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Abnormal dynamics of activation of object use information in apraxia: Evidence from eyetracking

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ABSTRACT

Action representations associated with object use may be incidentally activated during visual object processing, and the time course of such activations may be influenced by lexical–semantic context (e.g., Lee, Middleton, Mirman, Kalénine, & Buxbaum (2012). Journal of Experimental Psychology: Human Perception and Performance, 39(1), 257–270). In this study we used the "visual world" eye-tracking paradigm to examine whether a deficit in producing skilled object-use actions (apraxia) is associated with abnormalities in incidental activation of action information, and assessed the neuroanatomical substrates of any such deficits. Twenty left hemisphere stroke patients, ten of whom were apraxic, performed a task requiring identification of a named object in a visual display containing manipulation-related and unrelated distractor objects. Manipulation relationships among objects were not relevant to the identification task. Objects were cued with neutral ("S/he saw the…."), or action-relevant ("S/he used the….") sentences. Non-apraxic participants looked at use-related non-target objects significantly more than at unrelated non-target objects when cued both by neutral and action-relevant sentences, indicating that action information is incidentally activated. In contrast, apraxic participants showed delayed activation of manipulation-based action information during object identification when cued by neutral sentences. The magnitude of delayed activation in the neutral sentence condition was reliably predicted by lower scores on a test of gesture production to viewed objects, as well as by lesion loci in the inferior parietal and posterior temporal lobes. However, when cued by a sentence containing an action verb, apraxic participants showed fixation patterns that were statistically indistinguishable from non-apraxic controls. In support of grounded theories of cognition, these results suggest that apraxia and temporal–parietal lesions may be associated with abnormalities in incidental activation of action information from objects. Further, they suggest that the previously-observed facilitative role of action verbs in the retrieval of object-related action information extends to participants with apraxia.

1. Introduction

1.1. Apraxia

Limb apraxia (hereafter, simply "apraxia") is a disorder of complex skilled action not attributable to weakness, incoordination, or other elemental sensory or motor impairments. It occurs in approximately 50% of people who have suffered left hemisphere cerebral vascular accidents (LCVA) (Barbieri & De Renzi, 1988; Zwinkels, Geusgens, Sande, & Heugten, 2004). Classic accounts distinguish two major subtypes of apraxia, termed ideational and ideomotor. Ideomotor apraxia is frequently assumed to affect the accuracy of gesture pantomime and imitation due to abnormalities in joint angles and limb trajectories, and uncoupling of the spatial and temporal aspects of movement (Haaland, Harrington, & Knight, 1999; Smania et al., 2006; Smania, Girardi, Domenicali, Lora, & Aglioti, 2000). Ideational apraxia is traditionally distinguished on the basis of tool misuse errors on single and multiple-objects tasks (see Vanbellingen & Bohlhalter, 2011, for review). However, in practice, these distinctions have been difficult to validate. Deficits on pantomime tasks and impairments in real object use have been shown to correlate significantly in a positive direction (Randerath, Li, Goldenberg, & Hermsdorfer, 2009); furthermore, individuals with apraxia make similar types of errors on both tasks (Clark et al., 1994; Mcdonald, Tate, & Rigby, 1994; Poizner et al., 1995).

A long history in the apraxia literature attributes object misuse errors to impaired "action semantics", specifically, impaired knowledge of the manner in which particular objects are manipulated

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(De Renzi & Lucchelli, 1994; Heilman, Rothi, & Valenstein, 1982; Morlaas, 1928; Stamenova, Roy, & Black, 2010, see Bouillaud, 1825; Lordat, 1843, for similar proposals for articulation in aphemia). This comports with accounts of conceptual knowledge proposing that conceptual information is distributed across the same network of sensory and motor attribute domains activated when the information was first acquired (Allport, 1985; Barsalou, 2008; Stamenova et al., 2010; Warrington & McCarthy, 1987; Warrington & Shallice, 1984; see also Damasio, 1990; Shallice, 1988, but see Garcea, Mary, & Bradford, 2013 and Mizelle & Wheaton, 2010 for different views). In fact, consistent with a conceptual deficit, many stroke patients with apraxia are deficient in the recognition of skilled hand-object interactions and object-related hand postures (Buxbaum, Johnson-Frey, & Bartlett-Williams, 2005; Buxbaum, Kyle, Grossman, & Coslett, 2007; Buxbaum, Sirigu, Schwartz, & Klatzky, 2003; Buxbaum, 2001; Sirigu et al., 1995, 1996), and have difficulty learning new object-related gestures (Faglioni, Basso, Botti, Aglioti, & Saetti, 1990; Rothi & Heilman, 1985). For example, it has been shown that apraxics have difficulty matching familiar objects with the hand postures appropriate for their use (Buxbaum et al., 2003), or matching objects based on the similarity of their associated functional actions (Buxbaum & Coslett, 1998). In contrast, apraxics perform normally in producing or recognizing hand postures appropriate for grasping objects based on their structural properties (shape and size) (Buxbaum et al., 2003).

Object use and object pantomime deficits typically occur after lesions to left inferior parietal cortex (IPL) (Buxbaum et al., 2007, 2003; Haaland, Harrington, & Knight, 2000; Heilman et al., 1982; Randerath, Goldenberg, Spijkers, Li, & Hermsdorfer, 2010), although apraxia has also been observed after lesions in premotor areas, including middle frontal and inferior frontal gyri (Goldenberg, 2009; Haaland et al., 2000; Heilman et al., 1982). Lesions to left IPL as well as the posterior middle temporal gyrus (pMTG) also impair the recognition of familiar object use actions (Kalénine, Buxbaum, & Coslett, 2010). These regions overlap those that are activated in functional neuroimaging studies of manipulation knowledge (e.g., Boronat et al., 2005; Kalénine et al., 2010; Kellenbach, Brett, & Patterson, 2003) and object-related movements (see Caspers, Zilles, Laird, & Eickhoff, 2010 and Watson, Cardillo, Ianni, & Chatterjee, 2013 for meta-analyses).

