

Talking about quantities in space: Vague quantifiers, context and similarity

KENNY R. COVENTRY*

*Hanse Institute for Advanced Studies
Northumbria University*

ANGELO CANGELOSI

University of Plymouth

STEPHEN E. NEWSTEAD

University of Plymouth

DAVI BUGMANN

University of Plymouth

Abstract

In this paper we examine how vague quantifiers, such as few, several, lots of, map onto non-linguistic number systems. In particular our focus is to examine how judgements about vague quantifiers are affected by the presence of objects in visual scenes other than those being referred to. An experiment is presented that manipulated the number of objects in a visual scene (men playing golf; the 'focus' objects) together with the number of other objects in those scenes and their similarity—in terms of form (women or crocodiles) and function (playing golf, not playing golf)—to the focus objects. We show that the number of other objects in a scene impacts upon quantifiers judgements even when those objects are in a different category to the focus objects. We discuss the results in terms of the mapping between the large approximate number (estimation) system and language.

Keywords

Quantifiers, approximate number system, visual attention, context

* Correspondence address: Kenny R. Coventry, Cognition and Communication Research Centre, School of Life Sciences, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK. E-mail: kenny.coventry@northumbria.ac.uk.

1. Introduction

Understanding and communicating quantity is fundamental to human science and technology (Condry and Spelke 2008). There are two ways languages use to communicate information about number, associated with different (non-linguistic) number systems. The first method is to use natural number terms that refer to a precise number of objects. “One hundred and one Dalmatians” refers to 101 objects, and there is a one-to-one mapping between the number term and the number of objects referred to. This method of talking about number has been the subject of much recent interest given that some languages do not have words for exact numbers beyond 3 or 4 objects. Gordon (2004; see also Pica et al. 2004) claimed that the lack of number terms in Amazonian languages resulted in poorer performance in Pirahã speakers compared to English speakers across a range of tasks requiring the reproduction of exact numbers of objects. However the interpretation of these results remains controversial (see for example Casasanto 2005; Frank et al. 2008a, 2008b).

The second way in which a language can describe a number of objects is with the use of vague quantifiers. Terms such as *few*, *some*, *many*, and *lots of* do not refer to exact numbers, and most closely map onto a second number system that appears to be common to pre-linguistic infants, adults and many animals. This is the ability, even in the absence of an ability to use exact number, to approximate numbers (what has been termed the large, approximate number system; Condry and Spelke 2008). For example, when a number of objects is presented for a short period of time where counting is not possible, infants (e.g. Xu et al. 2005), adults with and without specific number terms in their language (e.g. Gordon 2004; Pica et al. 2004; Mandler and Shebo 1982; Trick and Pylyshyn 1993) and some animals (e.g. Hauser et al. 2003) show systematic errors in estimation in line with Weber’s law; the variability of their estimates tends to increase as the target set size increases.

Much of the focus on the mapping between number terms in language and number systems has been with the exact number system. Yet it may well be the case that languages without exact number terms greater than 2, 3 or 4 have vague quantifiers beyond exact number terms, and that corresponding difficulties with exact number have to do with language which is inherently vague to describe quantities (see Frank et al. 2008 for related discussion). Although English speakers are able to count and use exact number terms, in many situations they, too, use vague quantifiers to describe a number of objects. Under many circumstances vague quantifiers afford communication with less effort than the use of exact number terms in the same situations. For example, *there are lots of skiers on the slope* serves to indicate that the slope is busy, which may affect whether the hearer chooses to go skiing or decides to leave it for another day. Using exact numbers in such situations is effortful and time

consuming—counting the number of skiers may take a while, and in fact may not be possible as the skiers are continually moving.

In this paper we focus on vague quantifiers, and how they map onto numbers of objects. In particular we explore how the context in which a quantity of objects occurs affects judgements of vague quantifiers to describe those quantities. Our focus is to examine how other objects in the visual scene presented along with the objects being referred to using a vague quantifier impacts on vague quantifier judgements. Specifically we ask whether the similarity of those objects to the objects referred to affects quantifier judgements. In other words, is *there are lots of men skiing on the slope* influenced by numbers of women skiing, and/or other people watching the skiers, and/or the number of trees on the slope? Prior to presenting a new study designed to start to unpack how other objects and their similarity to the objects being described affects vague quantifier descriptions, we briefly review work on vague quantifier meaning illustrating that the mapping between vague quantifiers and number is affected by a range of variables in addition to the number of objects present.

2. Vague quantifiers and context

Vague quantifiers, whether they be of number (e.g. *many*), amount (e.g. *much*), or time/frequency (e.g. *often*) pervade natural language, and therefore constitute an essential part of the lexicon for the child to acquire. In AI, computational models and applications that use linguistic quantifiers and fuzzy quantification cover a wide range of domains. Vague quantifiers are necessary in natural language processing systems (e.g. Allen 1987; Alshawi 1990; Saba and Coriveau 1997), database access and retrieval (e.g. Weining Zhang et al. 1995), data mining (e.g. Kacprzyk 1999), financial decision making (e.g. Jager 1995), Internet and e-commerce (e.g. Cox 2001), control systems (e.g. Franceschini and Romano 1999), and expert systems (e.g. da Rosa et al. 1997). Furthermore, quantifiers play a crucial role in the design of many questionnaires, which are used as evaluation tools across a wide range of contexts, from usability of websites to personality assessments. Additionally, quantifiers occur across a range of reasoning problems, including syllogistic reasoning, and thus also constitute an important part of the understanding of non-monotonic and qualitative reasoning.

Historically, research on the understanding of vague quantifiers has often assumed that quantifiers refer to points or ranges on a scale. In its most extreme form, the temptation has been to treat quantifiers in terms of a quantifier-to-number mapping (e.g. Bass et al. 1984; Reyna 1981), thereby assuming that quantifiers relate to the first number system and therefore behave just like exact number terms. This approach has appeal from a computational point of view as

individual quantifiers can be represented on a scale; a scene can be parsed for the number of entities present, and the mapping between the number and the quantifier associated with the appropriate point on the scale can be easily achieved. However, the idea that quantifiers, such as *a few*, *some*, *many*, and *lots of* refer to a specific number of objects or a specific range of numbers has been challenged by a battery of empirical findings showing that the number referred to varies dramatically as a function of a range of variables beyond the actual number of objects presented. As Moxey and Sanford (1993) have argued, “the extent to which some possible interpretation is paramount will depend on the current situational context” (1993: 108). Here we briefly review some of these contextual variables.

