



A piece of the action: Modulation of sensory-motor regions by action idioms and metaphors

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ABSTRACT

The idea that the conceptual system draws on sensory and motor systems has received considerable experimental support in recent years. Whether the tight coupling between sensory-motor and conceptual systems is modulated by factors such as context or task demands is a matter of controversy. Here, we tested the context sensitivity of this coupling by using action verbs in three different types of sentences in an fMRI study: literal action, apt but non-idiomatic action metaphors, and action idioms. Abstract sentences served as a baseline. The result showed involvement of sensory-motor areas for literal and metaphoric action sentences, but not for idiomatic ones. A trend of increasing sensory-motor activation from abstract to idiomatic to metaphoric to literal sentences was seen. These results support a gradual abstraction process whereby the reliance on sensory-motor systems is reduced as the abstractness of meaning as well as conventionalization is increased, highlighting the context sensitive nature of semantic processing.

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Introduction

The idea that the conceptual system draws on sensory and motor systems has received considerable experimental support in recent years (see Barsalou, 2008; Gallese and Lakoff, 2005; Kiefer and Pulvermüller, 2011; Pulvermüller and Fadiga, 2010). This contrasts with the traditional view that all concepts are represented in an amodal, abstract format (Anderson, 1983; Bedny and Caramazza, 2011; Fodor, 1983; Mahon and Caramazza, 2008; Pylyshyn, 1984). Current debate concerns the precise nature of the relationship between concepts and perception/action. One question is whether the involvement of sensory-motor information is obligatory (because it is an essential part of semantic representation) or context-dependent (varying with factors such as task demands or expectations due to the nature of the stimuli). Figurative action language provides an interesting vehicle for addressing this issue as it allows comparisons between concrete verbs that are used to describe physical action (e.g., *grasp a hammer*), and use of the same verbs to convey an abstract idea by analogy with an action (*grasp an idea*). Involvement of sensory-motor areas in the processing of figurative action language would lend support to embodiment theories, which hold that even abstract concepts are grounded in sensory-motor systems (Gibbs, 2006; Glenberg et al., 2008).

Neuroimaging studies of figurative action language have yielded mixed results. Activation in the premotor cortex for literal action

sentences was reported by Aziz-Zadeh et al. (2006). They did not find motor activity for idiomatic/proverbial action phrases, such as ‘biting off more than you can chew’. Raposo et al. (2009) also did not find motor/premotor activation for figurative action sentences, but did find it for isolated action verbs and literal sentences, and did not find somatotopy (see also Postle et al., 2008). Boulenger et al. (2009), on the other hand, found somatotopic activation for figurative and literal action sentences involving leg and arm verbs. Activation of anterior inferior parietal lobe, a higher-level motor area, for literal and metaphoric action sentences, and modulation of primary motor cortex by metaphor familiarity, was reported by Desai et al. (2011). In a MEG study, Boulenger et al. (2012) found activation of their arm ROI (and a similar trend in a leg ROI) by figurative and literal arm and leg action sentences.

Activation in or near motion processing area MT+ for literal as well as figurative or fictive motion sentences (‘The man fell under her spell’) compared to non-motive sentences was found in three studies (Chen et al., 2008; Saygin et al., 2010; Wallentin et al., 2005). Finally, Lacey et al. (2012) reported activation of somatosensory regions by texture metaphors (‘She had a rough day.’) compared to abstract sentences (‘She had a bad day.’).

Thus, several studies have shown activation of sensory-motor areas during processing of figurative language, while some inconsistencies also exist. An important factor that may account for some of these differing results is the extent to which the figurative stimuli are conventionalized. Idioms like “spill the beans” are an example of figurative language in which collocated (frequently co-occurring) words become “frozen” as a whole phrase that functions as a single interpretive

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unit, with the individual words only remotely related to the meaning of the expression. Phrasal verbs (e.g., *run into*, *go about*) also convey idiomatic meaning through polysemy or combinatorial structure. In contrast, the interpretation of metaphors such as “all jobs are jails” depends on the meanings of the individual words and their linkage to other types of knowledge (Glucksberg, 2003). Although the boundary between idioms and metaphors is graded rather than absolute, there are many clear examples of the difference. Imaging studies of embodiment in figurative language have not compared idioms and metaphors; some have mixed idioms and metaphors together; and in some studies ‘idiom’ is used to refer to familiar metaphors.

Cacciari et al. (2011) conducted a TMS study comparing literal, metaphoric, and idiomatic motion sentences. They applied a TMS pulse over the leg motor area at the end of the sentence and measured motor evoked potentials (MEPs) in leg muscles. They found increased MEPs for literal and metaphoric sentences, but not for idiomatic sentences, suggesting context sensitivity in meaning access. It is not clear, however, whether higher-level motor areas such as the anterior inferior parietal lobule, reported in several studies of action processing (Desai et al., 2009, 2011; Goldberg et al., 2006; Noppeney et al., 2005; Rueschemeyer et al., 2010; Rueschemeyer et al., 2007) for both literal and metaphoric action sentences, participates in idiomatic action sentences, as only the primary leg motor area was examined in this study.

