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The effects of an action's "age-of-acquisition" on action-sentence processing☆,☆☆

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ABSTRACT

How does our brain allow us comprehend abstract/symbolic descriptions of human action? Whereas past research suggested that processing action language relies on sensorimotor brain regions, recent work suggests that sensorimotor activation depends on participants' task goals, such that focusing on abstract (vs. concrete) aspects of an action activates "default mode network" (rather than sensorimotor) regions. Following a Piagetian framework, we hypothesized that for actions acquired at an age wherein abstract/symbolic cognition is fully-developed, even when participants focus on the concrete aspects of an action, they should retrieve abstract-symbolic mental representations. In two studies, participants processed the concrete (i.e., "how") and abstract (i.e., "why") aspects of late-acquired and early-acquired actions. Consistent with previous research, focusing on the abstract (vs. concrete) aspects of an action resulted in greater activation in the "default mode network". Importantly, the activation in these regions was higher when processing later-acquired (vs. earlier acquired) actions—also when participants' goal was to focus on the concrete aspects of the action. We discuss the implications of the current findings to research on the involvement of concrete representations in abstract cognition.

Introduction

Much of human activity revolves around communicating with other humans using the symbolic form of language; and a large portion of human linguistic-symbolic communication entails an exchange of information concerning the actions of other humans (Dunbar, 2004). This exchange of information concerning human actions plays an important role in shaping our behavior; for example, if you are told that "Donald stole the candy from the baby's mouth", you may be less likely to vote for Donald for presidency. How does our brain allow us to comprehend and respond to such abstract and symbolic descriptions of human action? In recent years, two major alternatives have been suggested.

According to the "embodied cognition" framework (e.g., Barsalou, 1999; Niedenthal et al., 2005), humans' ability to understand action sentences is dependent on the retrieval of concrete sensory and motor representations. In a nutshell, this account suggests that in order to decipher the meaning of an abstract message such as "Donald stole the candy", we must re-create the concrete perceptual and motor experiences associated with taking candy from a baby (for example, imagining grabbing the lollipop and overpowering the baby in a tug o' war; then gleefully running away, blonde hair scattered by the wind). Furthermore, embodiment theory suggests that humans are able to re-create these perceptual and motor states by re-activating neural systems that are involved in actual action and perception (e.g., Barsalou, 1999).

Indeed, much neuroscientific research has been brought forth to support these predictions. For example, research has shown that motor verbs (e.g., Hauk et al., 2004) and sentences (e.g., Tettamanti et al., 2005) activate the motor cortex in a somatotopic manner (i.e., hand-related words activate regions associated with hand movement, leg-related words activated regions associated with leg movement, and so forth). Furthermore, some neuropsychological evidence likewise suggested that the motor cortex may play a causal role in processing action-related semantics; for example, lesions to hand-related motor-primary motor cortex regions were shown to be associated with disrupted processing of action-related semantics using a stimuli set that included mostly hand-related sentences (Kemmerer et al., 2012).

However, it is important to note that the role of the motor system in action language processing remains under considerable debate. For example, a meta-analysis of action language processing did not find statistically significant activations in premotor and primary motor cortex regions (Watson et al., 2013). Furthermore, it has been shown that

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non-words can produce reliable activation in primary and premotor cortex regions, and that motor activation during action word processing may stem from the computation of ortho-phonological properties that are involved in deciphering grammatical classes (de Zubicaray et al., 2013). Finally, a study investigating the consequences of lesions to effector-specific motor regions did not find evidence for effector-specific semantic impairments (Arevalo et al., 2012).

In contrast to embodied cognition theory, traditional accounts of human cognition (e.g., Fodor, 1983) have long argued that the neural and cognitive systems that are responsible for abstract cognition—as the type involved in language comprehension—are functionally segregated from the systems that are responsible for processing concrete sensory and motor experiences. These views are supported by much research (e.g., Binder et al., 2009; Stephens et al., 2010) that shows that processing linguistic-symbolic meaning activate a set of regions that include the ventromedial prefrontal cortex (vmPFC), dorsomedial prefrontal cortex (dmPFC), lateral temporal cortex, temporo-parietal junction (TPJ), posterior cingulate cortex (PCC), and superior frontal gyrus, often collectively referred to as "the default mode network" (Raichle et al., 2001). This network of regions is also recruited when thinking about people's goals and mental states (e.g., Frith and Frith, 2006; Van Overwalle, 2009; Spunt et al., 2011), as well as in other abstract cognitive tasks such as considering future (e.g., Schacter et al., 2007; Gilead et al., 2013b) and counter-factual events (e.g., Van Hoeck et al., 2012). Importantly, this network has very little to no overlap with the neural systems that subserve sensori-motor processing. As such, these findings were taken to support the hypothesized classic distinction between abstract/symbolic cognition and concrete/sensory-motor cognition (e.g., Binder et al., 2009).

