Neuropsychologia 48 (2010) 774–781

Contents lists available at ScienceDirect

Neuropsychologia

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

Body schematics: On the role of the body schema in embodied lexical–semantic representations

Shirley-Ann Rueschemeyer[a,*], Christian Pfeiffer[a,b], Harold Bekkering[a]

[a] Radboud University, Donders Institute for Brain, Cognition and Behavior, Nijmegen, The Netherlands
[b] Freie Universität Berlin, Berlin, Germany

ARTICLE INFO

Article history:
Received 20 April 2009
Received in revised form 11 August 2009
Accepted 14 September 2009
Available online 24 September 2009

Keywords:
Embodiment
Semantics
Action
Body schema
Sense of body

ABSTRACT

Words denoting manipulable objects activate sensorimotor brain areas, likely reflecting action experience with the denoted objects. In particular, these sensorimotor lexical representations have been found to reflect the way in which an object is used. In the current paper we present data from two experiments (one behavioral and one neuroimaging) in which we investigate whether body schema information, putatively necessary for interacting with functional objects, is also recruited during lexical processing. To this end, we presented participants with words denoting objects that are typically brought towards or away from the body (e.g., *cup* or *key*, respectively). We hypothesized that objects typically brought to a location on the body (e.g., *cup*) are relatively more reliant on body schema representations, since the final goal location of the cup (i.e., the mouth) is represented primarily through posture and body co-ordinates. In contrast, objects typically brought to a location away from the body (e.g., *key*) are relatively more dependent on visuo-spatial representations, since the final goal location of the key (i.e., a keyhole) is perceived visually. The behavioral study showed that prior planning of a movement along an axis towards and away from the body facilitates processing of words with a congruent action semantic feature (i.e., preparation of movement towards the body facilitates processing of *cup.*). In an fMRI study we showed that words denoting objects brought towards the body engage the resources of brain areas involved in the processing information about human bodies (i.e., the extra-striate body area, middle occipital gyrus and inferior parietal lobe) relatively more than words denoting objects typically brought away from the body. The results provide converging evidence that body schema are implicitly activated in processing lexical information.

1. Introduction

Recently, embodied theories of language processing have put forth the proposal that brain areas involved in perception and action are also recruited during language processing (Barsalou, 2008; Fischer & Zwaan, 2008; Pulvermüller, 2001). For example, words and sentences denoting actions (e.g., *grasp*, *run*) or objects highly associated with actions (e.g., *cup*, *hammer*) have been shown to elicit activation in brain areas relevant for action planning and execution (Beauchamp & Martin, 2007; Chao & Martin, 2000), while language materials denoting objects highly associated with a specific smell (e.g., *garlic* or *cinnamon*) activate olfactory cortex, relevant for processing smells (Gonzalez et al., 2006).

In particular, action-related objects selectively activate a network of neural areas including the ventral premotor cortex (vPMC), inferior parietal cortex, posterior lateral temporal cortex and medial temporal cortex (Beauchamp & Martin, 2007; Chao & Martin, 2000; Saccuman et al., 2006; but see also Assmus, Giessing, Weiss, & Fink, 2007). These sensorimotor lexical representations have been shown to be highly sensitive to the way in which an object is used functionally. For example, although both the words *cup* and *bookend* denote man-made tools that can be easily hand-held, *cup* elicits greater levels of activation in action-relevant areas than *bookend*, presumably because one must move a cup continuously (in contrast to a bookend) to use it functionally (Rueschemeyer et al., in press; see also Bub, Masson, & Cree, 2008; Masson, Bub, & Newton-Taylor, 2008 for converging behavioral evidence). These results show that how an object is typically manipulated is critical in determining how the lexical representation of the object is processed in the brain, and further that embodied lexical representations are quite specific in the type of experiential information they reflect.

