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Short Communication

The role of language in multi-dimensional categorization: Evidence from transcranial direct current stimulation and exposure to verbal labels

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ABSTRACT

Human concepts differ in their dimensionality. Some, like GREEN-THINGS, require representing one dimension while abstracting over many others. Others, like BIRD, have higher dimensionality due to numerous category-relevant properties (feathers, two-legs). Converging evidence points to the importance of verbal labels for forming low-dimensional categories. We examined the role of verbal labels in categorization by (1) using transcranial direct current stimulation over Wernicke's area (2) providing explicit verbal labels during a category learning task. We trained participants on a novel perceptual categorization task in which categories could be distinguished by either a uni- or bi-dimensional criterion. Cathodal stimulation over Wernicke's area reduced reliance on single-dimensional solutions, while presenting informationally redundant novel labels reduced reliance on the dimension that is normally incidental in the real world. These results provide further evidence that implicit and explicit verbal labels support the process of human categorization.

1. Introduction

Because no two experiences are truly identical, using past knowledge to respond appropriately to present events requires forming categories of like things that can be treated equivalently (Murphy, 2002). To determine which things are alike we must selectively represent category-relevant properties and abstract across irrelevant ones. Importantly, the ratio of relevant to irrelevant properties differs for different categories. For example, consider the category GREEN THINGS which includes items like limes and grasshoppers while excluding closely related items like lemons and locusts. This category requires selectively representing color while excluding shape, taste, etc. The category BIRDS on the other hand requires simultaneously representing multiple features (e.g., feathers, wings)—none individually necessary or sufficient for membership. Human concepts can be placed on a continuum from low-dimensional (e.g., GREEN THINGS) to high-dimensional (e.g., BIRDS) (Lupyan, Mirman, Hamilton, & Thompson-Schill, 2012; Pothos, 2005).

It has been previously noted that high-dimensional categories (alternatively called information integration, Ashby & Maddox, 2011; or similarity-based, Sloutsky, 2010) are easier to learn for young children (Kloos & Sloutsky, 2008) and non-human primates to (Couchman, Coutinho, & Smith, 2010) than low-dimensional categories (alternatively called rule-based, Ashby & Maddox, 2011; or selection based, Sloutsky, 2010). When a stimulus space is structured ambiguously, children and non-human primates tend to partition it using multiple dimensions suggesting high-dimensional categorization is a kind of default (Couchman et al., 2010; Smith & Kemler, 1977). In contrast, adults, have little trouble forming low-dimensional categories.[1] Not only do humans overcome the apparent default of high-dimensional categorization, but given the choice, older children and adults show strong preferences for low-dimensional solutions (Couchman et al., 2010; Smith & Kemler, 1977).

1.1. Effects of language on categorization

What enables older children and adults to do easily what is so challenging to young children and non-human animals? One possibility is that low-dimensional categorization is aided by

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[1] Although, when categorizing items into formal categories such as ODD NUMBERS and TRIANGLES—perhaps the most low-dimensional categories of all—adults never fully abstract from putatively irrelevant information (Lupyan, 2013).

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language. Indeed, Ashby and colleagues have noted that an effective strategy for learning low-dimensional categories is to verbalize a rule (e.g., green goes here, blue there). Such approaches are not feasible for high-dimensional categories if only because criteria for membership cannot be easily verbalized.

Additional support for the involvement of language in low-dimensional categorization comes from findings that children can learn low-dimensional categories at an earlier age if they are given category labels (Perry & Samuelson, 2013) or verbal instructions about category-relevant features (Kloos & Sloutsky, 2008). Conversely, disrupting language in adults through verbal interference (Lupyan, 2009), or more drastically, stroke-related aphasia (Lupyan & Mirman, 2013) impairs low- but not high-dimensional categorization.

A useful framework for understanding *why* labeling supports low-dimensional categorization is the Label Feedback Hypothesis (Lupyan, 2012): in associating a category name (i.e., a verbal label) with multiple exemplars, the label becomes most strongly associated with features that are most predictive/diagnostic of the category thereby facilitating selective activation of those features while simultaneously abstracting over irrelevant ones. Support for this hypothesis comes from findings that labels facilitate category learning (Lupyan, Rakison, & McClelland, 2007) and lead to faster object recognition (Lupyan & Thompson-Schill, 2012).

1.2. Rationale and predictions

Insofar as implicit and explicit labeling supports adults' low-dimensional categorization abilities, decreasing the extent to which labels are activated may decrease the likelihood that people form low-dimensional categories. One way to study the role of labels in categorization is to manipulate the ease with which participants can use labels and observe the outcome of this manipulation on categorization. For example, if the word "green" supports selective representation of a grasshopper's color, then interfering with activation of the label should disrupt the speed or accuracy with which, for example, people group grasshoppers with limes. The method often used for *down-regulating* the labeling process—verbal interference—has a number of shortcomings, (see Perry & Lupyan, 2013) some of which can be overcome through use of noninvasive cortical stimulation.