In an attempt to integrate the theorizing and research in "classic" and "embodied" theories of semantics, recent work has shown that when people focus on the concrete aspects of an action (e.g., think about "*how* Danny ate the bread"), they indeed activate sensory and motor regions; however, importantly, this is not the case when they focus on the more abstract aspects of the *same* action (e.g., think about "*why* Danny ate the bread"). Instead, when individuals focus on abstract aspects of the action they consistently and robustly activate the "default mode network" regions involved in social-cognitive and linguistic-symbolic processing (Spunt and Adolphs, 2014; Spunt et al., 2010, 2011; Spunt and Lieberman, 2012, 2013; Gilead et al., 2013a). Thus, according to this line of findings, the retrieval of sensory-motor representation may not be a necessary part of language comprehension, but rather, is dependent on the goals and processing mode of the perceiver.

In the current research we wish to build on this prior work (e.g., Spunt and Adolphs, 2014; Spunt et al., 2010, 2011; Spunt and Lieberman, 2012, 2013; Gilead et al., 2013a) and go one step forward, to suggest that for some actions, focusing on *concrete* aspects still calls upon *abstract*-symbolic mental representations. This is because many human actions are so intertwined with their symbolic significance, such that trying to think of the concrete aspects of these actions will nonetheless bring to mind abstract representations. Specifically, we suggest that one dimension that plays an important role in determining whether an action is represented abstractly or concretely is the age at which the person learned about this action.

Consider the case of a child learning to play drums at the age of six. In the terminology of the Piagetian framework (e.g., Inhelder and Piaget, 1958) this child is still in the "preoperational stage" of cognitive development: his/her symbolic thinking capacities have still not completely developed, and s/he is likely to focus on the concrete, sensory-motor properties of drum playing. However, if this child learns how to play the drums at the age of twelve (i.e., in Piagetian terms, a child that has passed the "concrete operational stage", and can now perform abstract, "formal operations"), the acquisition of drum-playing behavior is likely to recruit more abstract cognition. For example, at this later age s/he is more likely to focus on the more abstract social significance of the action (it makes me look cool, it is part of my overarching goal to become a musician) and rely on symbolic representations to learn the skill (e.g., follow explicit rules and musical notation). Because of these major differences, it is possible that when one learns to play the drums at a later (rather than earlier) age, the abstract aspects of drum-playing become part and parcel of the mental representation of this action. Likewise, "drinking juice", an action likely acquired at an early age, can perhaps be processed without bringing to mind any abstract and symbolic meaning. In contrast, "drinking beer", is likely to be acquired at an age at which a person would be already aware of its symbolic meaning in the social world. As a consequence, one's knowledge concerning this action may be inseparable from more abstract cognitive processing.

Based on this reasoning, we suggest that even when people consider "how" later-acquired actions are performed, they will nonetheless tend to process the abstract significance of this action—as indexed by the elevated degree of activity in neural regions that are typically recruited in processing abstract aspects of actions (namely, the regions that are typically activated when participants think "why" an action is performed).

The notion according to which "age-of-acquisition" could play an important role in cognitive processing has been supported in research showing that early-acquired words are processed more quickly than later-acquired words (e.g., Turner et al., 1998), possibly due to their greater familiarity/frequency (Lewis et al., 2001) or greater imageability (Wilson et al., 2013; but see Izura et al., 2011). Furthermore, theories of the structure of semantic networks (e.g., Steyvers and Tenenbaum, 2005) suggest that our semantic system may be built in a hierarchical manner, such that later-acquired semantics are built on the scaffolds of earlier-acquired semantics. However, despite the recognition of the importance of age-of-acquisition in research into lexical and semantic processing, previous work has not investigated how the age of acquisition of an action affects the processing of action sentences—and whether the age of acquisition of an action moderates the degree to which action sentence processing relies on concrete vs. abstract mental representations.

In order to investigate these questions we conducted two studies in both of which participants focused on the concrete (i.e., "how") vs. abstract (i.e., "why") aspects of actions that they acquired relatively earlier or later in life. Consistent with previous work, we predicted that default network activity will be relatively higher when participants thought about "why" (vs. "how") an action is performed. Furthermore, and most importantly, we predicted that default network activity will be higher for later-acquired (vs. earlier-acquired) actions, regardless of whether participants focused on "how" or "why" an action is performed.

Methods

Stimulus ratings

We created a list of 100 behaviors by complementing a verb with two different objects. The stimuli were constructed such that one of the verb-object pairings described a behavior that we suspected would be acquired at a relatively younger age (i.e., "scratching a *mosquito's bite*") and the second verb-object pair described a behavior that we suspected would be acquired later in life (i.e., "scratching *a lottery ticket*"). We used extensive pre-testing to establish the supposed differences in age of acquisition between the two groups of verb-object pairs. In the pre-test, we also obtained ratings on seven potential correlates of age of acquisition, such as familiarity, imageability and complexity.

In the pre-test, forty psychology students from Tel-Aviv University rated the stimuli along eight different dimensions. They provided an estimate of the age in which they first performed the described activity. In case they had never performed the activity they did not specify the age of acquisition. Participants also rated the activities along the following dimensions: frequency of performing the activity (1 = at least once a