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Research Report

Neural substrates of knowledge of hand postures for object grasping and functional object use: Evidence from fMRI

Laurel J. Buxbaum[a,b,*], *Kathleen M. Kyle*[a], *Kathy Tang*[c], *John A. Detre*[c]

[a]*Moss Rehabilitation Research Institute, Korman 213, 1200 W. Tabor Road, Philadelphia, PA 19141, USA*
[b]*Thomas Jefferson University, Philadelphia, PA 19107, USA*
[c]*University of Pennsylvania, Philadelphia, PA 19104, USA*

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ABSTRACT

A number of lines of evidence suggest that computation of hand posture differs for object grasping as compared to functional object use. Hand shaping for grasping appears to rely strongly upon calculations of current object location and volume, whereas hand shaping for object use additionally requires access to stored knowledge about the skilled manipulation specific to a given object. In addition, the particular hand postures employed for functional object use may be either prehensile (clenching, pinching) or non-prehensile (e.g., palming, poking), in contrast to the prehensile postures that are obligatory for grasping. In this fMRI study, we assessed the hypothesis that a left-hemisphere-lateralized system including the inferior parietal lobe is specifically recruited for the computation and recognition of hand postures for functional object use. Fifteen subjects viewed pictures of manipulable objects and determined whether they would be grasped with a pinch or clench (Grasp condition), functionally used with a pinch or clench (Prehensile Use condition), or functionally used with a palm or poke hand posture (Non-prehensile Use condition). Despite the fact that the conditions were equated for behavioral difficulty, significantly greater activations were observed in the left inferior frontal gyrus (IFG), posterior superior temporal gyrus (STG), and inferior parietal lobule (IPL) in Non-prehensile Use trials as compared to Grasp trials. Comparison of Non-prehensile Use and Prehensile Use activations revealed significant differences only in the left IPL. These data confirm the importance of the left IPL in storing knowledge of hand postures for functional object use, and have implications for understanding the interaction of dorsal and ventral visual processing systems.

1. Introduction

Consider the cognitive operations and hand movements entailed in grasping a pocket calculator and using it to perform a mathematical operation. The grasping movement requires calculation of the location of the calculator vis a vis the body and hand and the calculator's volume, with the aim of computing an appropriately scaled prehensile posture. The use operation, in contrast, requires knowledge about the precise part of the calculator affording performance of the

* *Corresponding author*. Moss Rehabilitation Research Institute, Korman 213, 1200 W. Tabor Rd., Philadelphia, PA 19141, USA. Fax: +1 215 456 5926.
E-mail address: Lbuxbaum@einstein.edu (L.J. Buxbaum).

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desired function (e.g., the keys), and the movement of those parts in service of a non-prehensile poking movement of the forefinger.

In daily life, structural and functional information is likely to richly interact in our use of familiar objects. There is evidence, however, that in neuropsychological populations, performance in scaling hand posture for grasping versus functional object use may doubly dissociate. Patient L.L., reported by Sirigu et al. (1995), had a specific impairment of hand posture for using familiar objects, but performed flawlessly with the *same* objects in a reaching and grasping task. She was also unable to discriminate correct versus incorrect functional hand postures. In describing L.L.'s grasping performance with familiar objects, the authors note, "…the wrist's orientation matched the object's, and the size of the finger grip was highly correlated with the size of the grasped portion of the object ($r = 0.87$). As these last results indicate, L.L.'s incorrect hand posture…seems to be specific to gestures involving the use of objects" (p. 46). The investigators further go on to postulate deficits in knowledge "specific to the complex manual configurations associated with the use of tools" (p. 53).

These data are consistent with work from our laboratory (Buxbaum et al., 2003) showing that in patients with left inferior parietal damage, selection of grasp for use was consistently biased toward the posture appropriate for picking up the object. In other words, we observed preservation of grasp posture and disruption of use posture with familiar objects. We have also recently demonstrated that IM patients may be strikingly impaired in recognizing the hand posture component of functional object-related gestures performed by others (Buxbaum et al., 2005). These data indicate that the representations underlying functional hand posture knowledge are deficient in many cases of left inferior parietal IM.

