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Research report

The processing of semantic relatedness in the brain: Evidence from associative and categorical false recognition effects following transcranial direct current stimulation of the left anterior temporal lobe

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A B S T R A C T

A dominant view of the role of the anterior temporal lobe (ATL) in semantic memory is that it serves as an integration hub, specialized in the processing of semantic relatedness by way of mechanisms that bind together information from different brain areas to form coherent amodal representations of concepts. Two recent experiments, using brain stimulation techniques along with the Deese–Roediger–McDermott (DRM) paradigm, have found a consistent false memory reduction effect following stimulation of the ATL, pointing to the importance of the ATL in semantic/conceptual processing. To more precisely identify the specific process being involved, we conducted a DRM experiment in which transcranial direct current stimulation (anode/cathode/sham) was applied over the participants' left ATL during the study of lists of words that were associatively related to their non-presented critical words (e.g., *rotten, worm, red, tree, liqueur, unripe, cake, food, eden, peel*, for the critical item *apple*) or categorically related (e.g., *pear, banana, peach, orange, cantaloupe, watermelon, strawberry, cherry, kiwi, plum*, for the same critical item *apple*). The results showed that correct recognition was not affected by stimulation. However, an interaction between stimulation condition and type of relation for false memories was found, explained by a significant false recognition reduction effect in the anodal condition for associative lists that was not observed for categorical lists. Results are congruent with previous findings and, more importantly, they help to clarify the nature and locus of false memory reduction effects, suggesting a differential role of the left ATL, and providing critical evidence for understanding the creation of semantic relatedness-based memory illusions.

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1. Introduction

The involvement of the anterior temporal lobe (ATL) in human memory functioning is now well established from a variety of sources of evidence, including computational models (McClelland & Rogers, 2003), neuropsychological (Patterson, Nestor, & Rogers, 2007) and neuroimaging studies (Visser, Jefferies, & Lambon Ralph, 2010) and, more recently, electrode-implantation studies (Shimotake et al., 2015). Of relevance here, a dominant view is that this temporal region serves as an integration hub, specialized in binding together modality-specific information from distributed brain areas, to form the coherent amodal representations that underpin concepts (Bonner & Price, 2013; Damasio, Tranel, Grabowski, Adolphs, & Damasio, 2004; Lambon Ralph, 2014; Lambon Ralph, Jefferies, Patterson, & Rogers, 2017; Patterson & Lambon Ralph, 2016; Wong & Gallate, 2012).

Consistent with its purported role as a semantic hub, the ATL is known to have connections with the temporal gyri (which receive inputs from visual, somatosensory and auditory processing streams) and the prefrontal cortex (Rogers et al., 2004). Also, damage to the ATL (as it is usually observed in semantic dementia) leads to impairments in conceptual knowledge that tend to result in generalization errors (e.g., Lambon Ralph & Patterson, 2008). In addition, a number of findings from functional neuroimaging studies fit well with this kind of involvement of the ATL in semantic aspects of cognition. Thus, it has been shown that the left ATL is more active for content (e.g., *chair*, *wall*) than function words (e.g., *in*, *under*) (Diaz & McCarthy, 2009), and that it exhibits specific significant activation when participants engage in conceptual combinations that require them to construct complex concepts (e.g., *boy*) rather than simpler ones (e.g., *male*) (Baron & Osherson, 2011).

More recently, the involvement of the ATL in semantic processing has started to be explored through non-invasive brain stimulation techniques, which allow for a different approach to understanding the relationship between brain regions and cognitive functions. By temporarily modulating cortical excitability in relatively specific brain areas (Harty, Brem, & Cohen Kadosh, 2016), these techniques allow neurocognitive researchers to test causal hypotheses about the role of particular brain regions in the behavior of neurologically intact participants, overcoming some of the drawbacks of neuroimaging and neuropsychological studies (Wong & Gallate, 2012). Brain stimulation research on the ATL has been used with a variety of experimental tasks and stimulation protocols, often making it difficult to arrive at consistent conclusions. However, the results from a few focused studies support the idea that the ATL is directly involved in semantic/conceptual processing (e.g., Lambon Ralph, Pobric, & Jefferies, 2009). Thus, for instance, temporarily disrupting neural processing in the ATL by means of repetitive transcranial magnetic stimulation (rTMS), leads to slower responses in synonym judgment tasks, with worse performance for abstract and high-order concepts than for basic ones (Pobric, Jefferies, & Lambon Ralph, 2007). Note that this is a pattern of performance that is largely comparable to that observed in people with semantic dementia (Lambon Ralph et al., 2011; Woollams, Cooper-Pye, Hodges, & Patterson, 2008).

A variety of cognitive tasks have been used to explore the involvement of the ATL in semantic processing (i.e., lexical decision, categorization, naming, decision making), all of which have contributed to provide different types of converging evidence (see for example Wong & Gallate, 2012). However, an experimental procedure that seems particularly well suited to study the role of the ATL as a semantic hub is the Deese–Roediger–McDermott (DRM) paradigm, a well-established cognitive task that is widely utilized to experimentally induce semantic-related false memories (Roediger & McDermott, 1995). In a standard DRM experiment participants are instructed to memorize, for a later test, a list of words which are associates (e.g., *table*, *sit*, *legs*, *seat* …) of a critical semantically related item (e.g., *chair*) that is never presented at study. When the participants' memory for the studied words is tested after a relatively short retention interval, they usually produce or endorse the critical item as a previously presented word, a memory illusion that has been shown to depend on the semantic relatedness between studied words and critical items. Experimental manipulations that normally favor the processing of the semantic features of the studied words [e.g., deep processing (Thapar & McDermott, 2001); list blocking (Tussing & Greene, 1997); relational processing (McCabe, Presmanes, Robertson, & Smith, 2004); or elaborative rehearsal (Read, 1996)] have shown to increase false memory effects (higher rates of recall and recognition of critical items). It is also the case that participants such as children, who display poor abilities at a variety of semantic tasks early in their development, tend to show lower rates of false memory in this paradigm (Brainerd, Reyna, & Ceci, 2008; Carneiro & Fernandez, 2010; Carneiro, Albuquerque, Fernandez, & Esteves, 2007). In addition, the characteristics of false memory effects in the DRM paradigm have proven to be of relevance for understanding semantic processing in connection with certain cognitive impairments. Thus, different types of brain damage have been related to false memory modulation in amnesic patients (e.g., Schacter, Verfaellie, & Anes, 1997; Schacter, Verfaellie, Anes, & Racine, 1998; Schacter, Verfaellie, & Pradere, 1996; Van Damme & D'Ydewalle, 2009), or Alzheimer's disease (e.g., Budson, Daffner, Desikan, & Schacter, 2000; Budson et al., 2002). Interestingly, there is evidence that atypical ATL functioning is associated with reduced false memories in DRM procedures. Thus, for example, patients with ATL damage (i.e., those with a diagnosis of semantic or fronto-temporal dementia), have been found to exhibit not only impaired performance in semantic memory tasks, but also lower rates of false recognition (e.g., Simons et al., 2005; de Boysson et al., 2011).

Of especial relevance here, two separate brain-stimulation studies found that altering ATL activity leads to lower rates of false recognition (Boggio et al., 2009; Gallate, Chi, Ellwood, & Snyder, 2009). Gallate et al. (2009) hypothesized that if the ATL is involved in the formation of false memories by virtue of the “semantic” attributes shared among the studied words, inhibiting the activity of the ATL through rTMS would reduce the probability of falsely recognizing critical items. Their results were consistent with that hypothesis, showing that disrupting ATL activity did not affect correct recognition, but