Short Research Article

Comparative Judgment of Familiar Objects Is Modulated by Their Size

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Abstract: Perceptual decisions such as that we have more strawberries than apples left in our fruit basket seem to be made effortlessly. However, it is not examined yet whether such decisions are also biased by the size of the objects, just like numerosity comparisons with meaningless dot arrays. We presented two homogeneous sets of larger and smaller fruits (e.g., three apples and four strawberries), and participants had to indicate which set was more numerous. Although accuracy was nearly perfect, a strong congruency effect was found in reaction times, showing it is more difficult to compare the numerosities of sets of 2 apples and 3 strawberries than the opposite, that is, 3 apples and 2 strawberries. Because the stimuli were selected to simulate everyday conditions as much as possible, the present results suggest that most likely also comparative numerosity judgment in daily life is biased by nonnumerical cues such as size of the objects.

Keywords: numerosity, comparative judgments, familiar objects, subitizing

Comparative numerosity judgments of familiar objects, like deciding there are more apples than strawberries in the fruit basket, are part of our everyday behavior. Intuitively, we feel that we are capable of doing this without much interference from non-countable continuous information like the size of the objects: For instance, deciding that apples are more numerous than strawberries is subjectively not more difficult than deciding there are more strawberries than apples. To make such comparative judgments, it has been suggested that humans are equipped with an approximate number sense (ANS) which enables humans to perceive, manipulate, and understand number independent of other non-countable information (Dehaene, 1997; Feigenson, Dehaene, & Spelke, 2004). This sense of number is not unique for humans, and numerical abilities have been reported in animals (Agrillo, Miletto Petrazzini, & Bisazza 2016; Pahl, Si, & Zhang, 2013) and infants (Libertus & Brannon, 2010; Starr, Libertus, & Brannon, 2013; Xu, Spelke, & Goddard, 2005).

Recently, the existence of such a sense of number is debated (Gebuis, Cohen Kadosh, & Gevers, 2016; Leibovich, Katzin, Harel, & Henik, 2017). More specifically, it is suggested that not discrete number but non-countable magnitudes like density of the objects, total area of all objects, or size of the individual objects are automatically extracted from visual sets of objects and affect perception of numerosity (see also Meck & Church, 1983, for a similar idea a long time ago). In most of the studies addressing this timely debate in the field of numerical cognition, two dot arrays are presented that need to be compared on the basis of numerosity (e.g., Gebuis & Reynvoet, 2012a; Halberda & Feigenson, 2008; Halberda, Mazzocco, & Feigenson, 2008; Leibovich & Henik, 2014; Piazza, Izard, Pinel, Le Bihan, & Dehaene, 2004).

Researchers are well aware there exists a natural correlation between numerosity and other non-countable information (total surface, density…). For instance, if all dots have the same size, the more numerous dot patterns will also have a larger total surface and a larger density. Therefore, to ensure that these comparative judgments are based on numerosity and not on non-countable magnitudes, researchers attempt to control these non-countable features in many different ways (see Leibovich et al., 2017; Smets, Moors, & Reynvoet, 2016 for overviews). Despite these controls, participants' performance is still characterized by a numerical ratio effect, showing a decrease in performance when the ratio between both dot arrays approaches 1. It is argued that the presence of a numerical ratio effect shows that performance must be based on numerosity information because all other non-countable magnitudes are supposed to be controlled for (Halberda et al., 2008; Piazza, 2010). However, this overall performance pattern is typically the result of aggregating different types of trials. Several methods that attempt to control for non-countable cues result in a trial list that contains congruent trials (i.e., trials where numerosity and non-countable information positively correlate; e.g., the more numerous set has larger total surface) and incongruent trials (i.e., trials where numerosity and

