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Internal model of gravity influences configural body processing

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A B S T R A C T

Human bodies are processed by a configural processing mechanism. Evidence supporting this claim is the body inversion effect, in which inversion impairs recognition of bodies more than other objects. Biomechanical configuration, as well as both visual and embodied expertise, has been demonstrated to play an important role in this effect. Nevertheless, the important factor of body inversion effect may also be linked to gravity orientation since gravity is one of the most fundamental constraints of our biology, behavior, and perception on Earth. The visual presentation of an inverted body in a typical body inversion paradigm turns the observed body upside down but also inverts the implicit direction of visual gravity in the scene. The orientation of visual gravity is then in conflict with the direction of actual gravity and may influence configural processing. To test this hypothesis, we dissociated the orientations of the body and of visual gravity by manipulating body posture. In a pretest we showed that it was possible to turn an avatar upside down (inversion relative to retinal coordinates) without inverting the orientation of visual gravity when the avatar stands on his/her hands. We compared the inversion effect in typical conditions (with gravity conflict when the avatar is upside down) to the inversion effect in conditions with no conflict between visual and physical gravity.

The results of our experiment revealed that the inversion effect, as measured by both error rate and reaction time, was strongly reduced when there was no gravity conflict. Our results suggest that when an observed body is upside down (inversion relative to participants' retinal coordinates) but the orientation of visual gravity is not, configural processing of bodies might still be possible. In this paper, we discuss the implications of an internal model of gravity in the configural processing of observed bodies.

1. Introduction

The perception and recognition of actions, moods or intentions of other people are important skills for social interaction and communication. Human faces and bodies provide a particularly rich source of visual information in support of these abilities. Bodies and faces have a peculiar status for the brain since it constitutes specific visual objects that could involve a specific configural processing mechanism in non-expert subjects (Brandman & Yovel, 2010; Brandman & Yovel, 2016; Carey, De Schonen, & Ellis, 1992; Carey & Diamond, 1994; Diamond & Carey, 1986; Leder & Bruce, 2000; Reed, Nyberg, & Grubb, 2012; Reed, Stone, Bozova, & Tanaka, 2003; Reed, Stone, Grubb, & McGoldrick, 2006; Rossion & Gauthier, 2002; Yin, 1969; Zhou, Zhang, Liu, Yang, & Qu, 2010). Configural processing is defined by Reed et al. (2006) as any phenomenon that involves perceiving spatial relations among the features of stimuli such as faces or bodies. Many authors have demonstrated that strong inversion effects in which recognition of faces (Carey & Diamond, 1994; Diamond & Carey, 1986; Leder & Bruce, 2000; Rossion and Gauthier, 2002; Yin, 1969) or of human bodies (Brandman & Yovel, 2010; Brandman & Yovel, 2016; Reed et al., 2003, 2006, 2012) is disrupted when turned upside down. Conversely, little or no inversion effect was reported for other stimuli such as animals or houses (Carey et al., 1992; Reed et al., 2003; Yin, 1969; Zhou et al., 2010). It has been suggested that inversion effects indicate configural processing. Indeed, turning familiar objects upside down disrupts the viewer's ability to rapidly process the interrelations between the parts of an object, at a configural level (Brandman & Yovel, 2010, 2016; Maurer, Le Grand, & Mondloch, 2002; Reed et al., 2003; Rhodes, Brake, & Atkinson, 1993).

Although body and face produce comparable body inversion effects they may be processed by different configural mechanisms.

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Indeed, body inversion effects involve distinct, specific bases from the face inversion effects (Brandman & Yovel, 2010; Brandman & Yovel, 2016; Rossion & Gauthier, 2002). Furthermore, evidence of dissociation of face and body configural processing mechanisms has recently been obtained in prosopagnosic patients (Susilo, Yovel, Barton, & Duchaine, 2013) who exhibited normal inversion effects for bodies despite face perception impairment.

Properties of the specific body processing were investigated using the size of the inversion effect as empirical indicator of change in configural processing. A reduced inversion effect was reported when visual stimuli violated human body biomechanics (Pinto & Shiffrar, 1999; Ramm, Cummins, & Slaughter, 2010; Reed et al., 2003, 2006, 2012) as well as in unfamiliar postures (Reed et al., 2012). Reed et al. (2012) suggested that biomechanical configuration as well as both visual and embodied expertise play an important role in body processing. Nevertheless, an important factor of body inversion effect may also be linked to visual information regarding gravity orientation. The visual presentation of an inverted body (inversion relative to participants' retinal coordinates) in typical body inversion paradigm (Reed et al., 2003) turns the stimulus upside down (body presented with the head down and the feet up) but also "up" and "down" directions of the surroundings (implicit visual gravity of the scene). Indeed, the inversion of a body stimulus induces the inversion of visual gravity orientation through the postural configuration of the body segments. The body seems to be standing on his/her feet as if it was drawn toward the ceiling by visual gravity. In this condition, the inversion of visual body orientation creates a conflict between the actual direction of gravity and the orientation of visual gravity extracted from the posture of the presented body. Astronauts are familiar with such a conflict as they experience visual reorientation illusion and motion sickness when viewing a crewmember floating upside down in their environment (Oman, Lichtenberg, Money, & McCoy, 1986).