The appropriate vague quantifier to describe a quantity is affected by knowledge of the objects concerned and expectations regarding the number of those objects expected in specific situations. Newstead and Collis (1987) found that to visit the cinema *often* represents more times per year than to visit the USA *often*. This suggests that expected rates may be used as a standard against which frequency expressions are calibrated. Similarly *some people in front of the fire station* is associated with a smaller number of people than *some people in front of the cinema* (Moxey and Sanford 1993). Our expectations suggest that large numbers of people would be present outside the cinema, but not outside the fire station, and this knowledge affects the specific estimated numbers associated with *some* in this case. Set size also affects the appropriateness with which an individual quantifier can be used. For example, Newstead et al. (1987) showed that, when questions such as ‘*how many out of 10,000 is some?*’ were asked, the appropriate number for quantifiers went up with set size, and the proportion did not remain fixed with changing set size. By the same token *lots of pandas* is associated with a smaller number than *lots of horses* as the set of all pandas is smaller than the set of all horses.

In addition to studies showing that expected frequency and set size affect quantifier judgements, a further series of studies has found that the size of objects also appears to affect how quantities are described. Hormann (1983) originally observed that the size of an object influences the quantifier used to describe a number of those objects. For example, *a few crumbs* is associated with estimates of more than eight, but *a few shirts* is associated with about four. Similarly *a few large cars* means a smaller number than *a few cars*.

In a series of experiments, Newstead and Coventry (2000) set out to test whether the relative size of objects influences the appropriateness of quantifiers to describe pictures showing a quantity of objects (balls) in a container (a bowl). The size of balls and bowl was varied (small balls, large balls, small bowl, large bowl), thereby manipulating the number of objects that could be contained by the container. They found that high magnitude quantifiers (*many*, *lots*; e.g. *there are many balls*) were rated as more appropriate when there was

a low size differential (i.e. large balls in a bowl) and low magnitude quantifiers (*a few, few*) were more rated as more appropriate when there was a large size differential (e.g. small balls in the same size of bowl). Furthermore, Newstead and Coventry also found that when the large balls in the bowl were piled above the rim of the bowl (and therefore were positioned such that the balls would be likely to fall out should the container be moved), appropriateness ratings for high magnitude quantifiers actually decreased with increasing number. Similarly, tilting the bowl such that the objects may fall out was also found to affect the ratings of quantifiers. These latter two effects mirror effects found for spatial expressions to describe similar scenes (e.g. *the ball is in the bowl*; cf. Coventry and Garrod 2004), although in Newstead and Coventry's study the sentence to be rated did not include a prepositional phrase. It would appear that situational knowledge—in this case the knowledge that the balls are likely to fall out the bowl—affects linguistic judgements about quantity as well as spatial relations.

In addition to knowledge of objects and object features affecting the mapping between quantifiers and number, it has also been shown that vague quantifiers are affected by the likes and dislikes of the speaker using them. Goocher (1965) found that people who do not like an activity, or do not participate in that activity, use higher denoting expressions to describe the same frequency of activity than do participants who do like the activity or participate in it regularly. Chase (1969), Newstead and Griggs (1984) and Wright et al. (1994) found that the ratings of the same quantifier were affected by other quantifiers presented in the judgement set (if they were predominantly high-frequency or low-frequency terms).

Finally, Moxey and Sanford (1993) have shown across a wide range of experimental settings that quantifiers control the pattern of inference made by a hearer. While *a few people went to the party* and *few people went to the party* seem to denote similar quantities, the focus in the first expression is the people who went to the party, but in the second expression the focus is on the people who did not go to the party. Thus the sentence continuation *they went to the cinema instead* is appropriate for the second sentence, but wholly inappropriate for the first. Moxey and Sanford (1993) have also argued persuasively that the presence of negation can influence the focus of quantified expressions. For example, an affirmatively quantified statement such as *at most 10 people went to the match* tends to direct attention to those who did go to the match, while the negatively quantified expression *no more than 10 people went to the match* focuses attention on those who did not go (Moxey et al. 2001). Thus Moxey and Sanford argue that quantifiers manipulate attention and patterns of inference and that context effects of the type reviewed are not mere pragmatic additions to information about number, but play a crucial role in language comprehension for vague quantifiers.

3. The origins of context effects

Given these myriad context effects, some authors have argued that quantifiers are not about number at all (Moxey and Sanford 1993). Yet clearly, as the number of objects increases, the appropriateness of high magnitude quantifiers increases and the appropriateness of low magnitude quantifiers diminishes. Coventry and colleagues (Coventry et al. 2005a; Coventry et al. in preparation; see also Halberda 2008b; Pietroski et al. 2009) have argued that vague quantifiers map onto the second number system—that is the approximate number system—and therefore that there is robust mapping between language and numerical understanding for both exact and approximate number systems.

In a series of experiments Coventry et al. (2005a; in preparation) asked participants to estimate a quantity of objects when presented visually for 500 msec—a presentation time short enough to eliminate counting as a strategy. Different participants rated the acceptability of sentences containing vague quantifiers (*a few, few, several, many, lots of*) to describe the same pictures. The visual scenes manipulated several variables in addition to the number of objects to be estimated/verbally evaluated. These included the number of other objects present in a scene, how far apart the objects were spaced, how many other objects were presented with the focus objects, whether the focus and non-focus objects were grouped separately or mixed together, and how many other objects were presented (see Figure 1). For example, participants judged the appropriateness of sentences of the form *There are a few/few/several/many/lots of striped fish*, or they judged how many striped fish were briefly presented. The number of striped fish varied from 3–18 (in increments of 3 striped fish), and these fish were presented with varying numbers of white (non-striped) fish.

Coventry et al. found that the number of white fish presented with the striped fish impacted upon estimations of how many striped fish were presented, and similarly affected judgements of both high magnitude and low magnitude quantifiers to describe the same pictures. When the number of white fish increased, judgements for high magnitude quantifiers to describe the number of striped fish generally decreased and judgements for low magnitude quantifiers increased. Similarly, when the number of white fish increased, participants estimated there to be fewer striped fish when scenes were presented briefly. How far apart the fish were spaced, and whether they were grouped together or separately also impacted on quantifier judgements and number estimation judgements. Moreover, Coventry et al. (in preparation) show that when participants are asked to count the number of striped fish prior to giving their judgements, the effects of number of other objects, grouping and spacing disappears.

