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Probing the mental representation of quantifiers

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ABSTRACT

In this study, we investigate the mental representation of non-numerical quantifiers ("some", "many", "all", etc.) by comparing their use in *abstract* and in *grounded* perceptual contexts. Using an approach similar to that used in the number domain, we test whether (and to what extent) such representation is constrained by the way we perceive the world through our senses. In two experiments, subjects either judged the similarity of quantifier pairs (presented as written words) or chose among a predetermined list of quantifiers the one that best described a visual image depicting a variable number of target and non-target items. The results were rather consistent across experiments, and indicated that quantifiers are mentally organized on an ordered but non-linear compressed scale where the quantifiers that imply small quantities appear more precisely differentiated across each other compared to those implying large quantities. This fits nicely with the idea that we construct our representations of such symbols mainly by mapping them to the representations of quantities that we derive from perception.

1. Introduction

One of the common goals of linguists and cognitive scientists is to uncover and formally characterize how linguistic symbols are mentally represented. Here we attack the issue by focusing on a specific class of words, that of quantifiers (words like "some", "many", "few", "a lot", "all", "none").

Quantifiers have long been considered as a particularly intriguing class of words especially by linguists, since they display several peculiar properties. First, from a formal semantic perspective they are conceived as non-referential (Barwise & Cooper, 1981; Keenan & Stavi, 1986; Montague, 1973; Szabolcsi, 2010; Van Benthem, 1986; Westerståhl, 1985): Differently from many other words, quantifiers do not denote objects, but instead relations between sets of objects. Second, quantifiers are widely affected by the linguistic context of use. This particularly holds for some quantifiers, like "few" and "many", which have therefore been proposed to be non-extensional (Keenan & Stavi, 1986; Westerståhl, 1985): The two sentences "Many doctors attended the meeting this year" and "Many lawyers attended the meeting this year", even assuming that the doctors and lawyers attending the respective meetings are equal in number, might have different truth values depending on the number of doctors and lawyers who used to attend the meetings. Third, from a pragmatic perspective it has been shown how the different degree of information or logical strength of the quantifiers (that "some" is less informative than "all") affects the implicit information that people *infer* from an utterance (Horn, 1984). For example, by listening to the sentence "Some students were satisfied with the marks" a hearer would infer that "Not all the students were satisfied". Fourth, quantifiers cannot be simplistically considered as words that stand for amounts, numbers, proportions (Moxey & Sanford, 1993, 2000; Nouwen, 2010; Paterson, Filik, & Moxey, 2009). Even when expressing approximately the same quantity (e.g. "few" and "a few"), quantifiers differ from each other with respect to the perspective they give to this quantity, by bringing the hearer to focus on either the target set ("a few") or the non-target set ("few"). For instance, "few of these cars break down" is likely to bring the hearer's attention to the vast majority of cars that do not break down. "A few of these cars break down", instead, is more likely to bring the attention to the cars that do break. This difference in the focus influences the hearer's behavior in a positive/negative way (Moxey & Sanford, 2000; Paterson et al., 2009). Consequently, quantifiers have been described in terms of probability distributions over scales (Moxey & Sanford, 1993; Schöller & Franke, 2017; Yildirim, Degen, Tanenhaus, & Jaeger, 2013). Finally, the variability of quantifiers across conditions, together with their rather elusive status with respect to the traditional linguistic classifications, have brought some researchers to take the extreme stance that devising a general semantics for these expressions might not even be possible (Nouwen, 2010).

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Although a long tradition of studies convincingly proved that numerical information, such as the mechanisms of quantity estimation and comparison, is fundamental in the comprehension of quantifiers (Deschamps, Agmon, Loewenstein, & Grodzinsky, 2015; Heim et al., 2012; Shikhare, Heim, Klein, Huber, & Willmes, 2015),[1] cognitive science has not been successful at characterizing how humans mentally represent quantifiers. Historically, even if there has been a shared intuitive assumption that quantifiers might be internally represented on an ordered scale (which some conceived as governed by absolute quantities, e.g. Newstead, Pollard, & Riezebos (1987), and other by proportions, e.g. Graves & Hodge (1947) and Hammerton (1976)), there has been little attempt at formally trying to capture the features of such scale in a quantitative manner. One approach has been to investigate the conditions of the external world that trigger the use of the different quantifiers: Subjects, presented with sets of a various number of target and non-target (visual) items, are asked either to pick, among a predetermined list, the quantifier that best fits the scene or to rate the appropriateness of a list of scene-quantifier associations. Studies of this sort are only very few, and they are hard to compare as they each investigate different sets of quantifiers, as well as slightly different aspects of the stimuli (some analyze the effect of the number of targets, e.g. Newstead & Coventry (2000), some the number of both targets and non-targets, e.g. Coventry, Cangelosi, Newstead, Bacon, & Rajapakse (2005) and Coventry, Cangelosi, Newstead, & Bugmann (2010), some the proportion of targets in the scene, e.g. Oaksford, Roberts, & Chater (2002), often taking into account perceptual factors like the size of the items, their spatial arrangements or their category, e.g. Newstead & Coventry (2000) and Coventry et al. (2010)), though without investigating the potential interactions across all the possible variables. Moreover, the experimental design of all these studies lacks cases where the various effects can be disentangled, for example visual scenes with a small number of targets corresponding to a high proportion (e.g., 3 targets out of 4 total objects). Although with some inconsistencies, the results of these studies overall suggest that quantifiers are evaluated by taking into account the number of both targets and non-targets such that, given a fixed number of non-targets, scenarios with increasing targets are associated with quantifiers implying "larger" quantities. A notable exception is that, when the targets are very few, the number of non-targets seems not to play a role (Coventry et al., 2005). This indirectly suggests that quantifiers might be represented on an internal scale based on proportions which behaves somewhat differently for small sets. What these studies lack, however, is a quantitative characterization of the laws subtending the relation between quantifiers and perceptual stimulation and thus a thorough description of the internal scale.