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non-countable cues negatively correlate; e.g., the more numerous set has smaller total surface). Studies that have looked into congruent and incongruent trials separately have shown that performance on incongruent trials is worse than on congruent trials (e.g., Clayton, Gilmore, & Inglis, 2015; Clearfield & Mix, 2001; Gebuis & Reynvoet, 2012a; Leibovich, & Henik, 2014; Szűcs, Nobes, Devine, Gabriel, & Gebuis, 2013), indicating that non-countable magnitudes are still processed, despite their irrelevance for the task. From a developmental perspective, this interference from non-countable cues seems to decrease with increasing age. Three-to-five-year-old children relied more on non-countable magnitudes than number (Rousselle & Noël, 2008; Soltész, Szűcs, & Szűcs, 2010), and the influence of non-countable magnitudes decreases with increasing age (e.g., Defever, Reynvoet, & Gebuis, 2013) but still remains visible in adults (Clayton et al., 2015; Gebuis & Reynvoet, 2012a; Leibovich, & Henik, 2014).

Two recent reviews dealt with these effects of non-countable magnitudes on number perception (Gebuis et al., 2016; Leibovich et al., 2017). According to Gebuis et al. (2016), numerosity cannot be extracted independently and is computed indirectly as the weighted product of all non-countable cues of the dot array. As a consequence, comparative judgments of numerosity are confounded by non-countable cues. Leibovich and colleagues (2017) suggested that humans are not endowed with a "sense of number." Initially, non-countable cues are extracted automatically. Through statistical learning of the relation between numerosity and non-countable information (i.e., number is positively related to nonnumerical cues in daily life) and later, the introduction of verbal numerals, we develop a sense of number that processes number in parallel with non-countable cues. To make accurate comparative judgments of numerosity, inhibition is then required. When the inhibition abilities are well developed, non-countable cues can be ignored resulting in more efficient performance in a numerosity comparison task. Crucially, despite the different underlying processes, both accounts have in common that they can easily account for the fact that comparative judgments of numerosity are influenced by non-countable cues.

So far, all studies addressing numerosity comparison have used abstract dot arrays as stimuli, implicitly assuming that the findings can be generalized to how we actually perceive the numerosity of sets of objects in daily life. However, there is a huge leap from how we perceive numerosity in the laboratory conditions to real-life numerosity perception. Rarely, numerosity decisions have to be made on sets containing abstract objects. In most cases, numerosity decisions are made on sets of familiar, known objects. Accordingly, it can be questioned whether the results we described so far can be generalized to numerosity decisions on familiar objects. More specifically, it is possible that familiarity of the objects stimulates the individuation of an object by its verbal label. Individuation of an object refers to the visual identification of the object and knowing it is distinct from other objects and as a consequence a very important step in enumeration and/or estimation of numerosities (Leibovich et al., 2017; Stoianov & Zorzi, 2012). More efficient individuation might in turn result in better processing of numerosity. There is indeed quite some evidence that familiarity may influence early stages in visual perception, including individuation. For instance, in a visual detection study, Lupyan and Spivey (2008) presented an array of shapes and participants were instructed to indicate whether the display was homogeneous or contained an oddball. Crucially, the shapes were familiar symbols ("2" and "5") rotated by 90°. In one condition, participants were informed about the nature of the shapes, whereas in another condition, they were told the stimuli were abstract shapes. Oddballs were detected faster in the condition in which participants were given the verbal labels (or when the participants spontaneously noticed that the shapes were known symbols), showing that familiarity has an effect on visual searching. In another study using electroencephalography, Gliga, Volein, and Csibra (2010) observed enhanced oscillatory activity over the visual cortex in one-year-old children when objects with labels familiar to the infant were shown. These results indicate that familiarity modulates visual perception, possibly through top-down influence of semantic knowledge on object perception. All together, these results suggest an interaction between conceptual and perceptual processing, an idea that also has been put forward in embodied cognition (Lakoff & Núñez, 2000).

