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Representational momentum for the human body: Awkwardness matters, experience does not

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ABSTRACT

Perception of the human body appears to involve predictive simulations that project forward to track unfolding body-motion events. Here we use representational momentum (RM) to investigate whether implicit knowledge of a learned arbitrary system of body movement such as sign language influences this prediction process, and how this compares to implicit knowledge of biomechanics. Experiment 1 showed greater RM for sign language stimuli in the correct direction of the sign than in the reverse direction, but unexpectedly this held true for non-signers as well as signers. Experiment 2 supported two biomechanical explanations for this result (an effect of downward movement, and an effect of the direction that the movement had actually been performed by the model), and Experiments 3 and 4 found no residual enhancement of RM in signers when these factors were controlled. In fact, surprisingly, the opposite was found: signers showed reduced RM for signs. Experiment 5 verified the effect of biomechanical knowledge by testing arm movements that are easy to perform in one direction but awkward in the reverse direction, and found greater RM for the easy direction. We conclude that while perceptual prediction is shaped by implicit knowledge of biomechanics (the *awkwardness effect*), it is surprisingly insensitive to expectations derived from learned movement patterns. Results are discussed in terms of recent findings on the mirror system.

1. Introduction

Human actions are perceived differently than other stimuli. In particular, implicit knowledge derived from the observer's own body-representation is engaged when watching or listening to the actions of others (for reviews see Rizzolatti & Sinigaglia, 2008; Schütz-Bosbach & Prinz, 2007; Shmuelof & Zohary, 2007; Wilson & Knoblich, 2005; recent results include Aglioti, Cesari, Romani, & Urgesi, 2008; Saunier, Papaxanthis, Vargas, & Pozzo, 2008). Current theories postulate that these activated motor programs contribute to a simulation, or *forward model*, which runs forward in time from a given perceptual input, tracking the probable course of the unfolding action in parallel to the external event (Knoblich & Flach, 2001; Prinz, 2006; Wilson, 2006; Wilson & Knoblich, 2005).

These forward models are not limited to the case of human action. Beginning with the discovery of representational momentum (Freyd & Finke, 1984; see Hubbard, 2005, for review) and the flash-lag effect (Nijhawan, 1994), and continuing on to more recent neuropsychological studies (e.g. Guo et al., 2007; Mulliken, Musallam, & Andresen, 2008; Rao et al., 2004; Senior, Ward, & David, 2002), it has become clear that perception of a variety of predictable types of motion involves mental simulation that anticipates the incoming signal, rather than lagging behind it (see Nijhawan, 2008, for review). Such mental simulation has substantial advantages: expectations generated by the forward model can provide top-down input to ongoing perception, resulting in a more robust percept; and motor control for interacting with the world can be

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planned in an anticipatory fashion, allowing rapid accurate interception of moving targets despite signal transmission delays within the nervous system.

What makes the case of human action different is the contribution of the observer's own body-representation to the simulation. For non-human actions, movement regularities based on simple physical principles, such as momentum, oscillation, collision, friction, and gravity, are used to generate predictions (see Hubbard, 2005, for review). In contrast, the prediction of human movement can tap into internal models of the body, including hierarchical limb structure, the dynamics of muscles, limitations on joint angles, and the forces involved in movement control (e.g. Desmurget & Grafton, 2000; Ito, 2008; Kawato, 1999; Wolpert & Flanagan, 2001).

Consideration of this possibility also raises a further question: whether movement patterns that are highly familiar, but learned and in some sense arbitrary, can generate perceptual expectations that result in representational momentum. Categories of movement that might qualify include performance skills such as dance, martial arts, and gymnastics; and the linguistic movements involved in signed languages such as American Sign Language (ASL). In this paper, we investigate whether long-term daily experience with ASL can influence RM for body motions. Two previous lines of research suggest that it might.

