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Number and Size matter: Discrete versus continuous entities

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Abstract

The distinction between discrete and continuous entities plays an important role in understanding of quantities as well as in categorical knowledge. There is a robust literature both in the domain of quantity perception and in noun learning concerning the factors relevant to this distinction; however, there has been little joint investigation of these issues. Here, we investigated the effects of number and size of named entities on the interpretation of a novel noun as an object or continuous mass. We found that number and size matter and may relate deeply to current distinctions between discrete and continuous estimators of quantity.

Keywords: number; size; discrete; continuous; object name learning.

Introduction

What determines whether some entity is conceptualized as being discrete versus continuous? Discrete entities are conceptualized as bounded, cohesive and countable. Continuous masses are noncohesive and are divisible only into portions of their whole. This distinction is important for issues of word learning as well as understanding of quantity; discovering the factors that influence it may also shed light on other processes related to perception.

Noun categories

Many languages, such as English, mandatorily mark the distinction between discrete and continuous mass such that count nouns label discrete items and mass nouns label continuous ones. Count nouns use plural marking and numeric quantifiers to indicate quantity (e.g., *four cups, three clouds*), whereas mass nouns are preceded by continuous quantifiers and no plural marking (e.g., *much dough*). The distinction is conceptual and is used to mark both concrete and abstract nouns; however, among the common words learned by children prior to 3 years of age, the vast majority of count nouns refer to solid entities (e.g., chair, cup, house) that are in categories well organized by similarities in shape. In contrast, early common mass nouns predominantly refer to nonsolid things (e.g., water, milk) that are in categories well organized by material (see Samuelson & Smith, 1999 for a relevant analysis of early nouns). Conceptually, then, in the early word learning environment discrete countable entities are those with bounded and fixed forms, and for which shape is a defining feature. Continuous masses have variable and nondefining shapes, and material is the defining feature of such entities.

There is considerable research indicating that infants, children and adults honor this distinction in nonlinguistic tasks as well as word learning. When shown rigid cohesive objects, eight month olds successfully track their movement behind an occluder; however, they do not track noncohesive or nonrigid entities (Chiang & Wynn, 2000; Huntley-Fenner, Carey, & Solimando, 2002;). When collections of dots move together in a cohesive manner, five month olds track them as if they were a unified whole (Wynn, Bloom, & Chiang, 2002). In word learning, cohesion of entities affects object name generalizations. Studies investigating word object mappings in children and adults frequently test attention to shape versus material using a novel noun generalization task. In this task, a novel entity is shown, it is labeled with a novel name (e.g., *Look at the dax*), and participants are then asked to judge whether other items are also in the same category. If the named exemplar is a single solid thing, children and adults judge category membership based on shape. If the named exemplar is a nonsolid substance, children and adults extend membership to entities of the same material (Colunga & Smith, 2005; Imai & Gentner, 1997; Landau, Smith, & Jones, 1988; Soja, 1992; Soja, Carey, & Spelke, 1991). Further, embedding the novel name in a count noun frame (e.g., *This is a wug*) increases generalizations by shape; embedding the novel noun in a mass noun frame (*e.g., This is some wug*) increases attention to material (Soja, 1992). In sum, count nouns quantify over individuals whereas mass nouns quantify over non individuals, and—importantly— shape matters for categories of discrete countable things, whereas material matters for categories of substances.

Estimators and counters

A large and robust literature suggests that humans directly apprehend the number of discrete instances in a set when the size is small (less than 4) (Feigenson & Carey, 2003, 2005; Trick & Pylyshyn, 1994; Wynn, 1998; Xu & Spelke, 2000). Recently, there has been a growing consensus that two distinct perceptual systems exist for determining the number of items in a set: a discrete number system that applies to small set sizes and an analogue or estimator system for large set sizes (Carey, 2001, 2004; Feigenson, Dehaene, & Spelke, 2004; Xu, 2003; Xu & Spelke, 2000). By some theoretical analyses, small sets of objects (≤3 or 4) are encoded separately as *object files* (Scholl, 2001; Simon, 1997; Trick & Pylyshyn, 1994; Uller, Huntley-Fenner, Carey, & Klatt, 1999); larger sets (≥4 or 5) are represented in an *analogue magnitude* system that seemingly does not encode individual items as separate but rather approximates across them as whole masses (Xu & Spelke, 2000). Studies with infants have shown different patterns of discrimination among large and small sets, supporting the hypothesis (see Feigenson, Dehaene, & Spelke, 2004 for a review).