To examine to what extent previous findings can be generalized to comparative judgments on sets of familiar objects, we conducted a study in which participants had to compare the numerosity of two different sets of fruits while manipulating congruency (by presenting small and large fruits), the numerical difference between both sets (ratio), and number range. Number range was manipulated because different performance signatures have been found for small and large numerosities. When only a few objects (maximally 3–4 objects) are presented, we are usually able to precisely determine the number, a process called subitizing (Trick & Pylyshyn, 1994). In contrast, when the number of objects is more than four, participants have to make an approximate estimation of the number of objects and these estimates are typically much less accurate than judgments in the subitizing range, usually resulting in an underestimation of the presented number (e.g., Gebuis & Reynvoet, 2012b). It has been suggested that this difference in behavioral performance is caused by two separate underlying systems for, respectively, small and large numbers (Feigenson et al., 2004; Krajcsi, Szabo, & Morocz, 2013; Revkin, Piazza, Izard, Cohen, & Dehaene, 2008 **[Author: please approve the edit in citation]**). Crucial for the purpose of the present study, it is also suggested that "large-number discrimination is robust over variations in continuous variables, whereas small-number discrimination is often affected by such continuous properties" (Feigenson et al., 2004, p. 311). As a consequence, congruency effects might be different in the small and large number ranges. Because studies conducting a direct comparison between small and large numerosity comparisons are scarce, we also included a condition with numerosity comparisons of typical dot arrays, manipulating exactly the same variables as in the fruit comparison task. Our central research question was whether comparative judgments of numerosity on artificial, meaningless dot arrays are reflecting how we make numerosity comparisons on sets of familiar objects, something we do on an everyday basis.

Method

Participants

Participants were 30 adults aged between 18 and 40 years. Four participants were removed from the analyses because of too many errors ($N = 1$; +2 *SD* above the group mean in at least one of the tasks) or too high reaction times ($N = 3$; +2 *SD* above the group mean in at least one of the tasks). Consequently, the final sample consisted of 26 participants (17 women; $M_{age} = 25.31$ years, $SD = 4.97$).

Procedure

The study was approved by the local ethics committee. Participants were tested individually in the research laboratory. Participants were informed about the general nature of the procedure and signed an informed consent before starting the experiment.

The participants conducted two numerosity comparison tasks: a dot-array numerosity comparison task and a fruit numerosity comparison task. Both tasks were presented on a 15″ color screen laptops **[Author: add manufacturer details]**, and stimulus presentation was controlled by E-Prime, version 2.0 (Psychological Software Tools, Pittsburgh, PA, USA). In the dot-array comparison task, participants had to indicate whether the left or the right array contained more dots by pressing "a" or "p" on an AZERTY keyboard with left and right hand, respectively. In the fruit comparison task, pictures with homogeneous sets of physically large fruits (either apples, pears, oranges) on one side and homogeneous sets of physically small fruits (either grapes, strawberries, raspberries) on the other side were presented. Again, participants had to indicate whether there were more fruits on the left or on the right by pressing "a" or "p". In both tasks, the correct response was in half of the trials on the left side and in the other half on the right side. The order of the tasks was counterbalanced over participants.

Dot-Array Numerosity Comparison Task

Dot arrays were constructed with the method of Gebuis and Reynvoet (2011) that controls for multiple non-countable cues: area extended by the dots, total surface, dot size, circumference, and density. Each trial started with a fixation cross ("+") that was presented in the middle of the screen for 500 ms. After the fixation cross, both dot arrays were presented. The dot arrays remained on the screen until a response was given or for maximal 1,000 ms. In the latter case, the dot arrays were replaced by a black screen. Participants could respond during stimulus presentation or during the black screen. After the response, an intertrial interval of 1,000 ms followed. First, eight practice trials were presented and feedback ("correct" or "incorrect") was provided for 1,500 ms before the intertrial interval started. After the practice trials, two blocks of 160 experimental trials were administered. Feedback was no longer provided during the experimental trials.

In the experimental trials, 8 different number pairs (1-2; 2-1; 2-3; 3-2; 4-8; 8-4; 6-9; 9-6) were presented for 40 times. In these trials, congruency, ratio, and number range were manipulated. First, congruency between number and non-countable cues was manipulated. In half of the trials, the non-countable cues (area, surface…) were larger for the larger number (congruent), and in the remaining half of the trials, they were smaller for the larger number (incongruent). Second, ratio was manipulated; half of the trials had a ratio of 0.5, and the other half had a more difficult ratio of 0.66. Finally, number range was manipulated. In half of the trials, small numerosities up to 3 were presented (Feigenson et al., 2004), whereas the other half contained larger numerosities (4 and more). The largest number was in half of the trials on the left side of the screen and on the right in the other half. A break was presented after the practice trials and after the first block of the experimental trials. Participants could take as long as they want and proceed again by pressing the space bar.

