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Free classification of large sets of everyday objects is more thematic than taxonomic

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ABSTRACT

Traditionally it has been thought that the overall organisation of categories in the brain is taxonomic. To examine this assumption, we had adults sort 140–150 diverse, familiar objects from different basic-level categories. Almost all the participants (80/81) sorted the objects more thematically than taxonomically. Sorting was only weakly modulated by taxonomic priming, and people still produced many thematically structured clusters when explicitly instructed to sort taxonomically. The first clusters that people produced were rated as having equal taxonomic and thematic structure. However, later clusters were rated as being increasingly thematically organised. A minority of items were consistently clustered taxonomically, but the overall dominance of thematically structured clusters suggests that people know more thematic than taxonomic relations among everyday objects. A final study showed that the semantic relations used to sort a given item in the initial studies predicted the proportion of thematic to taxonomic word associates generated to that item. However, unlike the results of the sorting task, most of these single word associates were related taxonomically. This latter difference between the results of large-scale, free sorting tasks versus single word association tasks suggests that thematic relations may be more numerous, but weaker, than taxonomic associations in our stored conceptual network. Novel statistical and numerical methods for objectively measuring sorting consistency were developed during the course of this investigation, and have been made publicly available.

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Organising our knowledge of the world into useful categories is one of the brain's most basic functions. Categories are collections or classes of objects or entities that are similar or related in some meaningful way. Two types of relation, taxonomic and thematic, have been widely proposed to provide structure to our stored, semantic knowledge about categories of concrete objects such as trees and hammers (Murphy, 2002). Taxonomic relations group together the same kinds of objects based on perceptual and functional similarities (De Deyne, Verheyen, & Storms, 2016; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). As an example, most members of the category *fruit* have similar shapes, sizes, smells and tastes and they are grown and used in similar ways. In contrast, thematic relations group together objects that need not be either perceptually or functionally similar to each other. Instead they normally have complementary roles in events and co-occur in common situations, locations and/or times (De Deyne et al., 2016; Lin & Murphy, 2001). For example, the thematic category *mail* might include an envelope, a post-box, a stamp, a post-man and a parcel.

Adults can easily categorize objects both taxonomically and thematically and they can vary this behaviour in response to task demands (Estes, Golonka, & Jones, 2011; Wisniewski & Bassok, 1999; Shafto, Kemp, Mansinghka, & Tenenbaum, 2011). Thus, at a fine scale of analysis, both types of semantic relation are readily available. However, at a coarse scale our long-term, semantic knowledge is often thought to be organised taxonomically because taxonomic relations reflect the deep, causal structure of our world and so can support useful inductions. In addition, much of our formal education may encourage us to categorize taxonomically (Estes et al., 2011). Thematic relations arise from storing our episodic experiences of the world and, specifically, co-occurrences in time and space. It has been argued that such relations may be less useful as a basis for induction. There is, however, little empirical evidence to evaluate the claim that, overall, our stored semantic knowledge is mainly taxonomic rather than thematic. The present study investigated this claim using a large-scale, open-ended free-sorting task where adults were asked to cluster sets of objects which go naturally together. We investigated whether these clusters were consistent across different people (rather than being idiosyncratic) and, if so, what type of semantic relations (taxonomic versus thematic) was principally used to structure them.

Several studies have suggested that adults prefer to categorize taxonomically (e.g., Olver & Homsby, 1966; Ross & Murphy, 1999; Smiley &

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Brown, 1979; Tare & Gelman, 2010). However, Murphy (2001, 2002) noted that many previous free-sorting studies presented small numbers of items that could easily be sorted into salient taxonomic clusters (with no leftover items) but that could not so readily be organised into thematic clusters. Murphy suggested that the results of such studies may have led to an overestimation of adult's use of taxonomic relations to categorize. Consistent with this claim, Lin and Murphy (2001); see also Koriat & Melkman, 1981; Saalbach & Imai, 2007) found that when salient thematic relations were provided, many people consistently matched thematically rather than taxonomically. To further investigate this issue, Murphy (2001) used a small-scale, free-sorting task in which a set of nine pictures could be divided into either three taxonomic clusters (vehicles, professions and locations) or three thematic clusters (with themes of travel by aeroplane, boat or car), with three items per cluster in both cases. Participants were told to group the pictures in the way that seemed "best and most natural". Murphy found that most people sorted the stimuli thematically, suggesting that if both thematic and taxonomic relations are readily available then adults do not show a strong inclination to sort taxonomically. Murphy also provided evidence of the effect of stimulus selection in a follow-up experiment in which the three location objects were replaced by three animals. This meant that there were still three salient and equal-sized taxonomic clusters but that it was difficult to sort all of the items into thematically organised clusters. Most people now sorted taxonomically, demonstrating that the semantic relations used in free-sorting are both flexible and sensitive to the stimuli provided. Overall, Murphy's data shows that the results of many previous free-sorting studies, which had originally been interpreted as revealing that adults mainly organise their semantic knowledge taxonomically, could instead have arisen from experimenters selecting items that were more strongly related taxonomically than thematically.

