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The role of numerosity in judgments and decision-making

Rajesh Bagchi[1] and Derick F Davis[2]

Numbers are ubiquitous in modern life. We focus on one fundamental feature of numbers — their numerosity or the number of units into which a stimulus is divided (Pelham *et al.*, 1994) [1••]. For instance, an object's weight can be measured in grams (100 g; lower numerosity) or milligrams (100 000 mg; higher numerosity). The *numerosity heuristic* predicts people infer greater quantity (weight) from higher numerosity (i.e. 100 000 mg), and judge the object as being heavier. We first review the numerosity heuristic and its bases, then discuss different manifestations in human decision-making contexts — when numbers denote attribute levels (e.g. size/quantity of products or attributes), reward points in loyalty programs, prices, currencies, and probabilities (to make predictions) among others. We conclude with ideas for future research.

Addresses
[1] Pamplin College of Business, Virginia Tech, 2023 Pamplin Hall, Blacksburg, VA 24061, USA
[2] School of Business Administration, University of Miami, P.O. Box 248147, Coral Gables, FL 33124, USA

Corresponding author: Bagchi, Rajesh (rbagchi@vt.edu)

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Numbers are ubiquitous in modern life. They objectively quantify the environment, and often serve as inputs in decision-making. Beyond actual objective values, incidental features of numbers, such as whether they are odd or even, precise or round (end in '0' or '5') [2–4], long or short [5•], or phonetically similar [6], can also influence judgments and decisions.

We focus on one fundamental feature of numbers — their numerosity. Numerosity refers to the number of units into which a stimulus is divided [1••]. For instance, an object's weight can be measured in grams (100 g; lower numerosity) or milligrams (100 000 mg; higher numerosity). According to the *numerosity heuristic*, people ignore other relevant information, and infer greater quantity (area, weight) from higher numerosity. Hence, 100 000 mg will be judged as being heavier [7•].

Numerosity also influences preverbal children, tribes with no numerical language, and animals [8••,9–11]. For example, chickens are more satiated when equivalent amounts of food are cut into more portions; rats prefer four 75 g food pellets to a single 300 g pellet [12].

We review the numerosity heuristic and its bases, and then discuss different manifestations in human decision-making contexts — such as judging product attributes (e.g. size/quantity), points in loyalty programs, prices, currencies, and probabilities, among others. We also discuss when numerosity effects can reverse, such as when individuals rely on units to make judgments, referred to as the *unitosity heuristic*. We conclude by considering future research directions.

Bases for numerosity

Why do people use this *numerosity heuristic*? One reason could be because numerosity is innate to the brain [13••]. Brain areas are organized topographically to reflect the structure of primary sensory organs; the brain also has topographic structures attuned to perceive numerosity, suggesting it may be a 'sixth sense' [13••]. High-field fMRI shows that when participants view small versus large number dot arrays, different brain areas respond [13••]. Furthermore, the space dedicated for processing (i.e. number of neurons involved) is inversely proportional to the number of dots (i.e. smaller space is dedicated for larger numbers). This can explain why processing of smaller versus larger numbers is more precise. Relatedly, evidence suggests individuals can accurately perceive small quantities via subitization (perceiving the number of items without counting), rather than through counting or pattern recognition [14•].

How the brain codes information can also explain why responses to numerical stimuli are often asymptotic [1••]. That is, people are more sensitive to changes near their reference point than more distant changes [15]. Consequently, two small gains (e.g. $500 each) from a reference point (of $0) seem greater than one larger, but equivalent gain ($1000) [16]. This suggests making a stimulus more numerous should increase quantity perceptions. Additionally, 'learned' associations between numerosity and size could increase reliance on the numerosity heuristic. For instance, an eight-bedroom house is — on average — larger than a 4-bedroom house, therefore individuals may overweigh the number of bedrooms in judgments.

Beyond neurological bases and learned associations, individuals must contend with a human-designed number system and its properties. The ability to understand and use this number system (referred to as numeracy) varies, which can increase reliance on heuristics [17], making people more susceptible to numerosity. Next we discuss how numerosity effects emerge in marketing contexts, beginning with judgments of tangible differences such as physical size, followed by intangible differences, such as those based on differences on some scale.

