Passive viewing paradigm. Numerosity judgments are influenced by non-numerical cues and vice versa, and such influences are non-linear and asymmetric (Allik & Tuulmets 1993; Gebuis & Reynvoet 2012b; Ginsburg & Nicholls 1988; Miller & Baker 1968; Mix et al. 2002a; Nys & Content 2012; Soltesz et al. 2010; Sophian & Chu 2008; Tokita & Ishiguchi 2013). Thus, the representation of one dimension (say, numerosity) will differ depending on whether the task requires focusing on numerosity or some other dimension. One can circumvent this issue by using a neural approach with a passive viewing paradigm. Indeed, using EEG to measure neural activity while participants were passively viewing dot arrays, we tested which magnitude dimension most contributes to the modulation of neural activity in a task-free design (Park et al. 2016b). However, the target article incorrectly states "a strong correlation between number and continuous magnitudes can change strategy [in our study]" (sect. 6, para. 2), when in fact there was no strategy involved.

Even under a passive viewing paradigm, attention might be directed toward one feature dimension over another because a larger range in one stimulus dimension may increase salience and consequently override the effects of another dimension with a smaller range. For an extreme example, imagine the apparent contrast of a set of 10 dots each with a radius of 1 cm and a set of 11 dots each with a radius of 0.1 cm. Clearly, the salience of the area difference would overwhelm the number difference, and neural activity modulated by such large salient differences in area could easily mask neural activity modulated by relatively less salient number differences. Therefore, it is important to use the same range of values in each magnitude dimension for a fair comparison between them. The target article incorrectly states that Park et al. (2016b) used a greater range of continuous magnitudes, when across two experiments we indeed used dot arrays that were constructed to cover equal ranges of number, size, spacing, total area, item area, total perimeter, item perimeter, convex hull, density, coverage, and overall scale. In fact, in Park et al. (2016b), we made this exact critique of the experimental design used by Gebuis and Reynvoet (2013), which employed a larger range of continuous magnitudes than numerosity. The Leibovich et al. (2016b) article that the authors rely on to develop their thesis suffers from this criticism because there was a greater difference in non-numerical magnitudes (ratio of about 2:5) than in numerical magnitudes (ratio of about 3:5). Therefore, the observed smaller interference of numerosity in non-numerical magnitude compared with the reverse in that study could have been driven by differences in the ratios between the two dimensions. Collectively, the target article mischaracterizes the stimulus design in Park et al. (2016b) and fails to recognize the implications of having unequal magnitude ranges in the very studies that it relies on to build the main thesis (e.g., Gebuis & Reynvoet 2013; Leibovich et al. 2016b).

High-temporal-resolution recording of neural activity. The target article asks which magnitude dimension is more "basic, innate, and automatic" (sect. 5.1, para. 3). In fact, the main contribution of our event-related potential approach (in combination with the aforementioned stimulus design and regression approach) was the demonstration of selective neural sensitivity to numerosity very early in the visual stream, prior to any neural sensitivity to other non-numerical magnitudes (Park et al. 2016b). Such a robust and selective effect of numerosity with negligible effects of non-numerical magnitudes was demonstrated in two independent experiments in Park et al. (2016b) and is now replicated in similar experiments investigating different neural index and different ranges of numerosities (Fornaciai & Park 2017; Park 2017). These results directly contradict the authors' conclusion that the representation of numerical magnitude stems from continuous magnitudes. Instead, our findings support the idea that numerosity is perceived directly and rapidly in the visual stream.

Conclusion. The target article argues that all prior studies suffer from flaws such that any claim of pure numerical judgments or numerical selectivity in the brain could be attributed to a generalized magnitude system. However, for the reasons mentioned previously, we find the authors' coverage of the prior work addressing these issues problematic and find their case for dismissing evidence that number is a salient primitive far from convincing. Moreover, at least 10 different continuous magnitude dimensions can be uniquely defined (see DeWind et al. 2015), but the target article lacks an explanation about which of those continuous magnitudes are biologically important and how they support the "sense of magnitude." Thus, the target article fails to provide a sufficient explanation of what a generalized magnitude system entails.