One line of research concerns the effect of sign language expertise on perception of the human body. Deaf native signers of ASL, in contrast to non-signers, show categorical perception of the handshapes of ASL (Baker, Idsardi, Glinkoff, & Petitto, 2005; Emmorey, McCullough, & Brentari, 2003); are better at detecting subtle changes in facial configuration (Bettger, Emmorey, McCullough, & Bellugi, 1997; McCullough & Emmorey, 1997); and are more likely to perceive paths that conform to real signs in apparent motion displays showing human arms (Wilson, 2001). In addition, brain imaging studies have found different patterns of activation in signers vs. non-signers when perceiving both linguistic and non-linguistic hand movements and facial expressions (Corina et al., 2007; McCullough, Emmorey, & Sereno, 2005).

The second line of research concerns object-specific effects on RM, though not involving the human body. There is evidence that an object's identity can influence the strength of the RM effect in particular directions. Objects such as arrows whose shapes have an inherent perceptual directionality (cf. Palmer, 1980) show stronger RM in the direction that they point (Freyd & Pantzer, 1995; Nagai & Yagi, 2001). Inanimate objects reliably show stronger RM downward than upward, presumably reflecting a perceptual expectation based on gravity (e.g. Nagai, Kazai, & Yagi, 2002), but a rocketship, which typically self-propels upward, does not show this bias. In fact the rocketship shows stronger RM than normally stationary objects, possibly in various directions (up, down, rightward), or possibly upward only (Reed & Vinson, 1996; Vinson & Reed, 2002; but see Halpern and Kelly (1993), and Nagai and Yagi (2001), for an absence of a self-propelled effect).

In Experiment 1, we bring together these two lines of research (effects of ASL experience on perception; object-identity effects on RM) to ask whether a fluent signer's perceptual expectations for the arm and hand movements of ASL can affect the strength of RM for signs. In many cases, handshape and arm position uniquely identify a sign, determining the direction the arm must move to produce a sign in ASL. Thus, fluent signers might be expected to show modulation of RM for stimuli based on these signs.

2. Experiment 1

2.1. Method

2.1.1. Participants

Two groups were tested. The *non-signers* were 20 University of California Santa Cruz undergraduates who received course credit. All non-signers reported that they had normal hearing and did not know any ASL or other sign language. The *signers* were 10 deaf students from Gallaudet University in Washington, DC, who received monetary compensation. All signers used ASL as their primary language and were exposed to ASL from birth by their deaf parents ($N = 5$) or before the age of 5 years ($N = 5$) by hearing signing parents and/or pre-school teachers.

2.1.2. Stimuli

A native ASL signer (not one of the subjects) was filmed producing the sign KING (see Fig. 1). Five frames were chosen from the video to be used as *inducing stimuli*, which we will refer to as frames a–e. The frames were chosen so that the distance moved by the hand between frames was as nearly equal as possible. In the *sign* condition, frames a, b, and c were shown, thus progressing in the direction that the sign KING actually moves. In the *reversed-sign* condition, frames e, d, and c were shown. The arm moving in this direction results in a "nonsense sign" that is phonologically allowable in ASL but is not a meaningful sign. Frame c was always the last inducing stimulus, also called the *memory stimulus*.

In addition, five *probe stimuli* were used, only one of which was shown on any given trial. These consisted of frame c, and the four frames immediately surrounding frame c from the video – that is, frames $c + 1$, $c + 2$, $c - 1$, and $c - 2$. (Frame rate was 30 frames/s, so that the probes differed from the memory stimulus by −67 ms, −33 ms, 0 ms, 33 ms, and 67 ms of movement as originally performed by the model.)

As a control condition, a directional movement that should be equally familiar to signers and non-signers was used. This consisted of a hand reaching for a mug. Inducing stimuli and probe stimuli were chosen in the same manner as described above.

2.1.3. Procedure

Each trial began with a fixation cross presented for 500 ms, followed by a blank interval of 250 ms. Next, four stimuli were presented for 250 ms each, with a 250 ms ISI. In the *sign* condition the stimuli were frames a, b, c, and one of the five probe stimuli (see Fig. 1). In the *reversed-sign* condition the stimuli were frames e, d, c, and one of the five probe stimuli. Subjects were instructed to indicate by a keypress whether the final stimulus (the probe) was