadmill, were asked to report the gait they would use if they were on the treadmill at its current speed. As expected, the increase of functional distance from (1) to (2) reduced the amount of classical hysteresis and promoted negative hysteresis, that is, a lower transition speed for walk-to-run transitions (ascending trials) than for run-to-walk transitions (descending trials). These results complement empirical findings in other behavioral transition experiments. More broadly, they signify the role of perception-action cycles for grounding natural on-going perception. In particular, they support the assertion that perception and action are intertwined and that lack of information about an impending action has consequences for perceptual judgments.

1. Introduction

For much of psychology's history, behavior has often been regarded as a mechanical response to a stimulus. In this classical view, behavior is assumed to be intrinsically mechanical (motor plans generated by an internal mechanism) and extrinsically functional (functions performed according to the internal motor plans). In an alternative view that is gaining currency (Gibson, 1979; Varela, Thompson, & Rosch, 1991), behavior constitutes a mode by which a functional relationship with the environment is established (e.g. Reed, 1985, 1996; also see Withagen & Michaels, 2005). In this view:

> “Behaviors are functionally specific (i.e. supported by resources specific to behavior, by affordances) as a counter to the traditional hypothesis that behaviors are functionally indifferent (or mechanically specific, which comes to the same thing).” (Reed, 1985, pp. 362–363).

The central idea is that activity is not simply a reaction to some perceived property but is instrumental to defining what perception reveals.

For experimentalists operating within this latter view of behavior, what we might call “functional distance” (Dotov, 2013) can provide a tool for examining the importance of the link between perception and action. Functional distance serves as an abstract, intuitive index of a perceiver's engagement in a function with respect to the environment. The richness of the functional relationship depends on the availability of information about the function: Decreased availability of information increases the functional distance between the perceiver and the environment.

The idea of functional distance can be traced to two sources. One is a collection of studies on the perception of *affordances*—the behavioral possibilities of an environment for an individual (Gibson, 1979)—that exploits insights from nonlinear dynamics. The other is a conceptual distinction between perception indexed explicitly by verbal reports and perception indexed implicitly by behavior. The relevant experiments examined perception of affordance boundaries (e.g., between what is reachable and not reachable, stand-on-able and not stand-on-able, sit-on-able or not sit-on-able, graspable with one hand or graspable with two hands) as nonlinear transitions between different stable modes; the use of the method of limits allows an examination of *hysteresis* in the transition boundary, that is, variation in the transition boundary as a function of whether a sequence of a property was increasing or decreasing (Dotov, 2013; Fitzpatrick, Carello, Schmidt, & Corey, 1994; Hirose & Nishio, 2001; Lopresti-Goodman, Turvey, & Frank, 2013; Richardson, Marsh, & Baron, 2007; van der Kamp, Savelsbergh, & Davis, 1998). Some of these studies found the transition to occur at a higher value (of object size, surface slope, etc.) for ascending sequences than descending sequences and others found the transition to be lower for ascending sequences than descending sequences. Beginning with Lopresti-Goodman et al. (2013) and further developed by Dotov (2013), the emerging understanding is that *positive hysteresis* ($Transition_{ascending} > Transition_{descending}$) accompanies affordance

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http://dx.doi.org/10.1016/j.actpsy.2015.09.004
0001-6918/

perception revealed by active behavior and *negative hysteresis* ($\text{Transition}_{\text{ascending}} < \text{Transition}_{\text{descending}}$) accompanies perception revealed by passive classification of an affordance (sometimes called "enhanced contrast"; Fitzpatrick et al., 1994; cf. Tuller, Case, Ding, & Kelso, 1994). This understanding owes much to a distinction provided by Heft (1993) that affordance experiments differ in the extent to which they allow participants to actively engage in perception-action cycles as opposed to requiring them to intellectualize the process by making an explicit perceptual judgment.

The present study investigates the effect of functional distance in the context of human gait transitions. Abdolvahab (2015b; Experiment 1) examined the transition between walking and running on a treadmill whose speed was gradually increased or decreased, allowing transitions between walking and running to occur spontaneously. In the current parlance, functional distance from the task was minimal. That experiment found positive hysteresis, namely a higher transition speed for ascending trials (walk-to-run transitions) than for descending trials (run-to-walk transitions). It will serve as a baseline for the present manipulations of functional distance.

In the present case, making a gait transition on a treadmill is the relevant action; functional distance, or subjective disengagement from that action, was manipulated in two ways. In the first condition, *active anticipation*, participants walking or running on the treadmill had to indicate verbally which gait would be required if treadmill speed were increased or decreased. In the second condition, *passive classification*, participants standing off the moving treadmill were asked to report the gait they would use if they were on the treadmill at its current speed. Because the former participants were actually engaged in the relevant task—locomoting on a treadmill—they were considered to be at less of a functional distance than the more passive participants. But unlike Abdolvahab (2015b) the active anticipation participants did not engage in actual gait transitions; they judged which gait would be needed by the next prospective speed. Therefore, they were considered to be at a greater functional distance from the relevant task than those of Abdolvahab's Experiment 1.