Coventry et al. (2005a) argue that the lack of success of scalar approaches to quantifiers in the literature, and the corresponding abandonment of this ap-

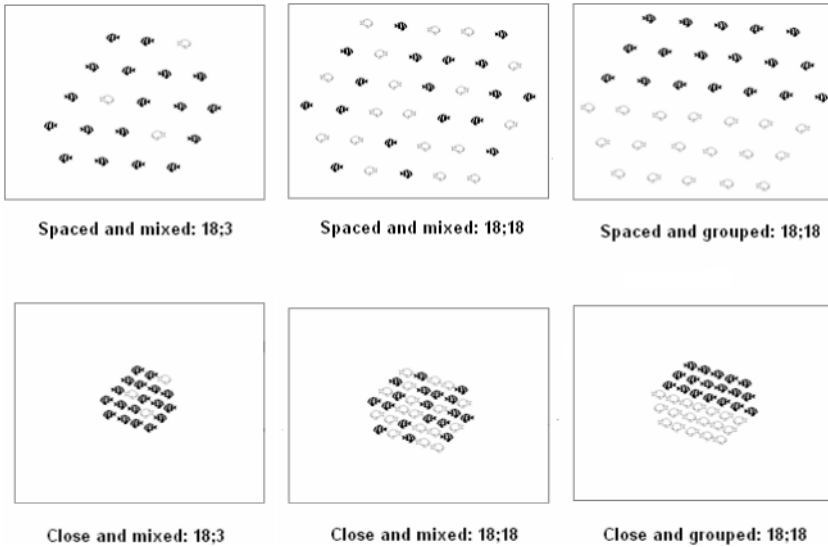


Figure 1. *Examples of stimuli used by Coventry et al. (2005a, in preparation). The scenes show 18 focus objects (striped fish) presented with different numbers of other (white) fish, with close or far spacing, and grouped either separately or mixed together. Participants had to judge how many striped fish were shown immediately after each scene had been presented for 500 msec. Different participants rated the appropriateness of “There are QUANT striped fish” to describe the same scenes (where QUANT = a few, few, several, many, lots of). Coventry et al. show that the contextual manipulations affect both language judgements and number estimations.*

proach (cf. Moxey and Sanford 1993), has been as a result of a conflation of number with the actual number of objects being referred to. Indeed, there is recent evidence to suggest that understanding of exact number and understanding of quantifiers are dissociated. Hurewitz et al. (2006) report asymmetries in the acquisition of exact number terms and quantifier expressions in children between the ages of 3 and 4 years.

A more fruitful linkage is between the large approximate number system, and vague quantifiers, as is illustrated in the above overview of experiments. The estimated numbers returned from visual attentional constraints under time pressure allow number to predict the appropriateness of natural language quantifiers. A range of “contextual” parameters affect judgements of number just as they affect judgements of quantifiers to describe the same scenes.

This mapping between the approximate number system and understanding of vague quantifiers is also supported by the work of Halberda and colleagues. Halberda et al. (2008b) found that comprehension of *most* in preschool children

is independent of knowledge of large exact number terms. Some children exhibit understanding of *most* without understanding exact number, while other children exhibited the reverse pattern. In contrast, Halberda et al. (2008b) and Pietroski et al. (2009) point to a link between understanding of the specific term *most* and the approximate number system, consistent with the approach taken by Coventry et al. (2005a).

4. The present experiment

One important issue arising from the Coventry et al. studies is whether the similarity of the other objects in the scene to the focus objects affects judgements, or alternatively whether it is the visual appearance of the scene that affects judgements. One possibility is that an increasing number of other objects simply affect how the visual array looks so that it appears that there are more or fewer objects presented, and as a consequence the estimated numbers and quantifier ratings are affected. If this is the case, then the nature of the objects (aside from their size and visual appearance) should not affect the extent to which quantifier judgements are affected by the number of other objects. Alternatively, it may be the case that participants consider the total number of focus objects in relation to the set of focus and non-focus objects when making their judgements. In the studies of Coventry et al. the other objects presented were always of the same species as the objects to be enumerated/rated (e.g. striped fish and white fish). Although participants were asked to rate quantifiers to describe striped fish for example, it is possible that they considered the striped fish in the context of all the fish presented. So when the set size of striped fish plus white fish increases through increasing the number of white fish, ratings for high magnitude quantifiers go down and ratings for low magnitude quantifiers go up.

In order to test between these two possible explanations, it is necessary to manipulate the similarity of the other objects to the focus objects, that is, the extent to which the focus objects plus other objects can feasibly combine into a set.

4.1. Design

We presented pictures that manipulated the number of focus objects and the number of non-focus objects presented and critically we manipulated the similarity in form and function of the non-focus objects to the focus objects. We presented pictures of men playing golf, containing 3–18 men (in increments of 3). Mixed in with these objects we either showed 3–18 women playing golf (same function, same form), 3–18 women not playing golf (different function, same form), 3–18 crocodiles playing golf (same function, different form) or

3–18 crocodiles not playing golf (different function, different form). This was to establish whether the number of objects presented with the focus objects affects quantifier judgements only when the similarity of the objects to the focus objects is sufficient. The design was a 6 (number of focus objects: 3, 6, 9, 12, 15, 18) \times 6 (number of other objects: 3, 6, 9, 12, 15, 18) \times 5 (quantifier: *a few, few, several, many, lots of*) \times 2 (function: other objects playing golf, other objects at rest) \times 2 (species: same species = women, different species = crocodiles) mixed design. All variables were within participants except for species, which was between participants.

4.2. *Participants*

Participants were 76 sixth form students (all English native speakers) from local schools in Plymouth, UK, who took part on a voluntary basis. 37 completed the same species materials and the remaining 39 completed the different species materials.

4.3. *Procedure*

Participants were told that they would be presented with sentences and pictures and that their task was to rate how appropriate each sentence was to describe each picture using a seven point scale (from 1 = totally inappropriate to 7 = totally appropriate). The pictures were randomized and were presented in hard copy booklet form mixed in with materials from other (unrelated) experiments. Each picture was presented with sentences of the form “*There are QUANTIFIER men playing golf*” directly underneath. The quantifiers used, always presented in the same order, were *a few, few, several, many, and lots of*. The pictures were of 3, 6, 9, 12, 15 or 18 men playing golf (see Figure 2). Randomly mixed in with these objects were 3–18 women playing golf (same function, same form), 3–18 women not playing golf (different function, same form), 3–18 crocodiles playing golf (same function, different form), or 3–18 crocodiles not playing golf (different function, different form). The scenes were all black and white, and the crocodiles and women were matched for size.

We did not control the presentation time for each sentence-picture combination. Participants were given a large set of materials to complete, and consistent with the studies of Coventry et al. (2005a), we expected that this would discourage participants from using an explicit counting strategy. Moreover, in the instructions to participants we emphasized that they should not spend too long on each page as they had to complete many pages.