A relatively understudied issue concerns the mechanisms underlying impaired action knowledge in apraxics. It has been shown that apraxic patients' knowledge of object-associated use-actions (i.e., manipulation knowledge) may be selectively impaired despite preservation of knowledge of objects' functional purpose (Buxbaum, Veramonti, & Schwartz, 2000; Buxbaum & Saffran, 2002). However, based on prior findings, it is not clear whether use-action knowledge in apraxics is entirely degraded, or whether it is relatively intact but difficult for apraxics to access. Similar distinctions between representational access and integrity have been investigated in a range of brain-damaged patients, including those with blindsight (e.g., Poppel, Held, & Frost, 1973), hemispatial neglect (e.g., Marshall & Halligan, 1988), aphasia (e.g., Blumstein, Milberg, & Shrier, 1982; Mirman & Britt, 2014), dyslexia (Colangelo, Stephenson, et al., 2003) and semantic deficits (e.g., Campanella, Mondani, et al., 2009; Predovan, Gandini, et al., 2014; Reilly, Peelle, et al., 2011). In a number of these cases, impaired performance in explicit behavioral tasks is accompanied by relatively intact performance when assessed implicitly. For example, the performance of patients with neglect or extinction may be influenced by visual stimuli despite lack of conscious detection (e.g., Ladavas, Paladini, & Cubelli, 1993; Di Pellegrino, Rafal & Tipper, 2005; Rafal, Ward, & Danziger, 2006; Riddoch, Riveros, & Humphreys, 2011), and Wernicke's aphasics' lexical processing can be primed by a semantically related word despite their poor performance in explicit semantic relatedness judgment tasks (Blumstein et al., 1982; Milberg & Blumstein, 1981). These findings suggest that impairment in overt behavioral responses may not reliably assess the status of conceptual knowledge.

The integrity and accessibility of conceptual knowledge in stroke patients has also been interpreted on the basis of their performance in conditions of priming or cuing (e.g., Auchterlonie, Phillips, & Chertkow, 2002; Brambati, Peters, Belleville, & Joubert, 2012; Corbett, Jefferies, & Lambon Ralph, 2011; Jefferies, Baker, Doran, & Ralph, 2007; Jefferies, Patterson, & Lambon Ralph, 2008; Jefferies & Lambon Ralph, 2006; Tyler & Ostrin, 1994; Warrington & Shallice, 1979). In such cases, improvement with increased 'retrieval cues' is often held to indicate that conceptual representations are relatively intact but poorly accessible, and absence of cueing effects are taken to indicate the representations are completely lost (Corbett et al., 2011; Jefferies et al., 2007, 2008; Jefferies & Lambon Ralph, 2006). As will be described below, we can make use of such hypothesized distinctions to shed light on the nature of the action knowledge deficit in apraxia. First, however, we will review relevant studies with healthy participants demonstrating incidental activation of action information during object processing and modulation of such activations by retrieval cues.

1.2. Action influences object identification in healthy participants

Several studies with healthy participants have shown that manual action information may be accessed during object processing even when action is entirely incidental to task demands. Strong evidence for this claim comes from studies using the "Visual World Paradigm" (VWP), a paradigm widely used in healthy participants (Huettig & Altmann, 2005, 2007) as well as patient populations (Kalénine, Mirman, & Buxbaum, 2012; Mirman & Graziano, 2012; Mirman, Yee, Blumstein, & Magnuson, 2011; Myung et al., 2010; Yee, Blumstein, & Sedivy, 2007). In a typical VWP study, participants' eye movements are recorded while they point to or click on an auditorially-cued target picture shown as part of a visual display. A related distractor ("competitor") that shares attributes of interest with the target is typically also displayed, along with unrelated distractor pictures that do not share these attributes (e.g., Huettig & Altmann, 2005; Mirman & Magnuson, 2009; Yee & Sedivy, 2006). For example, for a given target object such as 'typewriter', the distractors might include an object sharing action attributes with the target (the related distractor, e.g., 'piano') as well as objects unrelated to the target in action (the unrelated distractor, e.g., 'couch'; examples taken from Myung, Blumstein, & Sedivy, 2006). With such paradigms, it has been shown that participants tend to fixate more on distractors similar to the targets in manipulation actions than on unrelated distractors (Lee, Middleton, Mirman, Kalénine, & Buxbaum, 2012; Myung et al., 2006). As the related and the unrelated distractors in the same display are typically matched on other critical features (e.g., visual complexity, familiarity, general semantic similarity, etc.), fixations on the related relative to unrelated distractors (the "competition effect") can be used to infer incidental activation of action information.

Furthermore, it has been shown that incidental access to action information may be 'primed' or modulated by several types of cues. For example, in a recent VWP study (Lee et al., 2012), the activation time course of action information was modulated by provision of an action verb context (e.g., he "used the _____"), leading to an earlier-emerging competition effect or faster target detection. Furthermore, target identification is influenced by implicit action relationships between objects in blocked cyclic paradigms associated with a build-up of semantic interference (Campanella & Shallice, 2011a, 2011b) as well as during rapid presentation (Roberts & Humphreys, 2011) and in visual scenes requiring perceptual integration (Green & Hummel, 2006).