Acta Psychologica 181 (2017) 1–9

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

More than a feeling: The bidirectional convergence of semantic visual object and somatosensory processing

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ARTICLE INFO

Keywords:
Somatosensory priming
Action simulation
Object representation
Object processing

ABSTRACT

Prevalent theories of semantic processing assert that the sensorimotor system plays a functional role in the semantic processing of manipulable objects. While motor execution has been shown to impact object processing, involvement of the *somatosensory* system has remained relatively unexplored. Therefore, we developed two novel priming paradigms. In Experiment 1, participants received a vibratory hand prime (on half the trials) prior to viewing a picture of either an object interacted primarily with the hand (e.g., a cup) or the foot (e.g., a soccer ball) and reported how they would interact with it. In Experiment 2, the same objects became the prime and participants were required to identify whether the vibratory stimulation occurred to their hand or foot. In both experiments, somatosensory priming effects arose for the hand objects, while foot objects showed no priming benefits. These results suggest that object semantic knowledge bidirectionally converges with the somatosensory system.

1. Introduction

The involvement of motor and sensory systems in conceptual processing has recently become a central topic in cognitive science. One prominent view posits that conceptual processing is intrinsically bound to the sensorimotor system. For example, Tucker and Ellis (1998) asked participants to make a categorization judgment about objects (i.e., whether the object was upright or inverted) with unilateral action affordances (e.g., a handle). Their results indicated that participants were faster at making a motor response with the hand to which the site of action was oriented towards, suggesting that presentation of the object primed the motor system related to the relevant hand. This effect has also been shown through interference between motor simulation and motor execution, as Witt, Kemmerer, Linkenauger, and Culham (2010) found evidence for a functional role of motor simulation in the processing of manipulable objects. When participants performed a motor task while identifying tools, it was found that the motor task interfered with processing when the object's site of manipulation was on the same side.

These findings are not without opposition, however, as there is much debate throughout the literature as to whether sensorimotor contributions are intrinsically bound to an object's representation or whether they are auxiliary to it (see Proctor & Miles, 2014 for a review). Indeed, the findings of Tucker and Ellis (1998) have failed to be replicated in at least two separate studies (Bub & Masson, 2010; Yu, Abrams, & Zacks, 2014) and further evidence from Cho and Proctor (2011) has shown that alignment effects associated with the site of object affordance can be produced by asymmetries in the visual displays rather than by the motor properties themselves. Their results indicated that the salient features of objects biased responses with the corresponding hand, regardless of its affordance (e.g., the spout of a teapot elicited similar biases to the handle as those shown in the Tucker & Ellis, 1998 study). Thus, it has remained contentious as to whether the *passive* viewing of objects automatically triggers sensorimotor system involvement.

Many current prominent theories of semantic representation are consistent with, and can accommodate, the idea that contributions from the somatosensory system may be involved in conceptual processing (see Patterson, Nestor, & Rogers, 2007). For example, Barsalou (1999, 2008); Barsalou, Simmons, Barbey, and Wilson (2003)'s Perceptual Symbol Systems theory posits that perceptual experiences are intrinsically bound to semantic knowledge via simulation processes. As such, semantic knowledge is seen as being carried by the sensorimotor representations by which they were formed. Further, Patterson et al. (2007)'s distributed-plus-hub model argues that concepts consist of distributed contributions from all modalities that are integrated into one semantic representation via an amodal hub. These theories are in contrast to completely amodal theories of conceptual representation, which purport that concepts are symbolic, abstract, and require transformation from their sensorimotor origins, and that sensorimotor

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http://dx.doi.org/10.1016/j.actpsy.2017.09.016
Received 14 June 2017; Received in revised form 8 September 2017; Accepted 29 September 2017

involvement is purely auxiliary to conceptual processing (see Lachman, Lachman, & Butterfield, 1979). However, amodal theories are generally not strongly supported by behavioral (e.g., Helbig, Graf, & Kiefer, 2006; Witt et al., 2010; Yee, Chrysikou, Hoffman, & Thompson-Schill, 2013), neuropsychological (see Patterson et al., 2007 for a review), or neuroimaging (e.g., Esopenko et al., 2012; Simmons, Ramjee, McRae, Martin, & Barsalou, 2006) evidence, which instead suggest that conceptual representation includes, to at least some degree, modality specific contributions.

In line with these theories, electroencephalographic evidence from Kiefer, Sim, Liebich, Hauk, and Tanaka (2007) has shown that motor involvement in conceptual processing is dependent upon action experience with an object. Participants were required to categorize objects based on their motor attributes and, depending on the group, either pantomime interacting with, or point at, the object during a training period. Results at test indicated that objects in the pantomime group showed sensorimotor involvement (as indicated by event-related potentials associated with the pre-motor cortex) during object processing, suggesting that motor information contributes to semantic processing *depending* on specific learning experience (see also Weisberg, van Turrennout, & Martin, 2007). Research examining motor imagery has also corroborated this finding, for example Fourkas, Bonavolontà, Avenanti, and Aglioti (2008) found that when expert tennis players engaged in motor imagery of a tennis swing, but not a table tennis swing or golf swing, there was corticospinal excitability of their forearm and hand muscles, suggesting motor system contributions to conceptual processing (see also Schendan & Ganis, 2012, who found that engaging in motor imagery prior to object presentation can enhance object processing). Thus, it appears that the semantic representation of objects in the sensorimotor system is reliant on past individual experience, and that past experience can influence object processing.