Innateness of magnitude perception? Skill can be acquired and mastered at all ages

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Abstract: We agree with Leibovich et al.'s argument that the number sense theory should be re-evaluated. However, we argue that highly efficient skills (i.e., fluent and highly accurate, "automatic," performance) can be acquired and mastered at all ages. Hence, evidence for primacy or fluency in perceiving continuous magnitudes is insufficient for supporting strong conclusions about the innateness of this aptitude.

Leibovich et al. provide a critique of theories that posit an innate number sense. They propose that a "number sense" develops, via, for example, statistical learning, from the correlation between continuous magnitudes and numerosity. The authors argue that although numerosities are learned (through educational and cultural interactions), the perception of continuous magnitudes is innate. Thus, innate skills for the perception of continuous magnitudes set the stage for learning procedures for addressing discrete quantities.

Instead, we suggest that the evidence presented for (and against) the innateness of magnitude perceptions should be considered as addressing contrasts such as "primacy/no primacy" or even "automatic/not automatic" processing, in characterizing human numerical cognition at different phases of its development, rather than directly pertaining to innateness.

If innate means "not acquired" (e.g., Logan 1997), arguments for innateness and learning are mutually dependent. This is especially true when learning reaches a level wherein performance is "automatic" in the sense that it is fluent, is highly accurate, and exhibits a primacy in processing. Indeed, skilled automatized performance, especially when acquired implicitly, resembles innate processing. That is, both innate processing and automatized processing – perceptual, conceptual, or motor – are fast and may involve the involuntary direction of attention to stimuli and even, in some cases, a lack of conscious awareness (Karni 1996; Logan 1997). Specifically, both implicit learning and explicit learning may result in automatic processing of information that behaviorally is manifested in high levels of fluency. Fluency is reflected in the speed and accuracy of processin, as well as in a subjective experience of ease (Karni & Bertini 1997; Poldrack & Logan 1998). Thus, learning experiences can determine the saliency of a specific cue. Moreover, when a stimulus becomes salient, its salient (as opposed to the non-salient) features will automatically capture attention (Smith et al. 1996; Treisman & Gelade 1980), which in turn will further facilitate the learning process and enhance saliency. Therefore, saliency per se, even in early life or in animal studies, is not sufficient for proving "innateness"; it may simply indicate the end point of a learning process.

In both innate and acquired skills, automatized processing occurs independently of top-down expectancies and thus leads to processing primacy. Consider, for example, the Stroop effect lending primacy to a complex and clearly acquired ability, reading (MacLeod 1991; Stroop 1935). The Stroop effect reflects the robust primacy of script processing (reading) even over simple color report in skilled readers. In the classic Stroop task, participants are instructed to name the color of the ink in which words denoting colors are printed. The Stroop effect refers to the fact that skilled readers cannot refrain from reading the words and, in fact, from accessing the meaning of the color words. Reading attains such primacy (automatic processing) that it interferes with the naming of (ink) colors. The primacy effect of reading can be found in other sensory domains. A recent study shows that tactile texture discrimination is interfered with by unintentional Braille reading of incongruent texture-denoting words in the blind (Jarjoura & Karni 2016).

There is evidence that automatic Stroop-like interferences develop with practice. For example, in a numerical Stroop-like effect that occurs when participants are presented with two digits that differ in physical size and numerical value and have to compare the digits using one of the dimensions, the interference between these two dimensions changes with practice (Tzelgov et al. 2000) and schooling (Girelli et al. 2000; Rubinsten et al. 2002). Thus, a numerical Stroop effect does not occur in physical comparisons at the beginning of first grade, but an adult-like pattern of the numerical Stroop effect was found in third grade and on (Girelli et al. 2000; Rubinsten et al. 2002). These data suggest that automatic activation of the numerical values of Arabic numerals develops, and attains primacy in processing, over the first years of schooling.