Numerosity effects in marketing contexts

Physical size. Individuals presented with pairs of varying sized objects invariably prefer the larger object [18], due to a bigger-is-better heuristic, which generalizes to other contexts. Because physical size is a computationally simple heuristic to apply, nondiagnostic cues such as the height of a pile of materials (e.g. proofread pages) lead to higher productivity and progress perceptions, regardless of actual work performed [19]. Next we discuss the role of scales.

Scales. Attribute information can be presented using different scales/units. Height in millimeters versus inches (e.g. 51 mm versus 2 in) or weight in ounces versus kilograms (70 Oz versus 2 kg) should lead to judgments of greater height or weight, respectively.

Likewise, multiplying numbers by a scalar (e.g. 10) expands a scale and increases numerosity while retaining other characteristics. Such 'arbitrary' scales are often used to describe product attributes or points in loyalty programs. Individuals rely heavily on the (arbitrary) scale characteristics (points) and make inferences based on points on the scale, even when this is not optimal [20]. For instance, compare two scales — in the contracted (small numerosity) scale, consumers receive $5 upon earning 10 points, whereas in the expanded (high numerosity) scale, they need 50 points. In this case, consumers exert more effort in the expanded scale because by focusing on the number of points received, the reward feels more valuable [21].

Use of expanded versus contracted scales (e.g. number of new movies per year versus per week) can lead to greater discrimination between choice options. Consumers are willing to pay more for a superior (relative to an average) plan with expanded scales [22••]. Similarly, quality differences between product options appear larger when expressed using expanded (rating on a 1000-point scale), versus contracted (10-point scale) scales [23••]. A scale's numerosity also influences goal pursuit [24••,25]. Imagine consumers earn a $6 loyalty reward upon spending $100. Points required can be expressed with an expanded (1000 points to redeem reward) or a contracted scale (100 points). In the expanded (contracted) scale, step sizes are larger (smaller), as participants earn more points per dollar spent (10 versus 1). When consumers focus on points needed to redeem a reward, distances appear larger in the expanded (versus contracted) scale, as they are indeed larger (1000 versus 100). However, when the focus is on points earned per dollar spent (step sizes), distances appear smaller in the expanded (versus contracted) scale, as the step sizes are larger. These distance judgments impact progress inferences, as well as store loyalty and recommendation likelihoods.

While scales and units can be used to manipulate numerosity, sometimes they can reverse the numerosity effect. Imagine a delivery was delayed from 14 to 28 days. This delay could also be expressed in larger units (2–4 weeks). The numerosity heuristic predicts that the delivery change in days (the more numerous unit) would seem longer. However, when in an abstract mindset, for instance when envisioning an event in the distant future (a delivery in 6 months), individuals rely on units — referred to as the *unitosity* heuristic — to make judgments. Consequently, a change in large units (weeks) is considered larger than a change in small units (days) — counter to the numerosity heuristic. This reversal of numerosity emerges for several quantities — length, height, weight, and time [26••]. This suggests that the aforementioned numerosity effects may emerge only when individuals are in a concrete mindset — for instance, when envisioning near future events. Similarly, some attribute information (battery life) is processed more fluently in the units with lower (6 days) versus higher (144 hours) numerosity. In such instances, the lower default unit will be preferred, and will lead to more positive responses (higher willingness-to-pay) relative to the more numerous unit, reversing the numerosity effect [27••]. Next we discuss how numerosity can be manipulated by making numbers perceptually larger.

Prices. Numerical information (e.g. prices) can be presented and encoded in three different forms: visual (e.g. 25), verbal (e.g. 'twenty five') and analog (between twenty and thirty). These different presentation forms can affect perceptions of number size. For instance, adding commas and decimals to visual forms can influence how it is encoded, and the now increased syllabic length of the number can influence perception of magnitude (e.g. '1493' is coded as five syllables 'fourteen, ninety-three,' whereas '1,493' is coded as nine syllables 'One thousand, four hundred, ninety-three' and is perceived to be larger) [5•].