Gravity is one of the most fundamental constraints of our biology, behavior, and perception on Earth. It plays a role in structuring not only our world but also how we perceive it and act on it. Human beings construct an internal model of gravity leading to a sense of verticality and relate "up" and "down" directions in order to spatially orient themselves and the world (Barra & Pérennou, 2013; Barra et al., 2010; Jenkin, Dyde, Jenkin, Howard, & Harris, 2003). This internal model represents a general neural process used by the brain to integrate information from disparate sensory modalities, combine efferent and afferent information but also to resolve sensory ambiguity (Merfeld, Zupan, & Peterka, 1999). In the framework of the body inversion paradigm, the conflict between visual and actual gravity creates sensory ambiguity that integration of internal model processing resolves to maintain coherent overall orientation (Howard & Hu, 2001). This graviceptive processing may affect configural body mechanisms. To test this hypothesis, we dissociated the orientations of body and visual gravity so that body orientation could be inverted while visual gravity remained congruent with actual gravity. It is the case when someone does a handstand, for example. In this posture, body orientation is inverted relative to participants' retinal coordinates (the head is down while the feet are up) but the orientation of visual gravity remains congruent with the actual one. In our experiment, the only visual gravity available was from body postures being viewed. We predicted that the body inversion effect would be reduced when body orientation was inverted without conflict of gravity orientation. Before the experimental comparison of inversion effect in typical conditions and in conditions without gravity conflict, we conducted a pretest to investigate whether it was possible to turn an avatar upside down relative to participants' retinal coordinates while visual gravity orientation was kept aligned with the actual one.

2. Pre-test

2.1. Participants

Twenty-two volunteers (10 males and 12 females, 25 ± 2 years old), naive to the goals of the experiment, participated in stimuli pretest. All had normal or corrected-to-normal vision (subjects who wore glasses or contact lenses did so during the experiment), and none had any known visual, neurological, vestibular or oculomotor impairments. All subjects were right-handed (according to the Edinburgh inventory) and gave informed consent.

2.2. Pretest material

The body stimuli were created according to the paradigm developed by Reed et al. (2003). The stimuli were 14 cm × 10 cm three-dimensional male and female figures created using Poser Professional 10™ (e frontier). The arms and legs of each figure were positioned to create new poses that were visually distinguishable from one another, had no meaning, and could not be easily labeled. Visual gravity orientation was manipulated (Fig. 1) by modulating body postures. We created 16 stimuli with upright avatars standing on their feet and 16 stimuli with upside down avatars standing on their hands relative to retinal coordinates. Half were males and half were females. All poses were bio-mechanically possible in terms of configuration of the body segments. For example, extension of the forearm was limited to biological range. Furthermore, the poses were plausible in terms of balance per se - independently of the orientation of the image - with one or two hands or feet in contact with an invisible floor. The poses were asymmetrical with respect to both vertical and horizontal axes.

2.3. Pretest procedure

In our experiment, we aimed at manipulating the orientation of visual gravity by modulating avatar postures. In order to check that modulating avatar posture impacted visual gravity orientation, we asked the 22 participants to indicate the direction that a ball released by the avatar would take according to gravity within the picture (32 body-stimulus pairs). All the avatars were centered within the images and all the images were centered within the screen. The participants had to indicate the direction that a ball released by the avatar would take according to gravity within the picture. They pressed the "Up Arrow" key if they considered that the direction of gravity was upward and the "Down Arrow" key if they considered that gravity was downward. Using E-prime 2.0, the 16 avatars standing on their feet (Fig. 1a) and the 16 avatars standing on their hands (Fig. 1d) were randomly presented in an upright position and in an inverted one (180°; Fig. 1b and c) in a block of 64 items. The block was repeated 3 times with a break between each. Each participant was seated 70 cm away from a 17-inch computer screen. Chair height was adjusted so that the participants' eyes were level with the center of the screen. In each trial, the stimulus was displayed for 250 ms, followed by a blank screen until the participants responded. The participants had been informed that the direction of visual gravity could be upright or inverted (downward or upward). We measured the proportion of upward and downward responses to the different conditions of body orientation (upright or upside down relative to retinal coordinates) and postures (avatar standing on his/her feet or hands).

2.4. Pretest results

One sample-t tests were used to test the proportion of downward response rates for the four experimental conditions against