In the current paper we present data from two experiments (one behavioral and one neuroimaging) in which we investigate whether body schematic configurations, known to be critical for

* Corresponding author at: Donders Centre for Brain, Cognition and Behaviour, Centre for Cognition, Montessorilaan 3, 6525 HR, Nijmegen, The Netherlands.
E-mail address: s.rueschemeyer@donders.ru.nl (S.-A. Rueschemeyer).

0028-3932/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.neuropsychologia.2009.09.019

interactions with functional objects, are also recruited during lexical–semantic processing. The body schema is an on-line representation of the body in terms of posture and its extension in space (Head & Holmes, 1911; Holmes & Spence, 2004). It dynamically maps the current positions of body parts in relation to one another and interacts with motor systems to support action planning and execution (e.g., Parsons, 1994). Interestingly the body schema has been shown to temporarily extend beyond the physical realms of the body when tools are used (Iriki, Tanaka, & I, 1996; Maravita, Spence, & Driver, 2003; Maravita & Iriki, 2004). In other words, during tool-use, the body schema appears to become extended to incorporate physical attributes (e.g., length) of the tool. The tip of the tool, or the part of the tool which will create an action effect, becomes particularly relevant for these plastic extensions (Maravita & Iriki, 2004). Because both the physical extension (e.g. shape, length) and action-effector (e.g., distal part for a hammer, proximal part for hairspray) vary for different tools, it has been suggested that different tools extend the body schema in different ways (Arbib et al., 2009). This is particularly relevant for looking at the role of body schema in action planning, as action plans are known to rely heavily on action goals (Rosenbaum, Loukopoulos, Meulenbroek, Vaughan, & Englebrecht, 1995).

Clearly, different tools will extend and make use of body schema information in different ways. While a cup and a key may both extend the physical length of the hand (i.e., extend peripersonal space), the action goals of cups and keys are very different, and make very different demands on action planning. In preparing to use a cup, the user becomes implicitly aware of where the mouth is in relation to the hand, thus utilizing the body schema to guide one effector (the incorporated cup) to another (the mouth). In preparing to use a key, on the other hand, the user must visually detect the keyhole, and bring the hand holding to key to this location in peripersonal space, thereby creating an action plan with less reliance on the body schema than seen in the example of the cup. Embodied theories of language processing, as pointed out previously, state that internal simulations of actual interactions with functional objects (i.e., tools) are reflected in lexical–semantic representations. Thus in the current studies, we investigated whether different reliance on body schema (i.e., a representational system underlying action planning) in planning these real-world interactions are also reflected in lexical–semantic representations.

To this end, we presented participants with words denoting objects that are typically brought towards or away from the body when used (e.g., *cup* or *key*, respectively). In a behavioral study we tested the hypothesis that words denoting these different types of objects are associated with specific movement parameters. Previous research has shown that lexical and sentential meaning can modulate speed of response in action execution (e.g., Boulenger et al., 2006; Glenberg & Kaschak, 2002). Specifically, Glenberg and Kaschak (2002) introduced the action-sentence compatibility effect (ACE), which describes the observation that participants are faster to execute an action that is congruent rather than incongruent to the movement implied by a previous sentence (e.g., movement of hand towards body in response to the sentence "open the drawer" is faster than movement of the hand away from the body). This suggests (1) that action and language share neural resources, but also that (2) *specific* action parameters (i.e., movement in a specific direction), and not simply action in general is relevant for language representations (see also Tucker & Ellis, 2004). In the current study we investigated whether the ACE effect could be used to dissociate between single words denoting manipulable objects used with different action trajectories (i.e., towards vs. away from the body).

In addition to being associated with different movement parameters, we suggest that objects typically brought to a location on the body (e.g., cup) are relatively more reliant on body schema, since the final goal location of the cup (i.e., the mouth) is represented primarily through posture and body co-ordinates. In contrast, objects typically brought to a location away from the body (e.g., key) are relatively more dependent on visuo-spatial representations, since the final goal location of the key (i.e., a keyhole) is perceived visually. We tested this hypothesis in a neuroimaging experiment, in which we investigated whether brain areas known to support body schema are increasingly active when participants process words with putatively more body information (e.g., *cup* > *key*).