4.4. *Results*

The mean acceptability rating data were analysed using a 6 (number of objects) \times 6 (number of other objects) \times 5 (quantifier: *a few, few, several, many, lots*)

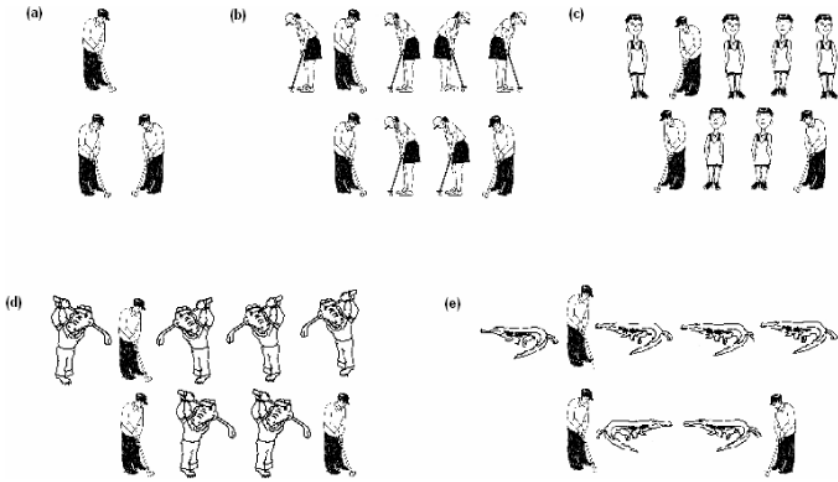


Figure 2. *Examples of scenes used in the present experiments. (a) shows three men playing golf, and (b)–(e) show three men playing golf plus six other objects. (b) shows same function, same species, (c) different function, same species, (d) same function, different species and (e) different function, different species.*

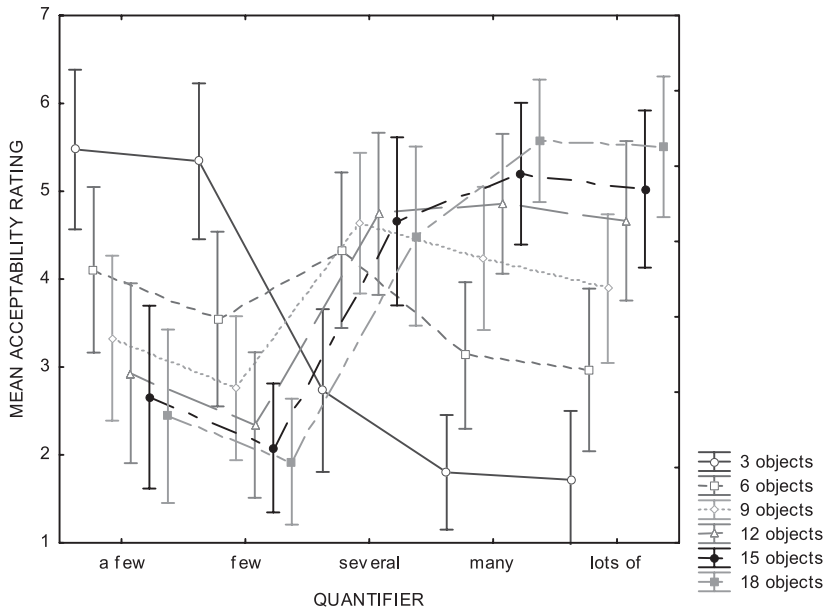


Figure 3. *The interaction between number of objects and quantifier. Bars represent 95% confidence intervals.*

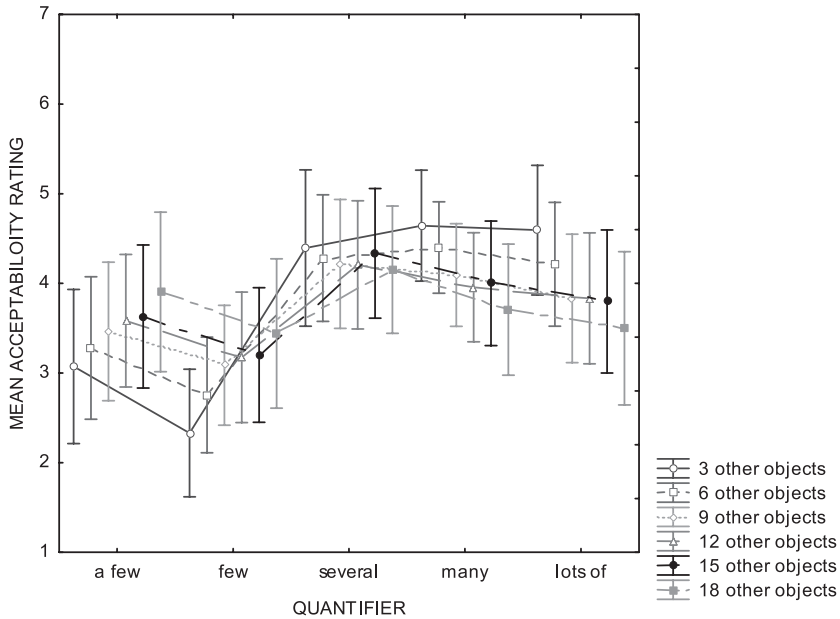


Figure 4. The interaction between number of other objects and quantifier. Bars represent 95% confidence intervals.

of) \times 2 (function: same, different) \times 2 (species: same, different) mixed ANOVA, with repeated measures on all variables except the last one.

Of primary interest in the analyses are effects involving quantifiers. There was a main effect of quantifier, $F(4, 252) = 42.52$, $MSE = 29.9$, $p < 0.0001$, and there was a significant interaction between quantifier and number of objects, $F(20, 1260) = 203.49$, $MSE = 7.0$, $p < 0.0001$, displayed in Figure 3. As expected, low magnitude quantifiers (*a few*, *few*) were rated as more appropriate to describe lower numbers of focus objects than high magnitude quantifiers (*many*, *lots of*), and vice versa for higher numbers of objects.

There were also a number of other interactions involving quantifiers. First there was a significant interaction between number of other objects and quantifier, $F(20, 1260) = 42.46$, $MSE = 2.3$, $p < 0.0001$, displayed in Figure 4. Low magnitude quantifiers were rated as being more appropriate in the presence of larger numbers of other objects, and vice versa for high magnitude quantifiers, consistent with the results reported by Coventry et al. (2005a). The three-way interaction between number of focus objects, number of other objects and quantifier was also significant, $F(100, 6300) = 4.82$, $MSE = 1.4$, $p < 0.0001$, and is displayed in Figure 5. This interaction shows several effects of interest. First, the number of other objects does not impact upon quantifier judgements

