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Contrasting effects of feature-based statistics on the categorisation and basic-level identification of visual objects

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ABSTRACT

Conceptual representations are at the heart of our mental lives, involved in every aspect of cognitive functioning. Despite their centrality, a long-standing debate persists as to how the meanings of concepts are represented and processed. Many accounts agree that the meanings of concrete concepts are represented by their individual features, but disagree about the importance of different feature-based variables: some views stress the importance of the information carried by distinctive features in conceptual processing, others the features which are shared over many concepts, and still others the extent to which features co-occur. We suggest that previously disparate theoretical positions and experimental findings can be unified by an account which claims that task demands determine how concepts are processed in addition to the effects of feature distinctiveness and co-occurrence. We tested these predictions in a basic-level naming task which relies on distinctive feature information (Experiment 1) and a domain decision task which relies on shared feature information (Experiment 2). Both used large-scale regression designs with the same visual objects, and mixed-effects models incorporating participant, session, stimulus-related and feature statistic variables to model the performance. We found that concepts with relatively more distinctive and more highly correlated distinctive relative to shared features facilitated basic-level naming latencies, while concepts with relatively more shared and more highly correlated shared relative to distinctive features speeded domain decisions. These findings demonstrate that the feature statistics of distinctiveness (shared vs. distinctive) and correlational strength, as well as the task demands, determine how concept meaning is processed in the conceptual system.

1. Introduction

Understanding how the meanings of concrete concepts are represented and processed stands at the heart of research on conceptual knowledge and has been approached from a number of different theoretical perspectives. Many models of conceptual knowledge assume some form of componentiality, where a concept is represented by its constituent parts, or features (Collins & Loftus, 1975; Murphy, 2002; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976; Smith & Medin, 1981). One class of feature-based model claims that the statistical characteristics of features capture how concepts are represented. However, within this class of models there are disagreements about the functional role of statistical characteristics in accessing a concept's meaning (Cree, McNorgan, & McRae, 2006; Gonnerman, Andersen, Devlin, Kempler, & Seidenberg, 1997; McRae, de Sa, & Seidenberg, 1997; Randall, Moss, Rodd, Greer, & Tyler, 2004; Vinson, Vigliocco, Cappa, & Siri,

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2003). Here, we focus on two statistical characteristics of features which have played a key role in current theorising – the extent to which features co-occur in different concepts, and the extent to which features are distinctive to a particular concept or are shared by many concepts. We suggest that previously contradictory findings in the literature may be accounted for by the influence of task-dependent factors in determining how we understand concrete concepts.

The relevance of feature co-occurrence for conceptual representations was first highlighted by Rosch and colleagues (Rosch et al., 1976). They noticed that certain feature combinations frequently co-occurred, e.g. birds tended to have beaks, feathers and lay eggs. The existence of these feature clusters in natural categories led Rosch et al. (1976) to suggest that they had a special status in the conceptual representation of natural categories. Keil (1986) subsequently reported that clusters of co-occurring features were larger and more densely intercorrelated for living things than for nonliving things see also (Malt & Smith, 1984). The proposal that the co-occurrence of features differs across the two domains of knowledge (i.e. living vs. nonliving things) has since been supported by data from property norm studies, which collate features produced by healthy participants to a set of individual concepts. By calculating Pearson product-moment correlations across pairs of feature vectors derived from their property norm study of 190 concepts, McRae et al. (1997) observed that 11% of the feature pairs of living things were significantly correlated, compared to only 6% in nonliving thing concepts (see also Randall et al., 2004; Vinson et al., 2003).