If the number of discrete items in small sets is directly perceived, whereas the number of items in large sets is not, are items in small sets apprehended as a collection of discrete individuals and items in large sets as portions of a continuous whole? If this is the case, then the name for a single item should be understood as referring to its particular shape whereas the name for a set of many things should be a reference to its material. Moreover, if a shift away from attention to shape occurs when one is perceiving items of four or more, then it would suggest a link between individuation and numerical processing.

Aggregates

Cups are discrete countable things. Dough is a continuous quantity. Between these two are aggregates— sets of things made up of bounded discrete individuals yet sometimes experienced as a mass. Aggregates such as sand, gravel, and rice, for example, are often thought of as continuous quantities. Moreover, their names in English are mass nouns, and they are often generalized by material (Middleton, Wisniewski, Trindel, & Imai, 2003). Thus aggregates present an interesting context in which to examine how set size influences the conceptualization of individuals as discrete entities versus continuous masses. Number and size of aggregate units may play a role in their perception. Accordingly, in our first two experiments in this domain (reported here), we simultaneously manipulated the number and size of the individual entities, keeping the overall amount of stuff in the object collections constant across levels.

Experiment 1

The task and its rational can be explained with respect to Figure 1. Participants were first shown a single entity of a particular shape and material (e.g, an inverted U-shaped object made of wire mesh) and told its name. They were then shown two choices of objects and asked which was in the same category. One choice was a single item that matched the exemplar in material but differed in shape; the other was an array that contained 1 to 25 objects of the same shape but of a different material. If participants attend to both the shape and material of the individuals in the two arrays, then there is a choice between a material matching and a shape matching array. If however, sets with some number of elements cause the shapes of the individual elements not to matter, then the choice is between a material matching array and a *nonmatching array*. Thus, if increasing the number of elements in a set decreases the individuality and shape relevance, then we would expect a shift from shape matching to material matching choices as number increases. The empirical question is thus whether and at what number this occurs. All sets were structured as in Figure 1; number levels varied across trials for the shape match as illustrated in Figure 2.

Methods

Participants Forty undergraduate students from Indiana University participated.

Stimuli Six sets of objects were used. Each set contained an exemplar, a material match, and six shape match sets. The exemplar and material match for each set were approximately equal in size (8cm x 6cm). The material match was the same color and texture as the exemplar but a different shape. The six shape match levels were identical in shape to the exemplar but varied in number of objects. The six number levels were 1, 2, 4, 6, 15, and 25 (see Figure 2). The sizes of the shape matches decreased as number increased such that overall mass of stuff in the collections was kept approximately equal at each number level. The 1 level shape match was approximately 8cm x 6cm. The units of the 25 objects level were approximately 1.5cm x 1.5cm each.

Figure 1. Structure of the task.

Procedure One open question for these experiments was how to ask the question of which array belonged in the same category as the exemplar. This is particularly difficult in

English which demands that every noun be a count or mass noun. Based on pilot work, in these first experiments we named the exemplar with a novel noun using a neutral syntactic frame (useable with either count or mass nouns) (*This is the tiso*). When the choice items were presented, we asked *Can you help me find more?* so as to avoid determiners and the plural. Pilot work indicated that this framing of the question works for informal queries with both count and mass nouns. (Both *"Look at this cup. Help me find more…"* and *"Look at this sand. Help me find more…"* are grammatically acceptable). We are currently replicating the findings in a non-naming task to ensure that this framing of the question did not in some way create the observed pattern.

Participants were tested in one of three conditions: Large 1-2, Medium 4-6, and Small 15-25. In each condition, two shape match levels were presented. Participants completed six trials, 3 in each of the two levels for their assigned condition. The order in which the adults saw the six stimuli sets was randomized as was the sequence of shape match levels.

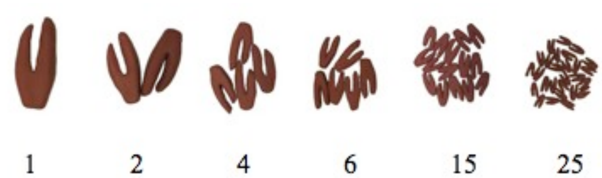

Figure 2. Example of the six number levels of the shape matches for one of the six stimuli sets.

Results and Discussion

As Figure 3 shows, the number (and size) of the shape matching objects mattered. Given a choice between a material matching item or an array of one or two larger objects, participants selected the shape match—suggesting that objects at this level are seen as discrete. However, when the number of objects increased to 4 or more, the adults frequently selected the material matching object. These results suggest that the shape of individual objects matters more when there are fewer than when there are many.

Critically, the switch from selecting shape matches to material matches occurred between two and four, suggesting that rejection of the shape match was not simply a matter of rejecting *all* sets that contained more than one object; rather, there may be something defining in discrete and continuous mass perception that involves the particular numerosity of 4.

