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The influence of event-related knowledge on verb-argument processing in aphasia

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ABSTRACT

Event-related conceptual knowledge outside the language system rapidly affects verb-argument processing in unimpaired adults (McRae and Matsuki, 2009). Some have argued that verb-argument processing is in fact reducible to the activation of such event-related knowledge. However, data favoring this conclusion have come primarily from college-aged healthy adults, for whom both linguistic and conceptual semantic processing is fast and automatic. This study examined the influence of event-related knowledge on verb-argument processing among adults with aphasia ($n=8$) and older unimpaired controls ($n=60$), in two self-paced reading studies. Participants read sentences containing a plausible verb-argument combination (*Mary used a knife to chop the large carrots before dinner*), a combination that violated event-related world knowledge (*Mary used some bleach to clean the large carrots before dinner*), or a combination that violated the verb's selectional restrictions (*Mary used a pump to inflate the large carrots before dinner*). The participants with aphasia naturally split into two groups: Group 1 ($n=4$) had conceptual-semantic impairments (evidenced by poor performance on tasks like Pyramids & Palm Trees) but reasonably intact language processing (higher Western Aphasia Battery Aphasia Quotients), while Group 2 ($n=4$) had intact conceptual semantics but poorer language processing. Older unimpaired controls and aphasic Group 1 showed rapid on-line disruption for sentences with selectional-restriction violations (SRVs) and event-related knowledge violations, and also showed SRV-specific penalties in sentence-final acceptability judgments (Experiment 1) and comprehension questions (Experiment 2). In contrast, Group 2 showed very few reliable differences across conditions in either on-line or off-line measures. This difference between aphasic groups suggests that verb-related information and event-related knowledge may be dissociated in aphasia. Furthermore, it suggests that intact language processing is more critical for successful verb-argument integration than intact access to event-related world knowledge. This pattern is unexpected if verb-argument processing is reducible to activation of event-related conceptual knowledge.

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1. Introduction

How world knowledge influences language understanding is a topic of long-standing debate in the cognitive science and psycholinguistic literature. Early approaches to this question were inspired by the existence of specialized systems for the perception of visual and other stimuli (such as feature detectors in primary visual cortex (Hubel and Wiesel, 1959), and the "what" and "where" visual pathways (Goodale and Milner, 1992; Haxby et al., 1991)). The models inspired by these approaches claimed that language was initially processed by similarly-specialized cognitive modules (Fodor, 1983; Frazier, 1987; Katz and Fodor, 1963), with general world knowledge being used only later, after language-specific processes have completed their work.

More recent work rejects this view. Results from a variety of experimental paradigms suggest that world knowledge may have a very rapid effect on language comprehension, as evidenced by event-related potentials (e.g., Bicknell et al., 2010), reading (e.g., Matsuki et al., 2011), and the visual-world paradigm (e.g., Kamide et al., 2003). These findings, in combination with evidence that world knowledge drives verb-argument processing (e.g. Bicknell et al., 2010) are consistent with the hypothesis that everything we know about verbs is reducible to world knowledge.

However, there is growing evidence that there may be important processing differences between verb knowledge and world knowledge, even though they are not processed by separate modules and verb knowledge might develop from abstractions

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across world knowledge (see Warren et al., in preparation). In the current paper, we use *verb knowledge* to refer to knowledge of a verb's core semantic and combinatorial requirements – for example, that *drink* entails both an agent and a theme (a person who drinks and an object being drunk) and requires that its object be liquid. In contrast, world knowledge is broad, experience-based knowledge about the objects and events that are described using language – for example, that humans and dogs typically drink different things, and the some liquids are much more likely to be drunk than others (for example, tea versus rubbing alcohol). The current paper addresses the relationship between event- and verb-knowledge during reading comprehension. In the following, we review previous evidence relevant to deciding whether these kinds of knowledge are represented or processed differently or similarly.

Hagoort et al. (2004) compared ERPs and fMRI activity elicited in response to sentences that violated readers' world knowledge about the world versus sentences that contained a semantically mismatching subject-predicate adjective combination (e.g. *The Dutch trains are white and very crowded* versus *The Dutch trains are sour and very crowded*). BOLD response in fMRI and ERP waveforms were almost identical for the world-knowledge and semantic-mismatch conditions, with only oscillatory EEG responses differing. Hagoort and colleagues concluded that the brain does not distinguish between world knowledge and lexical semantic information. The embodied approach to cognition (e.g., Barsalou, 2008; Pulvermüller, 2013) argues for a similar view, claiming that all cognition (including language) is grounded in and cannot easily be distinguished from sensory and motor representations in the mind and brain. These approaches all agree that language and world knowledge are likely not distinct, and they also do not give priority to language-specific knowledge in language comprehension.