Partitioning. Just like other stimuli, price can also be divided into many parts — referred to as price partitioning. However, unlike with other stimuli where increasing numerosity increases quantity judgments, partitioning price actually lowers total price perceptions. For instance, online retailers often have a product base price (e.g. $32 for a shirt) and an additional price (e.g. $4.95 for shipping

and handling). However, because consumers either ignore surcharges or anchor on the base price and adjust insufficiently for surcharges, partitioning prices relative to not (e.g. charging $36.95 for the shirt) lowers total price perceptions [28] and can affect consumer preferences [29–34].

Package-price perceptions. Numerosity can also influence package-pricing perceptions. With more numerous packages ($29 for 70 songs), individuals anchor on the first piece of information and adjust insufficiently for the second piece when it is difficult to compute unit prices [35••]. Thus, presenting $29 for 70 items versus 70 items for $29, leads to higher unit price perceptions and lower value judgments (liking, trial likelihoods). These effects do not emerge for less numerous packages (e.g. $2.9 for 7 items) or when unit price is easier to compute ($2 for 5 items).

Currencies. Numerosity effects can occur across currencies and currency differences can affect spending. For example, compare two currencies — US$ and S$ (Singapore dollar) with a US$1 = S$1.7 exchange rate. If a consumer's budget is $10 (S$17) and an item costs $1 (S$1.7) then the difference between the price and the budget appears larger in Singapore dollars (S$15.3 versus US$9), which based on the numerosity heuristic leads to greater spending [36]. However, when exchange rates are difficult to compute, as they sometimes are — the currency face value is used to make decisions. In the example above, the face value is higher in Singapore dollars, which leads to lower spending because prices seem higher [37]. One factor that determines if the former or the latter occurs is whether or not a reference value is considered. With a reference value (e.g. budget, reference price), larger differences between price and the reference value in more numerous currencies lead to higher spending. With no reference value, currency face value effects emerge. Interestingly, if one's home currency is a higher (lower) numerosity than the local currency, one over (under) estimates the value of the local currency [38•]. For instance, if someone familiar with French Francs compares product prices in Euros (a less numerous currency; 1 Euro = 6.5 FRF), they may overestimate the value of the Euro. However, budgets, income level, and product cost (inexpensive versus expensive) may all attenuate this cross-currency numerosity effect on judgments [39–41].

Probabilities. Numerosity may also influence judgments of probabilities. Consider two teams (A and B) playing against each other. One commentator predicts A has a 70% chance of winning, while another predicts B has a 30% chance. Note these predictions are functionally identical. Yet, the higher prediction is judged as being more accurate, and elicits greater confidence in the analyst [42•]. This suggests using different scales (e.g. larger versus smaller frequencies) to make predictions might affect inferences.

Conclusion

Numerosity effects have been demonstrated across a broad array of judgments and decisions. While this disparate set of studies show the generalizability and robustness of the numerosity heuristic, they also highlight the lack of a unifying theoretical framework. Recent research in neuroscience [13••] provides one potential cornerstone for such a framework. However, theorizing how innate bases for numerosity are translated into human-designed number systems while also integrating key moderators, such as the unitosity heuristic or default units, represent significant hurdles.

Much prior research focused on how numerosity may lead people to misjudge positive attributes, or a cost like price [35••]. In contrast, how numerosity affects pursuit of beneficial or pro-social goals (e.g. quitting smoking, recycling) or perceptions of negative information (effects of smoking 1 versus 100 cigarettes) has been under researched, and could yield important insights. For example, a deeper understanding of how repeated smaller incidences (e.g. spending in pennies, niggling injuries, small transgressions) are undervalued relative to one-time, larger incidences (e.g. spending in dollars, breaking a leg, a major faux pas) [43,44] could further elucidate numerosity effects. Perhaps in such instances, other psychological processes will mediate and moderate numerosity effects. Lastly, numerosity effects emerge because larger numbers are less well understood, suggesting education may play an important role. But, given the innate basis of numerosity, would education really help? The directions for future research are numerous.

Conflict of interest statement

Nothing declared.

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