1. A large-scale, free-sorting task

Research to date thus suggests that, first, people can flexibly use both taxonomic and thematic relations when grouping items, and that, second, many items can be readily grouped either taxonomically or thematically (Lin & Murphy, 2001; Murphy, 2001; Nguyen & Murphy, 2003; Smiley & Brown, 1979). This research is based on matching and small scale free-sorting studies which investigated categorization preferences at a fine-grained, detailed scale. However, this research is not informative about the overall nature of our stored semantic knowledge since experimenters usually selected stimuli to be either clearly taxonomically or clearly thematically related. Careful stimulus selection is necessary for such studies as the aim is to directly compare people's *choice* to respond based on taxonomic versus thematic relations of matching strength. A different and more coarse-grained method must be used to assess the relative number of taxonomic versus thematic relations *available* across a broad range of everyday items in order to infer the overall nature of our stored, semantic knowledge.

The present study investigated whether more thematic than taxonomic relations were available across basic level categories (such as apple, bowl and scissors; Lawson & Jolicoeur, 2003; Rosch et al., 1976) using a relatively unconstrained, large-scale, free-sorting task. We analysed how people clustered sets of 140–150 diverse, concrete objects. The large sets of items discouraged participants from assuming that there was a single, pre-defined, "correct" solution that the experimenter expected them to produce. This more exploratory, open-ended task provided considerable freedom for participants to choose the size and number of clusters to create and the semantic relations used to structure them. We assessed the consistency of clustering and the type of semantic relation used to cluster in order to provide evidence about whether the relations stored in our semantic knowledge are mostly idiosyncratic, taxonomic or thematic.

Several studies have examined the sorting of relatively large sets of objects but, unlike the present study, these have focussed on restricted domains of knowledge. For example, Medin et al. (2006); see also Medin, Lynch, Coley, & Atran, 1997) compared how two groups of experts (who lived in the same area but came from different cultures) clustered together 44 fish species. Sorting was similar overall but the Native American group used more ecological information, such as shared habitat, whereas the European American group was more likely to sort using biological class. Although knowledge was similar across the two cultures it was organised in different ways - more thematically than taxonomically for the Native Americans compared to the European Americans. Furthermore, Medin, Ross, Atran, Burnett, and Blok (2002) found that non-expert Native Americans and European Americans provided fewer taxonomic, and more goal-related, reasons for sorting when tested on the same task. Thus both culture and levels of expertise influenced the nature of semantic knowledge for this domain of fish species. Similarly, Lopez, Atran, Coley, Medin, and Smith (1997) found that USA undergraduates and indigenous Guatemalans both sorted around 40 mammals into categories similar to a standard scientific taxonomy. However, the USA students relied more on size to justify their sorting whereas the Guatemalans used a broader range of information and depended more on ecological relations. This, again, suggests that cultural differences can influence sorting. Note, though, that these studies only tested sorting for narrow domains of biological organisms which Western undergraduates are taught to think about taxonomically (Estes et al., 2011). Thus the responses to these single-domain sets of items may not generalise to the large, diverse sets of items that we used.

Recently, computational models have been shown to be able to extract and organise the types of semantic knowledge available to people using both thematic and taxonomic relations. For instance, natural language processing techniques such as latent semantic analysis (LSA) analyse the co-occurrence of words in text and can detect thematic relations (Landauer, McNamara, Dennis, & Kintsch, 2013). In contrast, deep learning approaches used in image recognition software such as GoogLe Net use visual similarity (features such as colour, size and shape) and can detect taxonomic relations (Szegedy et al., 2014). Recent modelling has suggested that a single mechanism can extract both types of relations (De Deyne et al., 2016) using a general principle that guides the organisation of the coarse-grained structure of semantic networks.

2. Experiment 1

In Experiment 1, adults sorted 140 familiar, nameable categories of objects. One group sorted pictures (e.g., a picture of a dog) and a second group sorted words (e.g., the word "dog"). In addition to investigating the nature of our stored semantic knowledge by examining whether, overall, taxonomic sorting dominated over thematic sorting, we also tested whether pictures were more likely than words to be sorted taxonomically. Greater taxonomic sorting of pictures could occur because visual similarity across items is more salient for pictures and because taxonomically related objects often look similar (Rosch et al., 1976). Supporting this hypothesis, Lin and Murphy (2001) found 17% less thematic matching when pictures were presented to adults in addition to words (see also Tare & Gelman, 2010). Alternatively, if people use a single, stable network of stored semantic knowledge then pictures and words should be sorted similarly.

In Experiment 1, unlike traditional small-scale sorting and matching tasks, the semantic relations that participants used to cluster items had to be inferred from the data rather than being specified a priori. This was done in two ways. First, we used mean subjective ratings of how strongly items in a cluster were related taxonomically and were related thematically, similar to measures that have been used in other tasks (Maguire, Brier, & Ferree, 2010; Mirman & Graziano, 2012). Second, to assess whether people sorted similarly to each other or idiosyncratically we developed two objective measures of categorization consistency based on Cramér's phi (Cramér, 1946). These novel measures assessed whether different people tested in the same condition showed

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