In contrast to this is the pattern of performance observed in optic ataxia, a disorder of visually guided reaching often occurring subsequent to superior parietal and intraparietal sulcus damage. Glover (2004) posits that optic ataxia is a deficit specific to the on-line control of actions. Patients with optic ataxia reported by Perenin and Vighetto (1988), Jeannerod et al. (1994), and Jakobson et al. (1991) have severe problems in grasping a variety of objects, some familiar, while showing no evidence of hand posture deficits on functional object Use tasks. Perenin and Vighetto (1988) specifically report apraxia in 4 of 10 optic ataxia patients; functional interaction with objects in the remaining 6 patients can probably be assumed to have been unremarkable, i.e., the patients were apparently able to position their hands appropriately for using objects. Supporting this possibility is a study from Karnath and Perenin (2005) reporting apraxia in 2 of 10 left hemisphere-lesioned and 0 of 6 right hemisphere-lesioned optic ataxics.

Behavioral studies in healthy subjects are also suggestive of differences in the programming of hand posture for use as compared to grasp. There are a number of lines of evidence that programming of hand posture shape for object grasping to lift and move objects has very limited access to stored knowledge. For example, Gordon et al. (1993) demonstrated that when asked to lift objects of unexpected weights, healthy subjects' hand aperture is appropriate even on Trial 1. Thus, current visual information about object structure is used to scale grip aperture. On the other hand, vertical lifting force and grip force do not become appropriate until later trials, reflecting the incorporation of experience in programming force appropriate to lifting the experimental objects. This is consistent with several studies showing that memory-guided but not visually guided grasping of novel objects can be primed by passive viewing or grasping of primes of various shapes and orientations (Cant et al., 2005; Garofeanu et al., 2004). Thus, the visuomotor processes involved in programming hand shape for visually guided grasping appear to rely on "moment to moment" computations (Garofeanu et al., 2004, p. 55). This appears to be computationally efficient given that different exemplars of the same object may differ in size, current location, and orientation with respect to the subject.

Recently, Creem and Proffitt (2001) demonstrated that functional use postures are more likely to rely upon stored semantic information than grasp postures. These investigators showed that when subjects are asked to grasp familiar objects that are oriented away from their bodies (e.g., a pan with handle far from the subject), they characteristically reach around the object to grasp its functional part. In contrast, when performing a secondary task that uses semantic resources (but critically, not an equally difficult non-semantic secondary task), subjects more often fail to reach to the functional object part, instead grasping the closest edge. In a related study, Klatzky et al. (1987) have demonstrated that healthy subjects could reliably rate which of 4 hand configurations (poke, pinch, palm, or clench) were associated with objects in three classes of functional context: hold/pick up, feel/touch, and use. Moreover, the investigators demonstrated that object structure alone was not sufficient to predict subjects' knowledge of the hand postures associated with use of the objects. For example, a discriminant function based on the shape of novel objects tended to assign certain shallow, flat real objects (e.g., nail, paperclip, zipper) to a "poke" category, although they are used functionally with a "pinch" movement. Thus, functional use knowledge in some cases superseded the hand posture predicted on the basis of object structure alone.

A recent functional magnetic resonance imaging (fMRI) study (Creem-Regehr and Lee, 2005) examined differences in neural activation for imagined grasping of familiar tools as compared to novel shapes, and found that imagined tool grasping activated left inferior parietal lobe (angular gyrus) and left posterior middle temporal gyrus more than did imagined novel shape grasping. No distinction was made between tools for which grasp and use postures were the same versus different. In this study we sought to extend these findings by providing evidence on the role of neural structures involved in cognitive representation of functional use hand postures when the task was a judgment not explicitly requiring imagined use. The Use task required a decision about whether a depicted object would be functionally used with a poke, pinch, palm, or clench, and the Grasp task entailed assessment of whether an object would be handed to someone with a pinch or clench. Note that the Use task entailed consideration of both prehensile and non-prehensile postures, whereas the Grasp task, of necessity, assessed only prehensile postures. Thus, the design enabled comparisons between Non-prehensile Use, Prehensile Use, and Grasp.