In a previous study, Lupyan et al. (2012) examined how transcranial direct current stimulation (tDCS) applied over left inferior frontal gyrus (subsuming Broca's area) affects on categorization. They found down-regulating activity over Broca's area decreased accuracy in low-dimensional, but not high-dimensional categorization. However, because Broca's area has been associated with both linguistic processes such as speech production (Gernsbacher & Kaschak, 2003) and domain-general cognitive control (Kan & Thompson-Schill, 2004), it is difficult to draw conclusions about the role of language in categorization.

To assess more directly the relationship between labeling and categorization, here we stimulate BA 22—posterior superior temporal gyrus (subsuming Wernicke's area).[2] The involvement of Wernicke's area in lexical and phonological processes is well known (e.g., Binder et al., 1997; Geschwind, 1970; Price, 2000). Modulation of Wernicke's area using tDCS has been previously shown to affect name-learning (Flöel, Rösser, Michka, Knecht, & Breitenstein, 2008) and picture–word verification (Lupyan, in preparation). This cortical region, however, has not been previously implicated in domain-general cognitive control (Cole & Schneider, 2007). Finding that tDCS over Wernicke's area can affect nonverbal categorization—specifically low-dimensional categorization—would support the hypothesis that language is involved in the ability to form object representations that emphasize task-relevant dimensions.

We predicted that stimulating over Wernicke's area should, by down-regulating the labeling process, nudge people to represent stimuli in a higher-dimensional way than they would normally. We also attempt to up-regulate the labeling process through a behavioral manipulation by providing learners with novel redundant category labels (see Lupyan et al., 2007) with the expectation that these should nudge people to represent stimuli in a lower-dimensional way than they would otherwise.

2. Experiment 1: Modulating labeling processes in categorization

To examine the relationship between labeling and selective representation of category-relevant features we trained participants to discriminate between two types of "minerals"—some nutritious and some poisonous. The minerals comprised gabor patches varying in orientation and spatial frequency. The categories were structured such that using a uni-dimensional (either orientation or frequency) or bi-dimensional boundary (co-occurrence of *both* orientation and frequency) would lead to approximately equal accuracy (Fig. 1). This configuration allowed us to distinguish effects on overall accuracy from effects on the dimensionality of learned categories. Participants were assigned to one of four conditions: (1) Cathodal stimulation over Wernicke's area, (2) Control cathodal stimulation over the vertex, (3) No-stimulation group receiving redundant labels following each categorization trial (see Section 7), and (4) a no-stimulation baseline group.

3. Results and discussion

We first assessed performance by comparing accuracy and response times (RT) for the four conditions (Wernicke's-cathodal stimulation, vertex-cathodal stimulation, label, baseline). Next,

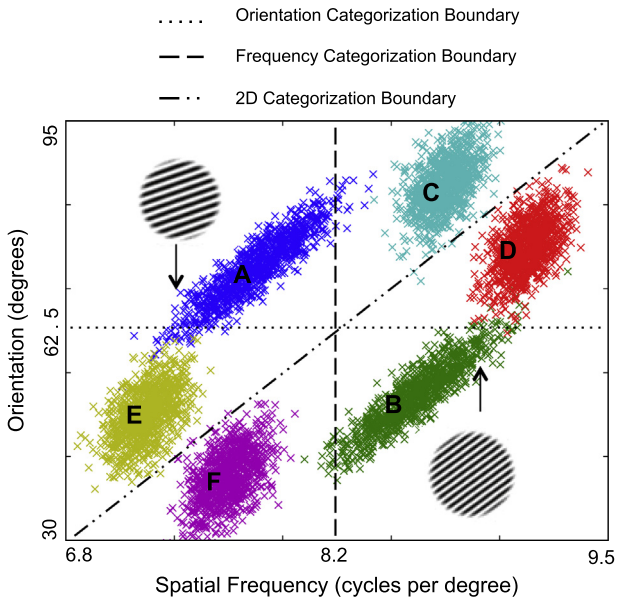

Fig. 1. Distribution of stimuli. Training stimuli was drawn from (A and B); two sample gabor patches from each distribution are shown. Generalization stimuli were drawn from (C–F). Lines denote potential category boundaries. Colors are used for visualization purposes only. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

[2] Much remains unknown about the functional extent of tDCS-induced changes to cortical excitability. Phrasing such as "stimulation over Wernicke's area" should therefore be taken to mean that we stimulated over the anatomical region corresponding to Wernicke's area (pSTG), not that the functional effects of stimulation were circumscribed strictly to Wernicke's area.