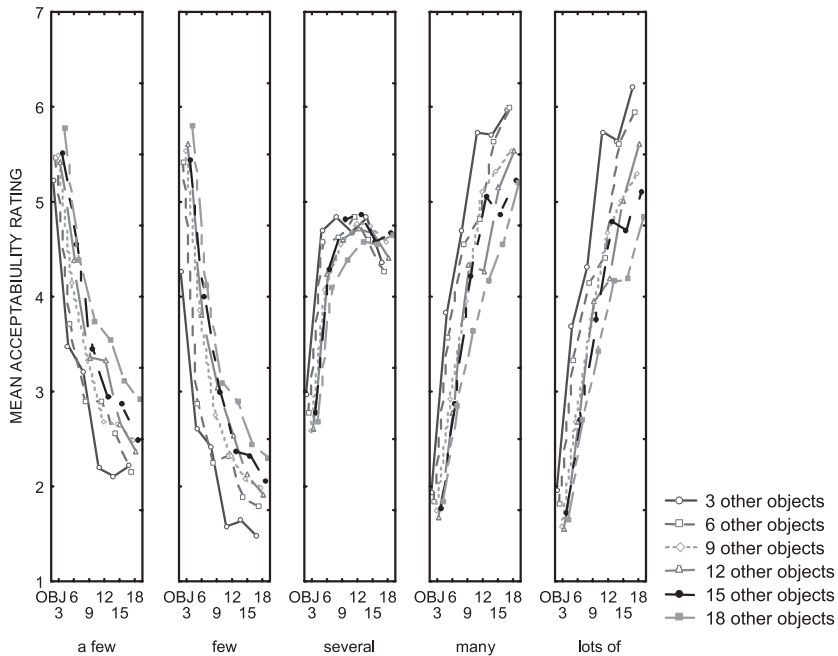


Figure 5. The interaction between number of objects, number of other objects and quantifier.

when there are only 3 focus objects, except for the case of *few*. This finding is consistent with those of Coventry et al. (2005a); 3 objects is within the ‘subitizing’ range (see Mandler and Shebo 1982), where it is neither necessary to count or to use less accurate number estimation. The exception of *few* fits with other work on context that shows that *few* focuses attention on the objects not in focus more than *a few* (and the other quantifiers used). So *few people went to the party* draws attention to the people who did not go—and consistent with this an effect of number of other objects is found for this term even when there are only three objects. Second, the effect of number of other objects appears to be more marked when the number of objects falls into the appropriate range for the use of each quantifier. So the effect of the number of other objects is more pronounced for low magnitude quantifiers (*a few*, *few*) at smaller numbers of focus objects, and vice versa for high magnitude quantifiers (*many*, *lots of*), with less marked effects for the mid range quantifier *several*.

Of most interest were a number of significant interactions involving quantifier, function and species. There were significant interactions between quantifier and function, $F(4, 252) = 11.32$, $MSE = 1.7$, $p < 0.0001$, between quantifier, function and species, $F(4, 252) = 6.62$, $MSE = 1.7$, $p < 0.0001$, between

quantifier, function and number of other objects, $F(20, 1260) = 3.06$, $MSE = 1.4$, $p < 0.0001$, and the four way interaction between quantifier, function, number of other objects and species was also significant, $F(20, 1260) = 2.40$, $MSE = 1.4$, $p < 0.001$. The central question we wanted to ask was whether the interactions between number of other objects and quantifier, and between number of objects, number of other objects and quantifier occur for all types of other objects, or alternatively whether the similarity in form and/or function between the focus objects and other objects impacts upon these interactions. In order to unpack the complex significant interactions found, we ran separate three-way ANOVAs (number of focus objects \times number of other objects \times quantifier) for each of the four types of other objects.

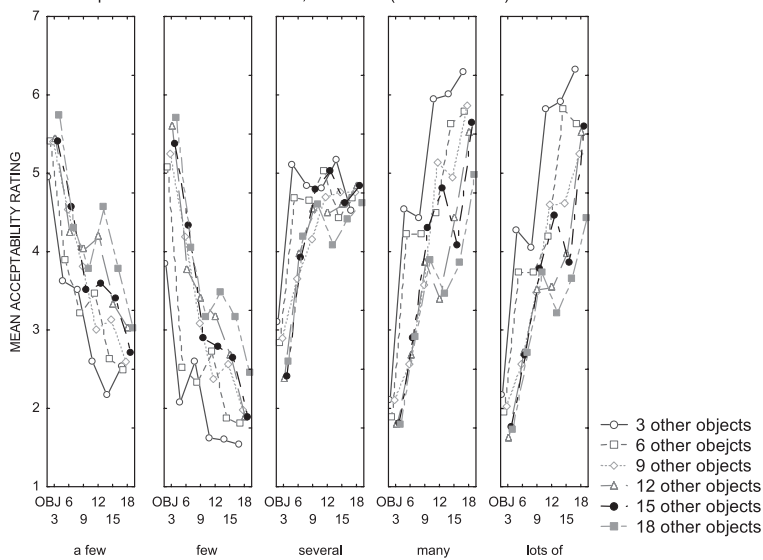
First, the two way interaction between number of other objects and quantifier was reliable for every type of other objects: same species, at rest, $F(20, 720) = 29.54$, $MSE = 1.84$, $p < 0.00001$; same species, same function, $F(20, 600) = 8.80$, $MSE = 1.79$, $p < 0.00001$; different species, at rest, $F(20, 760) = 17.36$, $MSE = 1.81$, $p < 0.00001$; different species, same function, $F(20, 660) = 12.79$, $MSE = 1.72$, $p < 0.00001$. All of these interactions exhibited the same pattern as displayed in Figure 4, with reliable effects of number of other objects for both low and high magnitude quantifiers, and in the opposite directions.

Second, the three-way interaction between number of focus objects, number of other objects and quantifier was reliable for every type of other objects: same species, at rest, $F(100, 3600) = 4.87$, $MSE = 1.24$, $p < 0.00001$; same species, same function, $F(100, 3000) = 82.49$, $MSE = 1.45$, $p < 0.00001$; different species, at rest, $F(100, 3800) = 2.35$, $MSE = 1.31$, $p < 0.00001$; different species, same function, $F(100, 3300) = 2.65$, $MSE = 1.34$, $p < 0.00001$. These interactions are displayed in Figure 6. As can be seen in this figure, the same basic pattern occurs across all four types of objects.

5. General discussion

The use of vague quantifiers is affected by a range of contextual variables including set size, size and relative size, function, expected frequency, and speakers' likes and dislikes. The present experiment examines how other objects presented with the objects described affect judgements using vague quantifiers to describe given numbers of those objects. In both the studies of Coventry et al. (2005) and in the present experiment, there were striking effects of the number of other objects presented with the focus objects on the quantifier-to-number mapping, but only when the number of focus objects increased outside the subitizing range. When there are three objects participants know there are three objects without counting, and context effects do not occur. As the number of other objects goes up, ratings for low magnitude quantifiers

Three-way interaction between number of focus objects, number of other objects and quantifier: SAME SPECIES, AT REST (women at rest)



Three-way interaction between number of focus objects, number of other objects and quantifier: SAME SPECIES, SAME FUNCTION (women playing golf)