Fruit Numerosity Comparison Task

Each trial consisted of the presentation of a picture with collections of two homogeneous sets of fruits in a random constellation on a white background (Figure 1). On each trial, one of the collections consisted of physically larger fruits (apples, pears, oranges) and the other one of physically smaller fruits (grapes, strawberries, and raspberries).

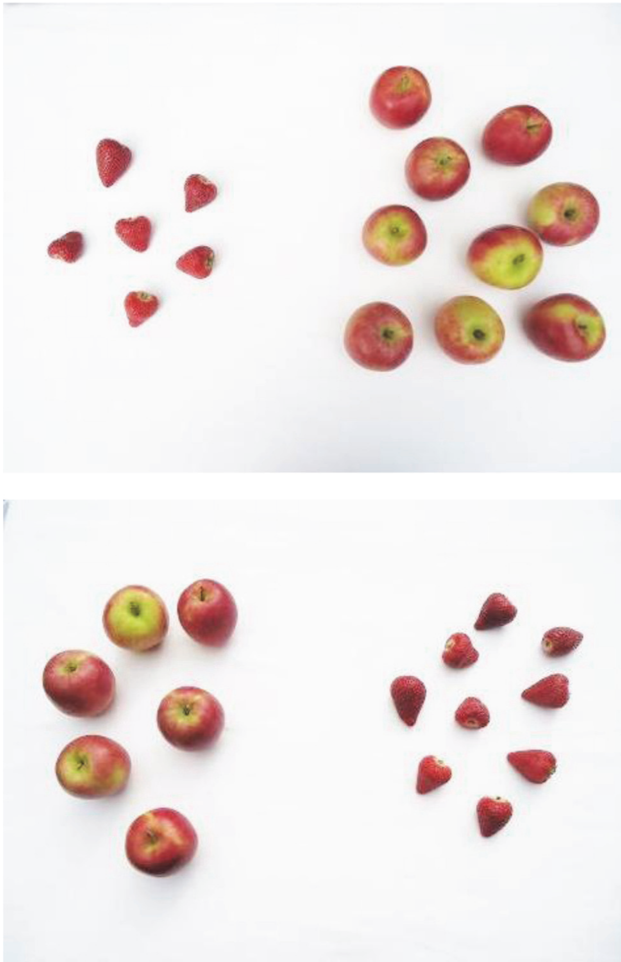

Figure 1. Example of a congruent (top) and incongruent (bottom) stimulus in the fruit numerosity comparison task.

The larger fruit was in half of the trials on the left, in the other half on the right. The trial sequence was identical as in the dot-array comparison task. Also, the same variables were manipulated. Congruency was manipulated by contrasting pairs in which the larger fruit (e.g., 8 oranges – 4 strawberries) was more numerous than the smaller fruit (congruent) with pairs where the larger fruit was less numerous (e.g., 4 oranges – 8 strawberries) than the smaller fruit (incongruent). Only the physical size of the objects was systematically manipulated. Ratio and number range were manipulated in the same way as in the dot-array comparison task. Like in the dot comparison task, first eight practice trials with feedback were provided. The list of experimental trials consisted out of 2 blocks of 144 trials. This way, each combination of large and small fruit (N = 9; apples-strawberries; apples-grapes, . . ., oranges-raspberries) could be presented an equal amount of times, taking into account the orthogonal manipulation of the other independent (ratio, congruency, and number range) and controlled (side of the correct response) variables.

Results

Original data can be found in Electronic Supplementary Material (ESM 1). Separate repeated-measures analysis of variance (rmANOVAs) with congruency, number range, and ratio as within-subject variables were conducted on reaction times (see Table 1) from the dot-array and the fruit numerosity comparison test.[1] Accuracy was at ceiling [dot-array comparison task: M = 98% (SD = 1.7); fruit comparison task: M = 96% (SD = 3.1)] and was not further analyzed.

