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Research report

Handedness, laterality and the size-weight illusion

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ABSTRACT

The goal of this study was to determine how handedness and lifting hand influence the way in which we lift objects and perceive their weights. To this end, we examined the fingertip forces and perceptual judgements of 30 left-handers and 30 right-handers during lifts of specially constructed 'size-weight illusion' (SWI) cubes with their left and right hands. All participants completed a series of lifts first with one hand and then the other, so we could additionally examine asymmetries in the retention and transfer of force information between the limbs. Right-handers experienced a larger illusion with their left hand than they did with their right hand, whereas left-handers showed no such asymmetry in their illusions. The perceptual illusion's independence from the application of fingertip force was highlighted by an unexpected lack of asymmetry in terms of fingertip force scaling. Left- and right-handers showed no dominant hand advantage in this task – they were no more skilled at correcting their fingertip force errors with their preferred hand than they were with their non-preferred hand. In addition, although no asymmetries were observed with regard to the most efficient *direction* of intermanual transfer, the right-handed individuals transferred force information between the hands more effectively than the left-handers. Overall, these findings indicate that hand dominance does not affect the control of the fingertip forces, suggesting that existing models of cerebral laterality must be re-visited to consider kinetic (i.e., related to forces), as well as kinematic (i.e., related to movement) variables.

1. Introduction

For over 100 years the size-weight illusion (SWI) has intrigued researchers in the overlapping fields of perception and action. First described by Charpentier (1891), the SWI is experienced during lifts of similar looking, but different-sized objects which have been adjusted to have the same weight as one another. When individuals lift these objects in turn they invariably report that the smaller object is heavier than the larger object. This dramatic and unchanging illusory difference in weight is persistent enough to be experienced even by the researchers who create the stimuli in the first place.

The dramatic and unchanging nature of the perceptual illusion contrasts with the rapidly adapting forces that individuals use to lift SWI-inducing objects. When first confronted with a set of SWI cubes, individuals will typically make a flawed prediction and apply forces in line with their expectations of heaviness. Lifters use too much force to lift the large object (which they expect to be relatively heavy), while barely

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succeeding to lift the smaller object (because they expect it will be comparatively light). With repeated lifts, however, individuals will unconsciously correct their errors and begin to lift each cube with a more appropriate rate of force for its actual mass (Flanagan and Beltzner, 2000; Grandy and Westwood, 2006). In other words, individuals are able to rapidly scale their fingertip forces to the real weight of the SWI-inducing cubes. Thus, even while experiencing a weight illusion, the motor system constantly (and unconsciously) works to optimize its performance.

A range of studies have shown fingertip force scaling to be an extremely robust phenomenon (although see Buckingham and Goodale, 2010a for a rare exception), which also has the virtue of being resistant to a wide range of delays. Individuals are able to 'pick up where they left off' after a 24-hour delay between interactions, continuing to adapt their forces towards the actual mass of the stimuli as if the delay had not occurred (Flanagan et al., 2001). It has even recently been shown that the individuals will continue to scale their forces when the SWI-inducing objects are passed from one hand to the other (Chang et al., 2008). Furthermore, this 'intermanual transfer' of the scaled forces is also unaffected by the duration of time between lifting with one hand and lifting with the other (Green et al., 2010). But beyond these studies, there has been little work on intermanual transfer of lifting forces, with the vast majority of transfer tasks examining *kinematic* variables (i.e., variables that describe the movement of a limb, such as its movement duration, curvature, and accuracy). Studies determining the types of skills that transfer most effectively from the dominant to non-dominant hand (and vice versa) have provided useful insights into the brain-basis of certain lateralized behaviours. For example, Sainburg and colleagues have built an influential model of cerebral laterality based on the observed behavioural asymmetries in various intermanual transfer tasks (for review, see Sainburg, 2005). One relevant example comes from a study describing the asymmetries in the transfer of the dynamics of a novel force field from one limb to the other (a task analogous to moving an object with one hand and then the other), in which the transfer was markedly better going from the dominant to non-dominant limb than in the reverse direction (Wang and Sainburg, 2004). This finding is not, however, easily reconciled with recent indications that transfer in an object-lifting task is the same whether going from the left to the right hand or the right to the left hand, suggesting that the transferred force commands are represented centrally, rather than in an effector-specific fashion (Green et al., 2010). In both these tasks, however, the transfer of forces has been examined only in right-handed individuals, making it is difficult to draw strong conclusions regarding the cerebral lateralization of force representations.