While the studies reviewed thus far have provided evidence of motor contributions to object processing, both the motor *and* somatosensory systems have been implicated in object representation. Specifically, although touch (i.e., somatosensation) is the first sense to develop (see Gallace & Spence, 2010) and therefore provides the first means of acquiring essential information from our environments, it has been relatively overshadowed by research focused on the motor, as well as other cognitive, systems. Thus, it remains one of the most under-researched senses in behavioral research. Regarding somatosensory contributions to conceptual processing, the somatosensory system has been shown to be involved in word processing (e.g., Connell & Lynott, 2010), social decision-making and judgments (Ackerman, Nocera, & Bargh, 2010), and during auditory processing (e.g., expert athletes listening to familiar sports sounds; Woods, Hernandez, Wagner, & Beilock, 2014). Interestingly, however, evaluation of somatosensory contributions to visual object processing in isolation have remained relatively unexplored.

As such, our experiments focus on uncovering how the somatosensory system may play a role in the semantic representation of visual objects. To investigate this, we developed two novel paradigms. Experiment 1 employed a vibratory hand prime that preceded a picture of either an object with a hand or a foot related action affordance (e.g., a cup or a soccer ball, respectively). In Experiment 2 we flipped the paradigm, whereby a vibratory stimulus to either the hand or the foot was used as the target, whereas the hand or foot objects were used as the prime. In both experiments, we hypothesized, based on modal theories of object representation, that when both a hand visual object and a hand vibration were present, processing benefits would occur in the form of faster reaction times, whereby the participant would be faster at indicating how they would interact with the object (Experiment 1) or detecting the vibratory stimulus (Experiment 2). In Experiment 2, there are two possible hypotheses for the foot objects. First, if their representations are integrated with foot related somatosensory contributions in a similar way as the hand objects and hand somatosensory contributions, then detection of vibration to the foot should be facilitated by the foot object prime. An alternative hypothesis, however, is that these objects will not be as strongly integrated with foot somatosensory contributions (a prediction supported by the findings of Esopenko, Borowsky, Cummine, & Sarty, 2008 who found somatosensory cortex activation only in response to arm object related semantic generation, and not leg object related semantic generation). Thus, priming of foot vibration detection by the foot object would not be expected. The present study is, to our knowledge, the first to directly address this question of whether the semantic representation of visual objects and the somatosensory system interact as a function of their primary modality of interaction.

2. Experiment 1

This experiment focuses on examining the impact of somatosensory stimulation on object processing based on whether the object is interacted primarily with the hand (e.g., grasping a cup) or primarily with the foot (e.g., kicking a soccer ball). We hypothesize that the hand objects should necessitate semantic processing in the somatosensory system and, thus, that somatosensory priming should lead to faster responses to these objects (see Connell, Lynott, & Dreyer, 2012). In contrast, responses to the foot objects should show no benefits of hand somatosensory priming as they lack hand related sensorimotor representations. We argue this on the basis of findings of Esopenko et al. (2008) who concluded (based on minimal shared activation between the leg motor localizer task and the semantic generation task) that there is decreased semantic knowledge associated with foot/leg related objects. However, if these objects *do* happen to evoke sensorimotor representations, they should be associated more strongly with the foot than with the hand (see Esopenko et al., 2012), and therefore the vibratory hand prime should not facilitate processing.

2.1. Methods

2.1.1. Participants

Twenty-eight university students who spoke English as their first language (M_{age} = 20.75, 25 right-handed) participated in this study. This study received ethical approval from the University of Saskatchewan Behavioral Research Ethics Board.

2.1.2. Apparatus

The experiment was completed on a standard Mac mini operating as a PC with Windows OS and *E*-Prime 2.0 software was used to program and run the experiment (Schneider, Eschman, & Zuccolotto, 2002, Psychology Software Tools, Inc., http://www.pstnet.com). Participants were seated approximately 100 cm from a 15-in. Compaq 7500 CRT monitor, on which the object pictures were presented. Directly in front of the participant on the same table as the computer was a 12-in. Alpine SWR-T12 Type-R subwoofer on which they placed their dominant hand, which served to provide the somatosensory prime (see Fig. 1). The subwoofer was interfaced to the E-Prime program on the computer via a Memphis PRX4.50 4-Channel amplifier. A LabTec AM-22 microphone interfaced with the E-Prime serial response box was triggered upon the participant's vocal response in order to obtain their reaction time (RT) for each trial.

2.1.3. Stimuli

Target objects consisted of colored photographs of 30 ‘hand’ action objects (e.g., a frying pan, a razor) and 30 ‘foot’ action objects (e.g., a soccer ball, a running shoe) presented randomly without replacement on a white background (see Appendix A). These stimuli were chosen based on the results of a pilot experiment that utilized graspable hand objects and non-graspable objects (e.g., an elephant). Results from this experiment found evidence of somatosensory priming for the hand objects, but not for the non-graspable objects, however participants had greater difficulty responding how they would interact with the non-graspable