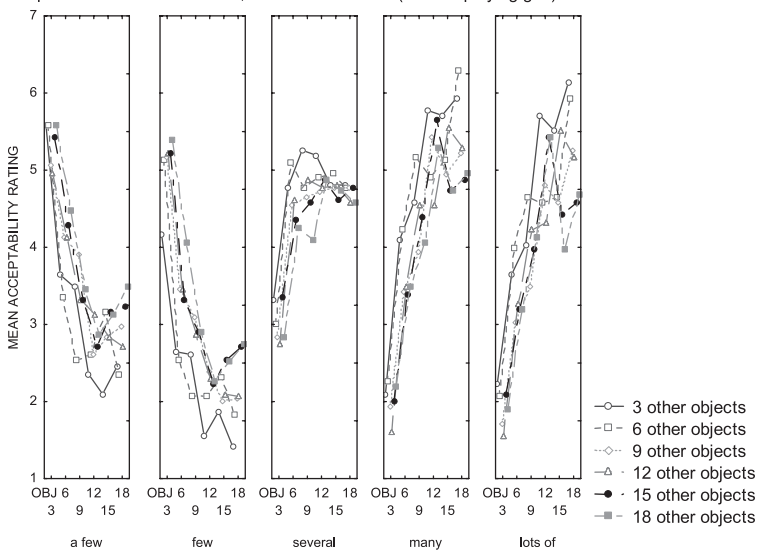
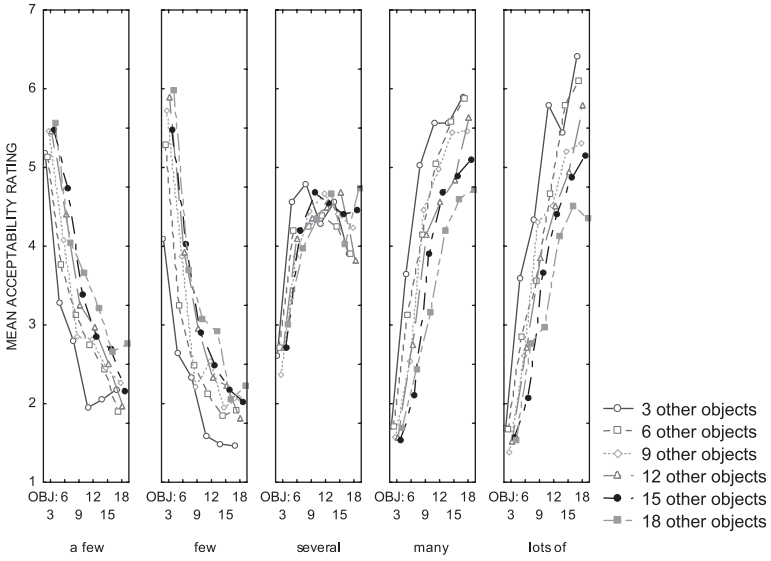


Figure 6. The interaction between number of objects, number of other objects and quantifier for each type of other object.

Three-way interaction between number of focus objects, number of other objects and quantifier: DIFFERENT SPECIES, AT REST (crocodiles at rest)



Three-way interaction between number of focus objects, number of other objects and quantifier: DIFFERENT SPECIES, SAME FUNCTION (crocodiles playing golf)

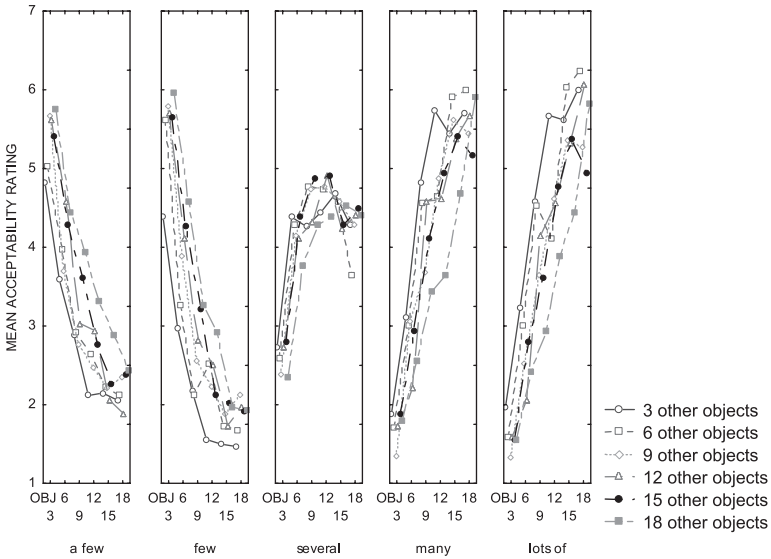


Figure 6. (Continued)

generally go down and ratings for high magnitude quantifiers go up. Moreover, the effects of number of other objects are most marked when quantifiers are appropriate to describe the number of focus objects present.

The results also begin to tease apart how objects not in focus impact on quantifier-to-number mappings. We considered two possibilities. First, it could be that other objects impact on quantifier judgements simply as a function of their visual salience. So describing a number of skiers on a slope would be affected just as much by the number of trees they are skiing around as they are by the number of women skiing. Alternatively, the number of other objects may only be important if they bear a similarity to the objects in focus. In that case, the quantifier used to describe the number of men skiing on a slope would be affected only by the number of skiers on the slope, and not by the number of trees. The results of the present experiment support the former hypothesis. Although there were interactions involving species (i.e. whether the other objects were women or crocodiles) and function (i.e. whether the other objects were performing the same activity as the focus objects), separate analyses for each type of other objects produced the key significant interactions between number of focus objects, number of other objects and quantifier, illustrating very similar patterns. This supports the view that the number of focus objects participants think is present is affected by the number of other objects, and that this in turn maps onto quantifier judgements.

In the present study we did not test how many objects participants thought were in each scene directly. However, using the same methodology, Coventry et al. found that judgements of the number of focus objects present in a visual scene were influenced by the number of other objects just as quantifier-to-picture mapping was affected by the number of other objects. Moreover, Halberda et al. (2008b) and Pietroski et al. (2009) also provide support for a linkage between the approximate number system and understanding of the quantifier *most*. Taken together, these studies suggest that different types of language to describe quantity map onto different non-linguistic number systems. Just as there is assumed to be a mapping between exact number and exact number terms, there is also a mapping between vague quantifiers in language and the large approximate number system.

Much of the focus on the mapping between number terms in language and number systems has been with the exact system. Yet vague quantifiers may well be more universal than exact number terms across languages; languages without exact number terms greater than 2, 3 or 4 have vague quantifiers for quantities greater than this (e.g. Amazonian languages). In many cases English speakers also use vague quantifiers to describe a number of objects, and accordingly may not have a good memory for the exact number of objects present following the use of these terms (see Frank et al. 2008a, 2008b). As we argued earlier, counting is effortful and time consuming, and communicating

quantity often does not require the precision the use of the exact number system affords. For example, *there are lots of biscuits in the tin* needs to communicate that there are enough biscuits to go around—a quick estimation of quantity is all that is needed.

