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Research Report

Physical experience leads to enhanced object perception in parietal cortex: Insights from knot tying

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A B S T R A C T

What does it mean to "know" what an object is? Viewing objects from different categories (e.g., tools vs. animals) engages distinct brain regions, but it is unclear whether these differences reflect object categories themselves or the tendency to interact differently with objects from different categories (grasping tools, not animals). Here we test how the brain constructs representations of objects that one learns to name or physically manipulate. Participants learned to name or tie different knots and brain activity was measured whilst performing a perceptual discrimination task with these knots before and after training. Activation in anterior intraparietal sulcus, a region involved in object manipulation, was specifically engaged when participants viewed knots they learned to tie. This suggests that object knowledge is linked to sensorimotor experience and its associated neural systems for object manipulation. Findings are consistent with a theory of embodiment in which there can be clear overlap in brain systems that support conceptual knowledge and control of object manipulation.

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1. Introduction

In daily life, we encounter an array of objects that we are able to effortlessly identify and interact with, based on prior experience with these objects. Converging evidence from research with neurological patients (Buxbaum, 2001; De Renzi, Faglioni, & Sorgato, 1982; Johnson, 2000; Johnson, Sprehn, & Saykin, 2002; Rothi & Heilman, 1997), non-human primates (Gardner, Babu, Ghosh, Sherwood, & Chen, 2007; Gardner, Ro, Babu, and Ghosh 2007; Gardner, Ro, Babu, & Ghosh, 2007; Sakata, Tsutsui, & Taira, 2005; Ungerleider & Mishkin, 1982), and neurologically healthy individuals (Bellebaum et al., 2012; Frey, 2007; Grol et al., 2007; Mahon et al., 2007; Tunik, Rice, Hamilton, & Grafton, 2007) underscores an important feature of visual object perception: a rich array of information pertaining to an object is automatically retrieved whenever that object is encountered. However, what it means to actually *know* what an object is remains a matter for debate. Once basic visual features of an object are constructed (such as the object's shape, size, texture, and colour), knowledge can then come from both linguistic and practical experience with that object (Martin, 2007). A fundamental question is whether these two sources of knowledge are distinguishable at a behavioural or neural level. Here we make use of a knot tying paradigm, which incorporates both linguistic and practical training procedures, to examine the emergence of experience-specific object representations. Participants learned either a knot's name, how it is tied, or both its name and how it is tied for a collection of knots that were novel to them before the experiment began. Such a paradigm enables us to test whether dissociable types of knowledge can be generated for the same class of novel objects and how this is manifest in the brain.

Object knowledge is related to the way we experience objects, through perceptual, linguistic, or motor modalities (Barsalou, Kyle Simmons, Barbey, & Wilson, 2003). Two rival theories of how object knowledge is organized in the brain have been proposed. The sensorimotor feature/grounded cognition model posits that object knowledge is organized based on sensory (form/motion/colour) and motor (use/touch) features (Martin, 2007). Such an account predicts that object knowledge should be closely tied to one's experience with a given object. In contrast, amodal accounts of object representation suggest that object knowledge is organized in the brain

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according to conceptual category (Caramazza & Mahon, 2003; Caramazza & Shelton, 1998; Mahon et al., 2007). In support of this theory, proponents cite an ever-increasing number of neuroimaging studies that provide evidence for dedicated neural tissue for category-specific processing of tools, plants, animals, and people as evolutionarily-salient domains (Mahon & Caramazza, 2009). However, directly comparing these theories can be problematic, as data can be used to support both camps (Grafton, 2009; Martin, 2007). In the present study, rather than attempting to falsify these general accounts of object knowledge or pit them against each other, we aim to further delineate which types of object knowledge are grounded in the systems used to gain that knowledge (sensorimotor vs. linguistic structures). Further, we investigate how *de novo* sensorimotor or linguistic information is encoded in the brain and examine which brain structures are engaged when performing a task that does not require explicit recall of such knowledge or experience.

Abundant data provide evidence for activation of parietal, premotor, and temporal cortices when viewing objects that are associated with a particular action, such as tools (Boronat et al., 2005; Canessa et al., 2008; Grezes & Decety, 2002; Johnson-Frey, Newman-Norlund, & Grafton, 2005; Kiefer, Sim, Liebich, Hauk, & Tanaka, 2007; Martin, Wiggs, Ungerleider, & Haxby, 1996). However, most of the prior research on perception of functional objects has measured brain and behavioural responses to familiar, every-day objects, which means each participant comes into the laboratory with individual sensorimotor histories with any given object. In an attempt to extend this prior work and explore how object knowledge is constructed, several recent experiments have sought to control the amount of action experience participants have with an object through employing laboratory training procedures (Bellebaum et al., 2012; Creem-Regehr, Dilda, Vicchrilli, Federer, & Lee, 2007; Kiefer et al., 2007; Weisberg, van Turennout, & Martin, 2007). Using a particularly innovative paradigm, Weisberg et al. (2007) taught participants how to use a set of novel tools across a three-session training period. By doing so, participants gained knowledge about each object's function. Participants were scanned before and after acquiring action experience with these novel objects, and their task in the scanner was simply to decide whether two photographs featured the same or different novel tool. Therefore, the task during scanning required a judgement of visual similarity and did not explicitly instruct participants to retrieve information gained from the training period. The authors reported training-specific increases within parietal, temporal, and premotor cortices when participants performed the perceptual discrimination task. This evidence, along with that reported by a recent study employing similar procedures (Bellebaum et al., 2012) suggests that brief experience learning how to use a novel object can lead to action-related object representations that are accessed in a task-independent manner.