While these studies showed that feature co-occurrence characterises the organisation of concepts, their functional relevance remained to be established. Early studies using category learning and typicality rating tasks found no effect of feature co-occurrence on performance (Malt & Smith, 1984; Murphy & Wisniewski, 1989). Instead, the effects of feature correlation were found when participants were required to explicitly compare correlated and uncorrelated feature pairs, and were presented with highly salient correlations (Malt & Smith, 1984). These studies appeared to indicate that feature co-occurrence was only functionally relevant when it was made explicit, or when participants were informed of the context for how features might co-occur (Murphy & Medin, 1985). However, McRae and colleagues (1997) explained the lack of feature co-occurrence effects as being due to the nature of the slow, off-line tasks used in these early studies, which required high-level reasoning processes (e.g. scripts, world knowledge). To test this hypothesis, McRae and colleagues contrasted performance on off-line concept similarity rating and typicality judgement tasks with that on speeded semantic priming and feature verification tasks. Consistent with their hypothesis, feature correlations predicted performance on the short SOA semantic priming and feature verification tasks, but not the concept similarity and typicality rating tasks (McRae et al., 1997). The facilitatory effect of feature correlation was subsequently replicated in a feature-concept priming study using lexical decision and single word stimuli to minimise syntactic processing: strongly intercorrelated features primed lexical decisions to target concepts significantly more than weakly intercorrelated features (Taylor, Moss, Randall, & Tyler, 2004). These and similar findings (Cree, McRae, & McNorgan, 1999; McRae, Cree, Westmacott, & de Sa, 1999; Randall et al., 2004) led to the proposal that strongly correlated features speed their activation in on-line comprehension tasks, a claim which has become a theoretical cornerstone in many current, feature-based accounts of conceptual representation and processing (Gonnerman et al., 1997; McRae, 2005; Moss, Tyler, & Taylor, 2007; Tyler & Moss, 2001; Vigliocco, Vinson, Lewis, & Garrett, 2004).

A second central variable in statistical feature-based accounts of conceptual knowledge is feature distinctiveness, or the extent to which features are distinctive to a particular concept or are shared by many concepts. The importance of distinctive features in the representation of concepts was already highlighted in the "classical view" of conceptual representations (Murphy, 2002; Smith & Medin, 1981). On this account, a concept could be classified as e.g. a tiger if it possessed all of the defining features of a tiger (Hull, 1920). Thus, defining features were sought that were cues to the identity of a concept. One key problem with this account is that it was not obvious how to identify defining features (Wittgenstein, 1953). To address this and other drawbacks (Medin & Smith, 1984; Murphy, 2002), a "probabilistic view" was developed that distanced itself from the defining feature view, and embraced the notion of feature similarity as a key representational dimension for concepts. According to this account, a feature belonged to a conceptual representation if it occurred in instances of the concept with a high probability, i.e. if it was shared across other instances of the concept (or category). Thus, an instance of a concept could be identified if it was sufficiently similar to a summary representation (Medin & Smith, 1984). As noted by Malt and Smith (1984), this model was recognised as incomplete since it neglected the importance of additional semantic information used during conceptual processing beyond shared features, e.g. correlated feature information.

Current statistical, feature-based views of conceptual representations unite the insights concerning defining and shared (similar) features into a single metric of distinctiveness: the inverse of the number of concepts a feature occurs in (Cree & McRae, 2003). Features that occur in many concepts are considered "shared" and have low distinctiveness values, whereas features that occur in very few concepts are considered "distinctive" and have high distinctiveness values. Thus, akin to defining features in the classical view, distinctive features are those that are true of a small number of concepts, and thus distinguish similar concepts from one another. For example, the distinctive feature ⟨has a hump⟩, but not the shared features ⟨has legs⟩ or ⟨has a tail⟩, distinguishes a camel from similar four-legged animals (Dean, Bub, & Masson, 2001).

Specific types of brain damage are associated with impairments in processing distinctive compared to shared features (Alathari, Trinh Ngo, & Dopkins, 2004; Martin, 1992; Moss & Tyler, 1997; Tyler & Moss, 2001; Warrington, 1975). Building on these patient findings, some investigators have hypothesised that distinctive features have a