Another complementary approach that psychologists have used to infer the structure of mental representations is that of directly asking subjects to compare words pairwise and to rate, on a given scale, their semantic similarity in a purely linguistic context (with no direct relation to concrete objects/sets). This way, the potential confounds due to the constraints imposed by perception are eliminated. In this approach, the analysis of the global pattern of rated distances across words can then be used to reconstruct the internal geometry of the representational space of those words (using Multi-Dimensional Scaling, e.g. Arnold (1971) and Steyvers, Shiffrin, & Nelson (2004)). To our knowledge, this approach has been applied to the domain of quantifiers only by Holyoak and Glass (1978), who experimented with a set of five items. Studies of this sort would be crucial for complementing the studies that explore quantifiers in grounded conditions. In particular, the comparison across the grounded and abstract use of quantifiers is useful to investigate whether, and to what extent, the mental representations of quantifiers (and, more generally, of symbols) are constrained by the way we perceptually elaborate the objects or objects features to which the symbols typically refer.

While the abstract view of semantics predicts that symbols are mainly organized according to purely linguistic variables (frequency of use, frequency of association in the lexicon, antinomy, etc.), the grounded cognition view predicts that symbols are mentally represented in a way that at least partially reflects (or is isomorphic to) the way we perceive the world through our senses. This should be reflected both in how subjects use quantifiers to describe perceptual scenes, and in purely abstract contexts when they evaluate quantifiers among each other. This approach has been taken for example in the number domain, where several pieces of data indicate that the internal representation of number symbols (words or Arabic digits, denoting cardinals) appears as governed by the same representational constraints that govern the perception of numerosities in concrete sets, namely on an internal scale which appears overall logarithmically compressed (see Piazza & Eger (2016), for a recent review). This is the case both when number symbols are compared among each other and when they are used to describe perceptual scenes (e.g. Izard & Dehaene (2008)). The aim of the current paper is to export this approach to study the mental space of quantifiers, its main dimensions, and its internal geometry, and to contrast the predictions from the abstract cognition and the grounded cognition by comparing grounded-perceptual and abstract tasks. Using a common list of quantifiers and two large groups of subjects, one experiment investigates quantifiers in grounded conditions, asking subjects to describe visual scenes choosing the most appropriate quantifier (Experiment 1). The other investigates quantifiers in a purely linguistic context, asking subjects to rate the similarity among quantifier word pairs (Experiment 2).

2. Methods

Two experiments were administered to native-Italian participants and employed the same set of 9 Italian quantifiers. The quantifiers used were *nessuno* ("none"), *quasi nessuno* ("almost none"), *la minor parte* ("the smaller part"), *pochi* ("few"), *alcuni* ("some"), *molti* ("many"), *la maggior parte* ("most"), *quasi tutti* ("almost all"), *tutti* ("all"). For sake of clarity, English translations will be used from now on throughout the paper. The selection of the quantifiers was aimed at experimenting with a fairly comprehensive set, including logical-Aristotelian ("none", "some", "all"), proportional ("the smaller part", "most"), and a range of other common quantifiers ("few", "many", "almost none", "almost all"). Moreover, an equal number of low-magnitude ("none", "almost none", "few", "the smaller part") and high-magnitude quantifiers ("many", "most", "almost all", "all") was ensured. Note that we did not consider "some" as belonging *a priori* to one or the other group.

2.1. Grounded task: quantifiers used in perception

Thirty native-Italian participants (21 females, 9 males) with normal or corrected-to-normal vision carried out the task of evaluating 340 synthetic visual scenes containing two categories of objects: Animals and artifacts. The total number of objects in the scene ranged from 3 to 20 (see Section 2.1.1 for a detailed description of the visual stimuli), and the number of items in each of the two categories varied from 0 to 20. The experiment was implemented in Matlab using the Psychtoolbox-3 package. All participants performed the experiment in a quiet, dimly lit room at the CIMeC Psychophysic lab (Rovereto, Italy) using the same desktop computer, same monitor (size 23.6″, resolution 1920 × 1080 pixels), and same mouse, and sitting at a distance of approximately 50 cm from the screen. Eighteen participants requested and obtained university credits for their participation.

[1] This work typically employs a verification task: Given a scene depicting a variable proportion of target and non-target dots and a sentence embedding a quantified expression, participants are asked to quickly verify the semantic truth value of the sentence. What these studies showed is that errors and reaction times are typically affected by perceptual difficulty in observance to Weber's law.