Dot-Array Numerosity Comparison Task

A main effect of congruency, $F(1, 25) = 52.66$, $p < .001$, $\eta_p^2 = .68$, was present: Participants were 74 ms faster on congruent trials compared to incongruent trials. Also, main effects of ratio, $F(1, 25) = 87.99$, $p < .001$, $\eta_p^2 = .78$ (faster responses on trials with a ratio of 0.5 than trials with a ratio on 0.66), and number range: $F(1, 25) = 28.04$, $p < .001$, $\eta_p^2 = .51$ (faster responses on trials with small numerosities) were observed. Congruency interacted with ratio, $F(1, 25) = 9.42$, $p = .005$, $\eta_p^2 = .27$, and with number range, $F(1, 25) = 24.38$, $p < .001$, $\eta_p^2 = .49$. Congruency effects were present in all conditions, but were larger in more difficult conditions (difficult ratio and larger numerosities). Finally, also ratio and number range interacted, $F(1, 25) = 6.40$, $p = .018$, $\eta_p^2 = .20$, the ratio effect was smaller with small numerosities.

Fruit Comparison Task

In general, the pattern of results of the fruit comparison task was similar to the pattern of results in the dot-array comparison task. Main effects of congruency, $F(1, 25) = 70.64$, $p < .001$, $\eta_p^2 = .73$, ratio, $F(1, 25) = 86.30$, $p < .001$, $\eta_p^2 = .78$, and number range, $F(1, 25) = 79.79$, $p < .001$, $\eta_p^2 = .76$, were found. Participants were faster on congruent trials compared to incongruent trials, faster on trials with a ratio of 0.5 than trials with a ratio of 0.66, and faster on trials with small numerosities.

[1] We also conducted a repeated-measures ANOVA with task (dot or fruit comparison) as additional variable. The pattern of results was similar as in the separate ANOVAs, but also an interaction with task emerged due to the larger congruency effect in the large fruit trials with a difficult ratio. These trials also led to the triple interaction that is reported in the separate ANOVAs.

Table 1. Mean reaction times (*SD*) in each condition of the dot-array and fruit comparison task

	Small				Large			
	Ratio 1:2		Ratio 2:3		Ratio 1:2		Ratio 2:3	
	C	IC	C	IC	C	IC	C	IC
Dots								
RT (*SD*)	508 (84)	539 (84)	557 (100)	618 (113)	564 (116)	645 (133)	645 (160)	771 (198)
Fruits								
RT (*SD*)	597 (158)	630 (116)	636 (161)	752 (187)	704 (175)	869 (207)	762 (209)	1,128 (324)

Note. C = congruent; IC = incongruent; RT = reaction times; *SD* = standard deviation. **[Author: please approve the edit]**.

In addition, all interactions were significant: congruency by ratio, $F(1, 25) = 62.22$, $p < .001$, $\eta_p^2 = .71$, congruency by number range, $F(1, 25) = 43.36$, $p < .001$, $\eta_p^2 = .63$, ratio by number range, $F(1, 25) = 15.75$, $p = .001$, $\eta_p^2 = .39$, and finally congruency by ratio by number range, $F(1, 25) = 14.46$, $p = .001$, $\eta_p^2 = .37$. Congruency effects were present in all conditions but most outspoken in the most difficult condition with the smallest numerical difference and larger numerosities (i.e., 6 vs. 9 objects).

Discussion

In this study, we examined whether comparative judgments of numerosity on familiar objects happen in the same way as the frequently studied numerosity comparisons of dot arrays. Several studies using these well-controlled dot arrays have reported influences of non-countable cues (e.g., Clayton et al., 2015; Gebuis & Reynvoet, 2012a; Leibovich & Henik, 2014): Incongruent trials where numerosity and non-countable cues negatively correlate are more difficult than trials where both dimensions positively correlate (i.e., congruent trials). It remains possible that these congruency effects are only observed when meaningless and similar shaped sets of dot arrays have to be compared. As we have explained in the introduction, it is possible that the individuation of a familiar object is facilitated through interactions between conceptual and perceptual processing levels. A more efficient individuation process might in turn result in better processing of numerosity and less influence of non-countable information.