There is, moreover, ample evidence supporting the notion that very early implicit learning experiences – from visual and motor constrained environments (e.g., Held & Hein 1963) to cultural-social exposure (e.g., see review by Kuhl 2010) – can effectively generate and shape processing primacies. Consider in this light the processing primacy (bias) attained within even a few hours of exposure to a given visual environment, as attested by classical studies on dark-reared kittens (Held & Hein 1963). Very early life experience-dependent bias can even eliminate "innate" abilities as manifest in, for example, the finding that babies lose their ability to perceive multiple phonemic cues (sounds used in languages) that are irrelevant to their language experience before they attain 1 year of age (Eimas 1975; Eimas et al. 1971; Lasky et al. 1975; Werker & Lalonde 1988). On the other hand, by 10 months of age, language-specific differences can be discerned in the babbling of infants raised in different countries (de Boysson-Bardies 1993). The main question is not of innateness of perception or action, but rather how infants learn and form selective phonemic categories that make a difference in their language so early in life (Kuhl 2010).

To summarize, most of the evidence reviewed in Leibovich et al.'s article, including the interpretation of brain imaging studies, relates to the automaticity-primacy of processing continuous magnitudes (inferred from measures of fluency). This, we would argue, does not constitute sufficient evidence for determining the status of task performance as "a basic sense" or "innate" because implicit (and explicit) learning experiences in infancy (and later in life) can generate fluency, accuracy, and, importantly, primacy for processing specific cues. There is no a priori reason to suppose that the processing of continuous magnitudes or discrete quantities cannot reflect implicit learning experiences even from very early on in life. Indeed, it has been argued that in some situations constructs such as discrete and countable magnitudes may precede constructs of continuous magnitudes and may affect their development (Starr & Brannon 2015). We suggest that studies of biology–environment interactions, shaping our repertoire of automaticity, are warranted.

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What is a number? The interplay between number and continuous magnitudes

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Abstract: Leibovich et al. argue that it is impossible to control for all continuous magnitudes in a numerical task. We contend that continuous magnitudes (i.e., perimeter, area, density) can be simultaneously controlled. Furthermore, we argue that shedding light on the interplay between number and continuous magnitudes – rather than considering them independently – will provide a much more fruitful approach to understanding mathematical abilities.

Leibovich et al. criticize the results of different studies employing non-symbolic numerical tasks, because the effect of continuous magnitudes would have not been adequately controlled. By definition, a non-symbolic number is the numerosity extrapolated from an array of elements (Feigenson et al. 2004). We agree that it is impossible to equate simultaneously both the overall area and the perimeter of two different arrays of elements, and that considering only the overall area is only a partial control. Nevertheless, Leibovich et al. did not consider that when the overall perimeter of two arrays of two-dimensional squares is equated, a negative correlation with the area occurs.

From a theoretical viewpoint, given a first array depicting a number $n_i \geq 1$ of squares of side l_{n_i}, and a second array depicting a number $n_j > n_i$ of squares of side l_{n_j}, it is impossible to simultaneously keep constant both areas $\left[\left(A_{n_i} = n_i l_{n_i}^2\right) = \left(A_{n_j} = n_j l_{n_j}^2\right)\right]$ and perimeters $\left[\left(P_{n_i} = n_i 4 l_{n_i}\right) = \left(P_{n_j} = n_j 4 l_{n_j}\right)\right]$ of the arrays. In fact, to do so, the following system has to be solved for l_{n_j}:

$$\begin{cases} l_{n_j} = \dfrac{n_i l_{n_i}}{n_j} & \text{when } P_{n_i} = P_{n_j} \\ l_{n_j} = \dfrac{\sqrt{n_i} l_{n_i}}{\sqrt{n_j}} & \text{when } A_{n_i} = A_{n_j} \end{cases}$$

This system can be solved if and only if $n_i = n_j$, thus violating the hypothesis $n_j > n_i$.

We can now evaluate the relation between P_{n_i} and P_{n_j} when the overall area is kept constant (i.e., $A_{n_i} = A_{n_j}$).

$$P_{n_j} = \frac{n_j}{\sqrt{n_j}} 4 \sqrt{n_i} l_{n_i}$$