The processing of verbs and verb-argument combinations have been central to the question of how distinct language and non-language processes are, and whether language-specific knowledge has a special role in guiding language understanding. For example, the processing of action verbs has been one of the primary sources of evidence for embodied approaches to language representation. fMRI studies show that literal (Hauk et al., 2004) as well as figurative uses of verbs (Boulenger et al., 2009) are associated with activation of motor and pre-motor areas corresponding to the body parts used to carry out the actions described by those verbs. In addition, the degree of effort implied by a predicate (throwing a frisbee vs. throwing a javelin) also appears to mediate the degree to which different cortical regions are recruited, with greater effort being associated with greater BOLD response in both left inferior frontal gyrus and middle frontal gyrus (Moody and Gennari, 2010).

Interestingly, the processing of verb-argument combinations has provided evidence for both sides of this debate. For instance, in a reading study of college-aged healthy adults, Warren and McConnell (2007) showed that verb-argument combinations that violate a verb's core selectional restrictions (such as *Mary used a pump to inflate the large carrots*) elicited earlier-emerging and longer-lasting disruption than combinations which violated world knowledge about likely events and participants (such as *Mary used bleach to clean the large carrots*), even when such combinations were rated very unlikely to occur in the real world. Rayner et al. (2004) found similar results in a separate reading study of college-aged adults, and Warren et al. (2008) found that the early penalty for an SRV persisted even when sentences were placed in fictional contexts which should have rendered the violations sensible (e.g., *Harry taught the bread* in the context of a paragraph about wizards bewitching objects and interacting with them as if they were animate).

Parallel to these findings, Paczynski and Kuperberg (2012) found different ERP responses among college-aged adults to SRVs (in this case, animacy restrictions on arguments) and violations of real-world expectations about likely verbal arguments. Both types of violations elicited an N400 response, but the SRV elicited an additional P600 response. Furthermore, having semantic associates of the critical word in the preceding linguistic context attenuated the N400 response to the world-knowledge violation, but did not attenuate either the N400 or P600 response to the verb animacy violation.

In addition to this evidence from rapid verb-argument combination, evidence from visual-world studies suggests that verb-specific knowledge may play a special role in anticipating upcoming verbal arguments. Boland (2005) showed that college-aged listeners gazed anticipatorily at both likely and unlikely indirect objects when the verb required an indirect object. For example, they looked at a picture of a toddler when hearing *The newspaper was difficult to read, but the mother suggested it anyway to …*, even though toddlers are highly unlikely indirect objects (recipients) in this context.

These findings point to the importance of verb-specific knowledge (such as semantic restrictions on potential arguments) in rapid understanding of verb-argument combinations. They also suggest that such knowledge may play a special role in comprehension, facilitating prediction or rapid integration or both prediction and integration of verbal arguments that fit the verb's core semantic restrictions.

In contrast to these findings, there is also evidence suggesting that verb-argument processing is not accomplished with reference to special verb-specific knowledge, but instead draws critically on general world knowledge about events. For example, in a study of college-aged adults, Bicknell et al. (2010) found faster reading times for likely verbal objects (*The journalist checked the spelling*) than for unlikely verbal objects (*The mechanic checked the spelling*) as well as an N400 for unlikely objects. Both likely and unlikely objects are compatible with the verbs' selectional restrictions, suggesting that a different source of knowledge (like event-related world knowledge) must be responsible for these differences. Furthermore, a separate lexical-priming study showed that the semantic association between the agent nouns (journalist/mechanic) and the critical object (spelling) was comparable across conditions, suggesting that facilitation of the likely object was due to activation of event-related knowledge by the agent-verb combination rather than simple associative priming.

In a similar vein, Matsuki et al. (2011) found that college-aged adults were faster to read likely objects than unlikely objects in sentences similar to those tested by Warren and McConnell (2007). In early reading measures, people were slower to read *hair* following *Donna used the hose to wash* than following *Donna used the shampoo to wash*. Again, this effect did not appear to be driven by lexical associations between the verb (*wash*) and the preverbal instrument (*hose/shampoo*): a separate priming experiment found comparable priming between these words across conditions.

Complementing this evidence suggesting that event-related knowledge facilitates rapid integration of likely objects, there is also evidence that event-related knowledge may guide the anticipation of likely upcoming verb arguments. In a visual-world study, Kamide et al. (2003) found that college-aged adults gazed at objects which are not only compatible with a verb's semantic constraints but are likely event participants, given the agent. Upon hearing *The girl rode the,* listeners were more likely to gaze at a carousel than an equally ride-able motorcycle (and vice versa when hearing *The man rode the*).

These findings point to the important role that world knowledge about typical events and event participants plays in the rapid understanding of verb-argument combinations. This knowledge, stored in semantic memory and activated in response to words