The answer to this question, provided by the results, is very straightforward: Yes, previous results from numerosity comparison tasks with dot arrays can be generalized to comparative decisions on familiar objects, in this case different sets of homogenous fruits. Just like in the dot-array comparison task, we observed a congruency effect, indicating it is more difficult to compare the numerosities of sets of 2 apples and 3 strawberries than the opposite, that is, 3 apples and 2 strawberries. Because of the stimuli that were selected to simulate everyday conditions as much as possible, the present results hint that in daily life, numerosity decisions are biased by non-countable dimensions also.

Interestingly, the effect of non-countable cues is observed in the small and the large number ranges. It has been suggested that small and large numerosities are represented in different systems (e.g., Feigenson et al., 2004) and that the large number system is, in contrast to the small number system, not sensitive for non-countable cues. The present data contradict such a claim and show effects of non-countable information in both number ranges. These effects were even larger on trials with the hardest ratio and the larger numerosities. This observation is in line with previous studies (Clayton et al., 2015; Defever, et al., 2013; Leibovich, Diesendruck, Rubinsten, & Henik, 2013; Smets et al., 2016) and is indicative for a complex interaction between numerical and non-countable cues: The effect on non-countable information increases as the uncertainty about the numerical difference increases. Because number of small numerosities can be processed precisely, the effect of non-countable cues in comparative decisions is actually reduced in that number range.

In our study, we presented photographs of a set of small fruits on one side and a set of large fruits on the other side (Figure 1). In this way, the relative difference in size between the two types of fruit was the same as in daily life perception. However, a downside of this design is that it is not possible to know whether the difference between congruent and incongruent trials is caused by the physical size congruency or by the conceptual size congruency. An object has several dimensions, some derived from superficial features (e.g., the *physical size*), other from intrinsic features (e.g., knowledge of the size of the object in real world – *conceptual size*). Both are magnitude dimensions that might possibly interact in magnitude-related decisions as the ones we studied. Paivio (1975) was the first to address the interaction between physical and conceptual magnitudes. He created congruent (e.g., a physically small lamp compared with a physically large zebra) and incongruent (e.g., a physically large lamp compared to a physically small zebra) conditions, and participants had to decide which object was larger in real life (i.e., conceptual size) and ignore the physical sizes of the objects. Paivio found that congruent trials were significantly faster than incongruent trials. These findings were taken as evidence for the automatic processing of physical magnitude. More recently, it was found that also conceptual size is processed automatically (Gliksman, Itamar, Leibovich, Melman, & Henik, 2016; Konkle & Oliva, 2011 **[Author: year changed as per references. please approve]**; Rubinsten & Henik, 2002; Shaki & Algom, 2002). For instance, Gliksman et al. (2016) presented two different objects on the screen and participants had to decide which object was larger on the screen (physical size) or in the real world (conceptual size). Congruent (the conceptually larger object was physically larger) and incongruent (the conceptually larger object was physically smaller) pairs of stimuli were created to examine the automatic processing of each magnitude. Significant congruity effects were found in both tasks (physical judgments and conceptual judgments), indicating that the processing of conceptual and physical magnitudes is equally automatic. Returning to our study, it is clear that both physical size and conceptual size may have caused the congruency effect we observed. Further studies are needed to unravel whether the congruency effect in the present study is caused by physical size, conceptual size, or both.

To conclude, the present study convincingly shows that previous findings concerning numerosity comparison can be generalized to comparative judgments of numerosity of familiar objects (and probably outside the laboratory). Numerosity comparisons on two sets of differently sized fruit were influenced by the size of the fruit and led to congruency effects, just like in a dot-array comparison tasks. To come back to our starting point, this means that if we see two apples and four strawberries in a fruit basket, although we might have the impression that we can easily decide there are more strawberries, it requires additional effort to do so.

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Electronic Supplementary Material

The electronic supplementary material is available with the online version of the article at https://doi.org/10.1027/1618-3169/a000418

ESM 1. Raw Data File (SPSS) (.sav)
This data files contain the mean RTs (per condition) for each participant.

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