2. Behavioral study

2.1. Experimental methods

2.1.1. Participants

Nineteen right-handed, native Dutch students of the Radboud University participated in the study. All participants had normal or corrected to normal vision and no history of neurological disorders. Beforehand all participants were informed about the experimental procedures, were given practice trials and signed informed consent. Afterwards all students were awarded monetarily or with course credit for participating.

2.1.2. Stimuli

A total of 100 lexical stimuli were created for the experiment. 80 of the total 100 stimuli were real Dutch words, and comprised the critical experimental stimuli; the remaining 20 stimuli were Dutch pseudowords (PW) (i.e., phonotactically and orthographically legal letter strings with no meaning in Dutch) and served as filler items and catch trials (see procedures below). Critical stimuli belonged to one of two experimental conditions: (1) words denoting objects whose functional use requires movement towards a goal location on the body (Body Words: BW) or (2) words denoting objects whose functional use requires movement away from the body towards a goal location in the surrounding environment (World Words: WW). All denoted objects were thus functionally manipulable objects (i.e., they require manipulation in order to function), but they differ with respect to the direction of movement typically associated with their functional use. BW are brought towards the body for functional use (e.g., *cup*, *comb*), whereas WW are brought away from the body for functional use (e.g., *key*, *screwdriver*).

The 80 critical word stimuli were matched across word conditions (BW, WW) for word length (BW: mean = 6.7 letters, SD = 2.6; WW: mean = 6.3, SD = 2.04), frequency of use according to CELEX (BW: mean = 569, SD = 128; WW: mean = 513, SD = 118) and imageability according to participants' own ratings on a scale of 1–7 (BW: mean = 6.53, SD = 0.34; WW: mean = 6.50, SD = 0.50). Independent sample *t*-tests showed that values for the two-word group did not differ significantly in any of these parameters (all $ps > 0.1$).

2.1.3. Procedure

Stimulus words were presented as white letter strings with a font size of 36 in Arial Style on a black background. Stimuli were presented on a 19 in. display with a resolution of 800 × 600 pixels and a refresh rate of 100 Hz. The viewing distance was approximately 70 cm resulting a visual angle of about 13° (for the largest lexical letter string = 12 letters). Participants gave responses by button press with the index finger of the right hand. A custom-built button box on which three equidistant buttons were mounted served as response device.

Participants were seated comfortably in front of a computer monitor, with the button box in front of them. The button box contained 3 equidistant buttons arranged linearly in front of the participant such that participants had a far, middle and a near button. Each trial was initiated by the participant pressing the middle button. Participants were instructed to keep the middle button depressed until giving their final response (see further below). With the middle button depressed, every trial followed the same structure: first, a fixation cross was presented in the center of the screen for 400 ms. This was followed directly by an action cue (the letter A or B) which was shown for 500 ms, and which instructed participants as to which of the two other buttons on the button box they should press in response to the target word stimulus. For half of the participants the cue A indicated that the participant should move from the middle button to the button farthest away from them on the button box (i.e., away movement), while the cue B indicated that a movement should be made from the middle button to the closest of the three buttons (i.e., towards movement). For the other half of the participants the opposite was true. Following the action cue, participants saw a second fixation cross for 1000 ms, and then finally the target word. Participants were instructed to respond to the target word stimulus using the previously cued action if the word stimulus was a real Dutch word. In the event of a pseudoword participants were instructed to withhold the prepared response. Participants thus saw an action cue for all trials, but were required to respond only to trials in which the target word was a real word. Target words remained visible until participants responded, or for a maximum of 3000 ms. No feedback was provided during the experiment. The differences between the experimental procedure adopted here and that introduced initially by Glenberg and Kaschak (2002) were motivated primarily by two factors: (1) by having participants prepare responses before seeing word stimuli, action preparation served as