Another feature that can be accessed when viewing an object is the name or linguistic label for that object. Portions of the left inferior frontal gyrus and the middle temporal gyrus are implicated in mediating linguistic knowledge about familiar objects, whether accessed in a deliberate or spontaneous manner (Chao & Martin, 2000; Ferstl, Neumann, Bogler, & Yves von Cramon, 2007; Grafton, Fadiga, Arbib, & Rizzolatti, 1997; Shapiro, Pascual-Leone, Mottaghy, Gangitano, & Caramazza, 2001; Tyler, Russell, Fadili, & Moss, 2001). As with studying the function of objects, most of the research to date that has investigated naming knowledge for objects has studied the perception of well-known, every day objects. Of the few researchers who have investigated *de novo* name learning for novel objects, they report generally consistent results, demonstrating inferior frontal and middle temporal cortical activations when accessing newly learned linguistic representations of objects (Gronholm, Rinne, Vorobyev, & Laine, 2005; James & Gauthier, 2003, 2004). What remains underexplored is whether such cortical activity is present when participants perform a task independent of the linguistic information learned about an object, and how name learning compares to learning action-related information about an object.

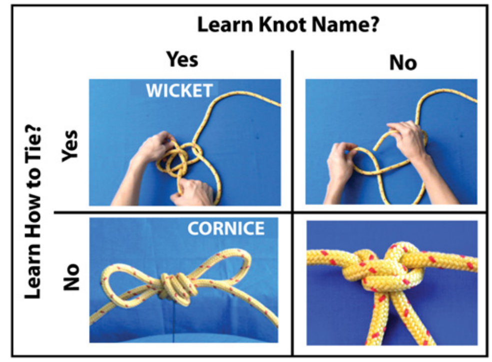

Fig. 1. Two-by-two factorial design for training procedures. Participants spent approximately the same amount of time watching video stimuli for knots they were meant to learn to tie, to name, and to both name and tie.

To address these outstanding issues and further delineate how object knowledge is constructed in the human brain, we measured participants' neural activity before and after they learned to construct and name a set of novel objects. Importantly for the purposes of the present experiment, all objects had the same function (knots) and category membership. The task was a simple perceptual discrimination task (after Weisberg et al., 2007 and Bellebaum et al., 2012), which enables direct comparison of the influence of linguistic or action experience on task performance, and is not biased towards any one type of experience. Importantly, both the function and visual familiarity of all objects used in this study are held constant. All that is manipulated is prior exposure to an object's name or how to create it, using a two by two factorial design (Fig. 1). Thus, participants' experience with each object fit into one of four training categories: (1) knowledge about a knot's name and how to tie it; (2) knowledge about a knot's name only; (3) knowledge about how to tie a knot only; or (4) no knowledge concerning a knot's name or how to tie it. When performing the perceptual discrimination task, it has been argued that participants automatically draw upon whatever associated knowledge systems are available (Martin, 2007). We hypothesize that both perceptual-motor experience and linguistic knowledge play important roles in object knowledge, and that both kinds of experience will be differentially represented in the brain during object perception.

2. Materials and methods

2.1. Subjects

Thirty right-handed (Oldfield, 1971), neurologically healthy undergraduate and graduate students participated in the behavioural portion of this study. These participants ranged in age from 17 to 27 years (mean age 19.03 years; parental consent was obtained for the one participant under the legal age of consent), and 23 were female.

Of the 30 participants who completed the behavioural training procedures, 28 of these individuals participated in the functional imaging portion of the study. Eight of these subjects were excluded from final data analyses due to unacceptably high levels of noise in the MRI data due to scanner malfunction. Of the 20 participants (14 females) who composed the final fMRI sample, all were right handed (determined by the Edinburgh handedness inventory; Oldfield, 1971) and had a mean age of 19.4 years (range 17–27 years). Informed consent was obtained in compliance with procedures set forth by the Committee for the Protection of Human Subjects at Dartmouth College. All participants were compensated for

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