Here, we conducted an fMRI study comparing literal, (non-idiomatic) metaphoric, and idiomatic action sentences to abstract sentences. One possibility is that to process action words, engagement of sensory-motor areas is always needed, regardless of context or task demands. An alternative is context sensitivity, where the sensory-motor roots of meaning are accessed at varying levels of depth depending on context. A further alternative, representing the traditional view, is that all concepts are represented abstractly. Once a concept is learned from sensory-motor experiences, no access to sensory-motor systems is involved, as the conceptual system functions as an independent symbolic module. Similar activation in sensory-motor areas for the literal, metaphoric, and idiomatic sentences, all of which use an action verb, would suggest that the meaning of the verb is processed by accessing its motoric basis, regardless of context. A lower level of activation for more conventionalized language such as idioms would indicate a context-sensitive abstraction process.

Methods

Participants

Participants in the fMRI experiment were 27 healthy adults (15 women; average age 24.7 years, range 18–38), with no history of neurological impairment. One additional participant was removed due to low behavioral performance in the scanner (accuracy < 75%). Participants were native speakers of English, and were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971). Informed consent was obtained from each participant prior to the experiment, in accordance with a protocol sanctioned by the Medical College of Wisconsin Institutional Review Board. Participants were paid for participation.

Stimuli

Stimuli were sentences divided into four main conditions: literal action (Literal), non-idiomatic metaphoric action (Metaphor), idiomatic action (Idiom), and abstract sentence (Abstract). The stimuli were constructed in quadruples consisting of one sentence from each condition (examples in Table 1; complete listing provided in the Supplemental material part D).

The Literal sentence in each quadruple used a hand/arm action verb to depict a physical action. The corresponding Metaphor sentence used the same verb in a figurative but non-idiomatic manner, such that

Table 1

Example stimuli. ‘/’ separates the two parts used in presentation.

Literal	<i>The instructor is/grasping the steering wheel very tightly.</i>	<i>The craftsman/lifted the pebble from the ground.</i>
Metaphor	<i>The congress is/grasping the state of the affairs.</i>	<i>The discovery/lifted this nation out of poverty.</i>
Idiom	<i>The congress is/grasping at straws in the crisis.</i>	<i>The country/lifted the veil on its nuclear program.</i>
Abstract	<i>The congress is/causing a big trade deficit again.</i>	<i>The country/wanted the plan for a nuclear program.</i>

abstract meaning was conveyed. The Idiom sentence used the same action verb in an idiomatic manner. The idiomaticity of the Idiom sentences as well as the non-idiomaticity of the Metaphor sentences was verified using an online idiom dictionary compiled from the *Cambridge International Dictionary of Idioms* and the *Cambridge Dictionary of American Idioms* (<http://idioms.thefreedictionary.com/>). The Abstract sentence used an abstract verb (with no direct associations with physical actions). The agent in each sentence was chosen to imply either a literal or abstract/figurative interpretation of the verb. For Metaphor, Idiom, and Abstract sentences, this agent was an entity that makes literal physical actions unlikely (e.g., *the question*, *the business*). The Literal sentences, in contrast, always used a person (*the firefighter*, *the janitor*) as an agent. As in our previous study (Desai et al., 2011), this was done to facilitate nonliteral interpretation of the action verbs for Metaphor and Idiom sentences (e.g., when processing “The business is pinching pennies,” a nonliteral interpretation is encouraged when *pinching* is encountered).

There are numerous constraints on the verbs and the nouns that can be used in each sentence. Most idioms only allow limited flexibility in their form in order to be interpreted naturally and idiomatically. Hence, we opted to allow some syntactic variation in the sentences belonging to the same quadruple in order to make stimuli natural to the extent possible while maintaining similar sentence length.

Forty quadruples were created, producing 40 sentences in each of the Literal, Metaphor, Idiom, and Abstract conditions. Eighty Nonsense sentences (e.g., *The speech strangled all the snow*) were created by combining action and abstract verbs with inappropriate nouns. Twenty Filler sentences (used to obscure the quadruple construction of stimuli) and 40 false font sentences were also used. The Filler sentences used variable syntax, included both action and abstract verbs, and contained both literal and figurative sentences (*Her dog is running after the rabbit*; *He finally managed to kick the habit*; *He learned a new skill to benefit the company*). The conditions of interest were matched in the number of words, syllables, phonemes, and letters (Table 2). It was not possible to match the conditions on frequency (average CELEX log per million frequency of the content words) while maintaining similar processing difficulty (see the next section). The Metaphor condition had similar frequency to the other three conditions, but the pairwise differences between the other conditions (Literal, Idiom, Abstract) were significant (all $p < 0.001$; two-tailed t-tests).

Table 2

The mean (s.d.) number of words, syllables, phonemes, and letters, as well as the average log per million frequency of the content words in the sentences in the conditions of interest.

Condition	#Word	#Syll	#Phon	#Lett	Freq
Literal	7.8 (1.3)	11.0 (1.8)	29.2 (4.8)	37.0 (5.8)	1.6 (0.4)
Metaphor	7.8 (1.2)	11.1 (2.0)	29.0 (5.0)	36.2 (6.1)	2.0 (0.3)
Idiom	7.7 (1.3)	10.3 (2.3)	27.8 (5.5)	34.9 (6.8)	1.9 (0.3)
Abstract	7.7 (1.3)	11.4 (2.4)	29.7 (5.5)	35.1 (6.2)	2.1 (0.3)

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