Irrespective of whether fingertip forces transfer between the hands in this context, the ability of individuals to re-scale their fingertip force from the expected to the actual weight of each of the SWI cubes is fascinating for two reasons. First, it demonstrates that the unchanging perceptual illusion is not caused by differences in the way that the cubes are lifted. Second, and even more interestingly, individuals never lift the cubes with forces that reflect their perception of the effort required to perform the lift; the heavy-feeling small cube is never lifted with more force than the light-feeling large cube. Similar dissociations have even been shown to occur outside of the SWI literature. For example, a recent interesting study demonstrated that an individual's fingertip forces automatically scale to a change in visual size that is too small for the lifter to consciously notice (Cole, 2008). It seems clear that lifters' perceptions of heaviness are largely isolated from the kinetic parameters that describe the way in which they actually lift objects (e.g., their peak grip force – GF and load force – LF and their rates of change; Buckingham et al., 2009; Mon-Williams and Murray, 2000).

The motor system's isolation from perception seems to parallel findings in the 'perception action model' (PAM – Milner and Goodale, 2006). Of specific relevance to the SWI literature is the notion that the kinematics of the reaching hand are largely unaffected by a wide variety of visual illusions (e.g., Haffenden and Goodale, 1998; Westwood and Goodale, 2003). This widely replicated finding, taken as strong evidence for a dissociation between vision for perception and vision for action (see Carey, 2001, for review), is subject to a surprising behavioural asymmetry. Gonzalez and colleagues demonstrated that the immunity to visual illusions is only available to the right hand, regardless of the handedness of the individual doing the reaching (Gonzalez et al., 2006). While the authors of that study interpreted their findings in terms of a left-hemisphere specialization for skilled visually guided movements, this behaviourally lateralized immunity to visual illusions may have wider-ranging consequences. It is particularly intriguing to consider such lateralized effects within the framework of the SWI, where the illusion itself is perceived by virtue of haptics. This is not to say that the SWI is a purely haptic phenomenon since the SWI may be induced by haptics, vision or a combination of both (see Ellis and Lederman, 1993). Rather, the fact that the SWI is *perceived solely via the lifting hand* makes it more theoretically interesting to study in the context of laterality than an illusion that is perceived via the visual system. This asymmetrical interaction between perception and action, in combination with the many well-documented asymmetries that exist between the hands in a wide variety of skilled manual tasks (see Goodale, 1990 for review), leads us to hypothesise that the dominant hand will outperform the non-dominant hand. However, given that there are many ways to 'fail' at this particular task, this hypothesis needs to be expanded upon. One specific way in which this prediction could manifest would be that the non-dominant hand would not show the immunity to the SWI, and instead scale the fingertip forces to match the illusory difference in weight between the large and small cubes. Alternatively, the non-dominant hand might merely show a weaker learning effect, taking longer to adapt to the actual mass of the identically weighted SWI-inducting cubes. Furthermore, these predictions could be further modulated by any between-hand differences in the magnitude of the illusion that left- and right-handed individuals perceive – a question that has not, to the best of our knowledge, been directly investigated in the SWI literature.

To investigate perceptual and motor asymmetries during object lifting, we asked left- and right-handed individuals to repeatedly lift SWI-inducing cubes with their dominant or non-dominant hand, before switching to perform a series of