The results showing a mapping between vague quantifiers and the large approximate number system need to be examined in other contexts. One issue is the extent to which estimates of number of objects are able to account for the other context effects we considered earlier. Certainly some of these effects can be accommodated with this basic mechanism. The size of objects, and their relative size as found by Newstead and Coventry may well lead to differences in estimates of the number of objects present just as the number of other objects affects judgements. Furthermore, it is possible that parameters such as set size and the number of object sets present also influence the approximate number system judgements (see for example Halberda et al. 2006). This will necessitate further experimental work to identify just how many of these effects have an affect on quantifier judgements by virtue of differences in estimated numbers.

The approach to quantifiers offered by Moxey and Sanford presents more of a challenge for the view that vague quantifier meaning is grounded in the approximate number system alone. Moxey and Sanford argue that quantifiers control the inferential patterns of their hearers, and that such effects are different from numbers being referred to. For example, they contrast the inferential patterns associated with two low magnitude quantifiers—*a few* versus *few*. *A few* focuses attention on the focus set, while *few* focuses attention on other objects (the complement set). *A few men are playing golf* focuses attention on the men playing golf, while *few men are playing golf* focuses attention on the people who are not playing golf. In the present experiment, we found evidence that *few* does indeed behave differently from the other quantifiers tested when there are three focus objects. There were no effects of number of other objects for *a few*, *several*, *many* or *lots of*, but an effect of number of other objects was found for *few*. Therefore the linkage between quantifiers and approximate number may be mediated by the individual quantifier concerned. Indeed as Geurts et al. (2010) point out, we should not be surprised that quantifying expressions are a heterogeneous lot. Such an approach to quantifiers resembles work on spatial prepositions—another relatively small category of high frequency words. Although individual prepositions are associated with the same basic geometric and extra-geometric relations, it has been shown that these parameters are weighted individually by lexical item (cf. Coventry and Garrod 2004). So too might multiple constraints be at play with vague quantifiers, with each quantifier weighting these constraints in context.

One can also ask about the origins of the mapping between approximate number and vague quantifiers. Is the approximate number system fully in place

prior to the understanding of vague quantifiers, for example? There is surprisingly little empirical work examining vague quantifier comprehension and production from a developmental perspective. Certainly, since the original work of Inhelder and Piaget (1958) it has been recognised that quantifiers present a challenge for the child and more recently it has been established that understanding of these terms develops gradually between the ages of two and five years (see for example Barner et al. 2009). However, developmental work on vague quantifiers is much more limited than work on other types of quantifiers with a main focus on research examining quantifiers in reasoning and inference.

Although the approximate number system is an evolutionary old system common across humans and some non-human species, there is not much work to date that has examined how this system develops. Halberda and colleagues offer notable exceptions to this. First, Halberda and Feigenson (2008) tested children across a range of age groups (from three to six years) as well as a group of adults on a number discrimination task that did not permit counting, and therefore engaged the approximate number system. They found that the approximate number system continues to develop (in terms of increased acuity) until early adolescence. Second, employing an individual differences methodology, Halberda et al. (2008b) have shown that there are surprisingly large differences in number approximation abilities of children at 14 years of age (that also correlates with performance on standardised maths achievement test scores). So just as talking about number using vague terms develops over time, so, too, does approximate number estimation ability.

To get at the mapping between approximate number and vague quantifier use, a novel approach has been to use computational modelling to examine whether being able to estimate numbers affects the speed with which one can learn to map vague quantifiers onto numbers of objects. Conversely, modelling can also test whether the reverse is the case: whether learning how to map vague quantifiers onto numbers of objects affects the speed with which approximate number estimation is learned. We developed a computational model consisting of a modular (connectionist) artificial neural network trained to reproduce the experimental data on number estimation and quantifier ratings from the experiments described in Coventry et al. (2005a, in preparation) that we reviewed earlier. The model is based on modular connectionist architecture for perceptual grounding of language (Coventry et al. 2005b; Cangelosi et al. 2005). Using this approach Coventry et al. (in preparation) show that approximate number estimation and vague quantifier understanding bootstrap each other during learning. These results are consistent with recent 'epigenetic' approaches to the development of language that view language development as emerging from a gradual multi-causal process (see for example Spencer et al. 2009 for discussion). Future developmental work would do well to target the issue of the degree of synchronization of the development of approximate

number systems judgements and vague quantifier understanding in visual scenes within a range of contexts.

References

- Allen, J. 1987. *Natural language understanding*. Menlo Park, CA: Benjamin/Cummings.
- Alshawi, H. 1990. Resolving quasi logical forms. *Computational Linguistics* 16. 133–144.
- Barner, D., K. Chow & S.-J. Yang. 2009. Finding one's meaning: A test of the relation between quantifiers and integers in language development. *Cognitive Psychology* 58. 195–219.
- Bass, B. M., W. F. Cascio & E. J. O'Connor. 1984. Magnitude estimations of frequency and amount. *Journal of Applied Psychology* 53. 313–320.
- Cangelosi, A., K. Coventry, R. Rajapakse, D. Joyce, A. Bacon, L. Richards, S. Newstead. 2005. Grounding language in perception: A connectionist model of spatial terms and vague quantifiers. In A. Cangelosi, G. Bugmann & R. Borisjuk (eds.), *Modelling language, cognition and action: Proceedings of the 9th neural computation and psychology workshop*, 47–56. Singapore: World Scientific.
- Casasanto, D. 2005. Crying “Whorf”. *Science* 307. 1721–1722.
- Chase, C. I. 1969. Often is where you find it. *American Psychologist* 24. 1043.
- Condry, K. F. & E. S. Spelke. 2008. The development of language and abstract concepts: The case of natural number. *Journal of Experimental Psychology: General* 137(1). 22–38.
- Coventry, K. R., A. Cangelosi, S. N. Newstead, A. Bacon & R. Rajapakse. 2005a. Grounding natural language quantifiers in visual attention. In B. G. Bara, L. Barsalou & M. Bucciarelli (eds.), *Proceedings of the 27th Annual Conference of the Cognitive Science Society*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Coventry, K. R., A. Cangelosi, R. Rajapakse, A. Bacon, S. Newstead, D. Joyce & L. V. Richards. 2005b. Spatial prepositions and vague quantifiers: Implementing the functional geometric framework. In C. Freksa, M. Knauff, B. Krieg-Bruckner & B. Nebel (eds.), *Spatial cognition, volume IV. Reasoning, action and interaction*, 98–110. Lecture notes in computer science. Berlin: Springer-Verlag.
- Coventry, K. R., A. Cangelosi, S. Newstead, R. Rajapakse, D. Bugmann & A. Bacon. in preparation. Number estimation and talking about number bootstrap each other during learning.
- Coventry, K. R. & S. C. Garrod. 2004. *Seeing, saying and acting. The psychological semantics of spatial prepositions*. Hove: Psychology Press.
- Cox, E. 2001. Fuzzy logic and the measures of certainty in eCommerce expert systems. *PC AI* 15(3). 16–22.
- da Rosa, V. S., F. G. Beckenkamp & N. Hoppen. 1997. The application of fuzzy logic to model semantic variables in a hybrid model for classification expert system. In N. Steele (ed.), *ISFL '97. Second International ICSC Symposium on Fuzzy Logic and Applications*, 301–7. Zurich: Academic Press.
- Franceschini, F. & D. Romano. 1999. Control chart for linguistic variables: A method based on the use of linguistic quantifiers. *International Journal of Production Research* 37(16). 3791–801.
- Frank, M. C., D. L. Everett, E. Fedorenko & E. Gibson. 2008a. Number as cognitive technology: Evidence from Pirahã. *Cognition* 108. 818–824.
- Frank, M. C., E. Fedorenko & E. Gibson. 2008b. Language as cognitive technology: English speakers match like Pirahã when you don't let them count. *Proceedings of the 30th annual meeting of the Cognitive Science Society*. 439–444.
- Geurts, B., N. Katsos, C. Cummins, J. Moons & L. Noordman. 2010. Scalar quantifiers: Logic, acquisition and processing. *Language and Cognitive Processes* 25. 130–148.
- Goocher, B. E. 1965. Effects of attitude and experience on the selection of frequency adverbs. *Journal of Verbal Learning and Verbal Behavior* 4. 193–195.