In affordance language, we are asking whether a particular treadmill speed affords a particular gait. The current objective is to examine whether negative hysteresis emerges as a result of increasing functional distance in a manner similar to the above-mentioned studies in bistable behavioral transitions. The advantage of such a setting is that a synergetic model of spontaneous behavioral transitions (Frank, Richardson, Lopresti-Goodman, and Turvey, 2009)is available. Consequently, the parameters of this model adapted for human gait transitions (Abdolvahab, 2015b) were estimated and compared to those of other experimental paradigms. The underpinnings of spontaneous gait transitions are considered next.

2. Human gait transitions

The transition between gaits in human locomotion is a classical problem in motor control that has been tackled from different perspectives. In a number of studies researchers have tried to establish the relation between transition speed and metabolic (Hreljac, 1993b), kinematic (Hreljac, 1995a), or kinetic (Hreljac, 1993a) parameters. Characteristics of the transitions have also been modeled dynamically (Diedrich & Warren, 1995) and probabilistically (Li, 2000). In general, gait transitions are examined in a laboratory setting and, in particular, on a treadmill with increasing (for walk-to-run or WR transitions) or decreasing (for run-to-walk or RW transitions) speeds. In dynamical models, speed and Froude number,[1] *Fr* (a normalized measure of speed for differently sized human participants) have been considered to play the role of a control parameter, a variable with a critical value at which a phase transition occurs spontaneously. In most studies of human gait transitions, regardless of the choice of control parameter, hysteresis has been found. Moreover, the transition boundary (critical speed or critical *Fr*) is usually larger for the WR transition than the RW transition, indicating classical, or positive, hysteresis (Fig. 1, left; e.g., Abdolvahab, 2014, 2015a,b; Abdolvahab & Gordon, 2015; Diedrich & Warren, 1995; Hreljac, 1995b). In special cases, however, negative hysteresis (a larger critical speed for the RW transition than for the WR transition) has also been observed empirically (Fig. 1, right; e.g., see Getchell & Whitall, 2004; Li, 2000; Turvey, Holt, LaFiandra, & Fonseca, 1999). The present research exploits synergetics, one prominent dynamical strategy for modeling behavioral transitions, to which we now turn.

3. A synergetic model of gait transitions

Synergetics, a branch of physics founded by Haken (1977, 1983, 1991), addresses the formation of patterns and structure in nonlinear physical systems. The application of synergetics to the study of behavioral transitions starts with the assumption that the transition between behavioral patterns is similar to nonlinear phase transitions in physical systems. Correspondingly, analogous governing equations of physical phase transitions can be derived for behavioral transitions.

A synergetic (or amplitude equation) model for human gait transitions, adapted from the grasping transition (GT) model developed by Frank et al. (2009),[2] was used in Abdolvahab (2015b) to describe the results of two experiments on human gait transitions under biomechanical constraints. This nonlinear dynamical model assumes that the behavioral dynamics of a system can be described as the competition among its possible behavioral modes (see Appendix A for further details about the model). The competition between these behavioral modes (in the context of gait transitions, walking or running) is quantified through an *interaction* parameter, *g*, which is estimated from critical *Fr* values for WR or RW transitions. A secondary control parameter, *h*, is required to describe the dynamics of a system displaying negative hysteresis (Lopresti-Goodman et al., 2013). In the present case *h* is estimated based on critical *Fr* and the interaction parameter, *g*. Moreover, the *offset* parameter, $L_{2,0}$, of the secondary mode (e.g., running in a WR transition), measures the overall strength of the attractor of the second mode with respect to the first mode (walking in the WR transition). The larger the parameter $L_{2,0}$, the stronger the attractor of the second mode (i.e., its basin of attraction is larger). In other words, with larger $L_{2,0}$, the critical *Fr* that induces a transition is shifted to a lower value. Such early transitions constitute negative hysteresis.

Accordingly, in the present study, the afore-mentioned parameters of the synergetic model were estimated for the observed empirical results. The estimations were then compared to those of similar experimental paradigms to evaluate the efficacy of the model to describe hysteretic phenomena in behavioral transitions.

4. Experiment

In the present study, the aim was to examine whether early transitions or negative hysteresis can be promoted as a result of manipulating the functional distance between the perceiver and the relevant action. A variety of experimental examinations of behavior mode transitions seem to show (at least in retrospect) that functional distance between the perceiver and a relevant property of the environment contributes to early transitions and eventually to a decrease in the size of the

[1] Some researchers have proposed that locomotory movements are dynamically similar when their Froude numbers are equal (e.g., Alexander and Pond, 1992). Froude number is defined by the squared speed divided by the product of leg length and gravitational acceleration. The dimensionless number *Fr* can be characterized as the ratio of inertial to gravitational forces.

[2] The GT model was first developed to describe dynamical (positive) hysteresis in unimanual and bi-manual grasping transitions and was later extended to account for negative hysteresis in the grasping transition (Lopresti-Goodman et al., 2013) and perception of multi-stable displays (Dotov, 2013).