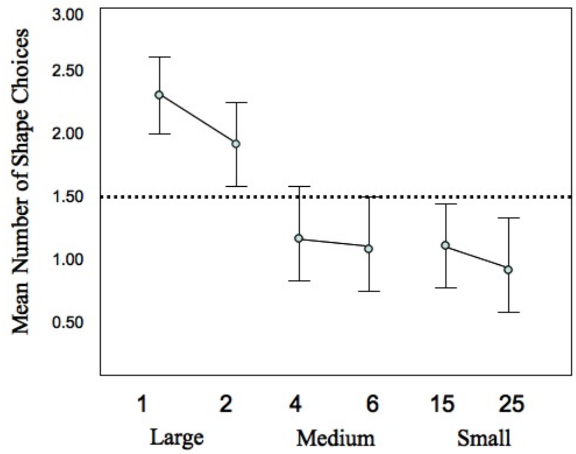

Figure 3. Adult shape choices in each set condition (Experiment 1).

Experiment 2

Past research suggests infants and young children also possess a discrete quantity system that applies to small set sizes, although there is some debate as to whether this system is the same as in adults or if it develops over time (see Carey, 2004). Research has also shown that young children generalize names for objects by shape but by material for substances. As a first step to understanding the developmental relations between these two domains, we examined 4 and 5 year olds' performances in the same task used in Experiment 1. We used a within-subjects design.

Participants Twelve children four to five years of age (M=57.5 months) participated. Children were recruited in Bloomington, Indiana. They were tested individually at their daycare or in the laboratory and received a small gift for participation.

Stimuli Stimuli were identical to Experiment 1.

Procedure The procedure for Experiment 2 was similar to Experiment 1; however, for Experiment 2 each level was a condition, and each child was tested at all six levels.

Results and Discussion

Figure 4 shows the mean proportion of shape choices as a function of the number of items in the shape matching choice array. Choices towards the shape-matching array declined with increasing number, and were reliably greater than chance only for set size 1; choices towards the material match were only reliably greater than chance for set size 25. These results indicate a consistency between the adults and children: one object was perceived as discrete; a set of 25 objects was viewed as a continuous mass.

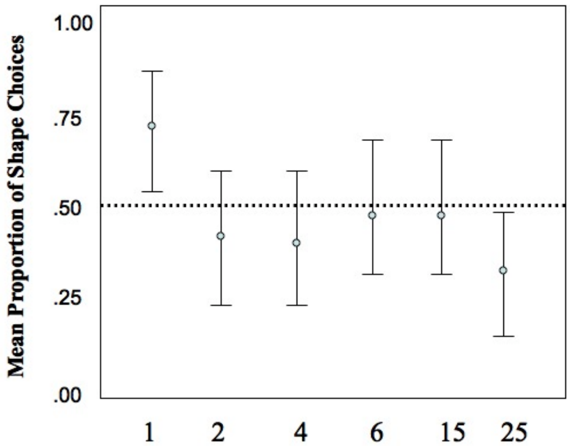

Figure 4. Children's shape-match choices at each number level (Experiment 2).

Interestingly, children's shape responses dropped dramatically at the two object level. This is in contrast to adults who shifted at four. It is possible that the shifting point differs from adults and actually occurs for children between one and two. Another possibility is that the within-subjects design and carry over effects from trial to trial with different set sizes obscured a much sharper function. Analyses of individual data suggests that this is possible, with some children shifting to material at higher number values than others, in ways that may be related to the particular random order of trials. Ongoing experiments that manipulate set size between subjects will answer this question. Nonetheless, the main result from the child data is like that of the adults: as the set size increases, the individual shapes of elements appear to become less salient and less defining.

General Discussion

Results from both children and adults in these experiments show that number and size matter in perception of discrete and continuous entities. Given one or two items, objects are seen as individuals, and shape is important for their identity. Although children appear to shift earlier in their perception towards continuous mass, adults show a clear switch at four for these experiments. Objects seen in sets of four or more perceptually become continuous and units lose individuality.

The fact that the present results indicate this shift at four is also intriguing in light of current theories of quantity and perception: four is suggested as the number at which a switch occurs from a discrete object based perception system to the estimator system (Xu, 2003). The present results are new and require replication and exploration; however, if the findings hold up upon further examination using different experimental tasks, they would suggest an important link between conceptualization of entities and the two-number-system hypothesis of numerosity discrimination.

Results here may also be deeply related to phenomena outside the scope of quantity concepts and word learning. Findings in sociology and group behavior, for example, have shown that as the number of people increase in a group, individuality and distinguishing identity decreases. Our results are fascinating because they may very well indicate a tie between larger sociological phenomena and humans' general perception of discrete and continuous entities.

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