- Gordon, P. 2004. Numerical cognition without words: Evidence from Amazonia. *Science* 306. 496–499.
- Halberda, J. & Feigenson, L. 2008. Developmental change in the acuity of the “Number Sense”: The approximate number system in 3-, 4-, 5-, 6-year-olds and adults. *Developmental Psychology*, 44(5). 1457–1465.
- Halberda, J., Mazocco, M. & Feigenson, L. 2008a. Individual differences in nonverbal number acuity predict maths achievement. *Nature*, 455. 665–668.
- Halberda, J., S. F. Sires & L. Feigenson. 2006. Multiple spatially overlapping sets can be enumerated in parallel. *Psychological Science* 17(7). 572–576.
- Halberda, J., L. Taing & J. Lidz. 2008b. The development of “Most” comprehension and its potential dependence on counting ability in preschoolers. *Language Learning and Development* 4(2). 99–121.
- Hauser, M. D., F. Tsao, P. Garcia & E. S. Spelke. 2003. Evolutionary foundations of number: Spontaneous representation of numerical magnitudes by cotton-top tamarins. *Proceedings of the Royal Society, London*, B 270. 1441–1446.
- Hormann, H. 1983. Then calculating listener, or how many are einige, mehrere and ein paar (some, several and a few). In R. Bauerle, C. Schwarze & A. von Stechow (eds.), *Meaning, use and interpretation of language*. Berlin: Mouton de Gruyter.
- Hurewitz, F., A. Papafragou, L. Gleitman & R. Gelman. 2006. Asymmetries in the acquisition of numbers and quantifiers. *Language Learning and Development* 2. 77–96.
- Inhelder, B. & J. Piaget. 1958. *La genèse des structures logiques élémentaires: Classifications et Sériations*. Delachaux et Niestlé, Neuchâtel. [English translation published (1964): *The early growth of logic in the child: Classification and seriation*. Routledge and Kegan Paul, London].
- Jager, R. R. 1995. Multicriteria decision making using fuzzy quantifiers. In *Proceedings of the IEEE/IAFE 1995 Computational Intelligence for Financial Engineering*, 42–46. New York: IEEE.
- Kacprzyk, J. 1999. Mining sales data at a computer retailer via fuzzy-logic-based linguistic. In T. Gedeon, P. Wong et al. (eds.), *ICONIP'99 6th International Conference on Neural Information Processing*, 591–596. Piscataway, NJ: IEEE.
- Mandler, G. & B. J. Shebo. 1982. Subitizing: An analysis of its component processes. *Journal of Experimental Psychology: General* 111. 1–22.
- Moxey, L. M. & A. J. Sanford. 1993. *Communicating quantities. A psychological perspective*. Hove, East Sussex: Lawrence Erlbaum Associates.
- Moxey, L. M., A. J. Sanford & E. J. Dawydiak. 2001. Denials as controllers of negative quantifier focus. *Journal of Memory and Language* 44. 427–442.
- Newstead, S. E. & J. Collis. 1987. Context and the interpretation of quantifiers of frequency. *Ergonomics* 30. 1447–1462.
- Newstead, S. E. & K. R. Coventry. 2000. The role of context and functionality in the interpretation of quantifiers. *European Journal of Cognitive Psychology* 12(2). 243–259.
- Newstead, S. E. & R. A. Griggs. 1984. Fuzzy quantifiers as an explanation of set inclusion performance. *Psychological Research* 46. 377–388.
- Newstead, S. E., P. Pollard & D. Reizebos. 1987. The effect of set size on the interpretation of quantifiers used in rating scales. *Applied Ergonomics* 18. 178–182.
- Pica, P., C. Lemer, V. Izard & S. Dehaene. 2004. Exact and approximate arithmetic in an amazonian indigene group. *Science* 306(5695). 499–503.
- Pietroski, P., J. Lidz, T. Hunter & J. Halberda. 2009. The meaning of ‘Most’: Semantics, numerosity and psychology. *Mind and Language* 24(5). 554–585.
- Reyna, V. F. 1981. The language of possibility and probability: Effects of negation on meaning. *Memory and Cognition* 9. 642–650.

- Saba, W. & J.-P. Corriveau. 1997. A pragmatic treatment of quantification in natural language. *Proceedings of the AAAI national conference on artificial intelligence and 9th innovative applications of artificial intelligence conference (AAAI97-IAAI97)*, 610–615.
- Spencer, J. P., M. S. Blumberg, B. McMurray, S. R. Robinson, L. K. Samuelson & J. B. Tomblin. 2009. Short arms and talking eggs: Why we should no longer abide the nativist-empiricist debate. *Child Development Perspectives* 3(2). 79–87.
- Trick, L. M. & Z. Pylyshyn. 1993. What enumeration studies can show us about spatial attention: Evidence for preattentive processing. *Journal of Experimental Psychology: Human Perception and Performance* 19. 331–351.
- Weining Zhang, Y. C., B. Reagan & H. Nakajima. 1995. Context-dependent interpretations of linguistic terms in fuzzy relational databases. In P. S. Yu & A. L. P. Chen (eds), *Proceedings of the 11th International Conference on Data Engineering*, 139–146. Taipei, Taiwan & Los Alamitos, CA: IEEE Computer Society Press.
- Wright, D. B., G. D. Gaskell & C. O’Muircheartaigh. 1994. How much is “quite a bit”? Mapping between numerical quantities and vague quantifiers. *Applied Cognitive Psychology* 8. 479–496.
- Xu, F., E. S. Spelke & S. Goddard. 2005. Number sense in human infants. *Developmental Science* 8(1). 88–101.