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Second-order characteristics don't favor a number-representing ANS

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Abstract

Clarke and Beck argue that the ANS doesn't represent non-numerical magnitudes because of its second-order character. A sensory integration mechanism can explain this character as well, provided the dumbbell studies involve interference from systems that segment by objects such as the Object Tracking System. Though currently equal hypotheses, I point to several ways the two can be distinguished.

Clarke and Beck make a convincing argument that the hypothesis that the Approximate Number System (ANS) represents rational numbers shouldn't be rejected. They also argue, in section 5.3, that the competing claim that the ANS represents magnitudes (such as pure magnitudes, Burge, 2010; Buijsman, 2021 or "quanticals", Nuñez, 2017), is less plausible. The crucial point being, according to them, that the ANS is sensitive to a second-order property and the magnitudes, being first-order properties, do not fit the bill. I argue here instead that on the view of the ANS as a sensory integration mechanism (Gebuis et al., 2016), which readily accompanies magnitude-based views, this second-order character can be explained. The view that the ANS represents magnitudes cannot (yet) be dismissed, as Clarke and Beck wish to do.

Their first claim is that only a number-based view can explain why the study that found elephants to be sensitive to the number of sunflower seeds in a bucket (Plotnik et al., 2019) is insufficient to establish that they have an ANS. In contrast to studies that control for the intensity of the odor, this study fails to show that different sensory modalities are integrated in a single place. Elephants can succeed at the task using a single sensory modality, namely their sense of smell. Hence, the study fails. Clarke and Beck argue that it does by appealing to the second-order character of rational numbers, whereas this study (may) only measure the first-order property of intensity of smell. They also claim that a magnitude-based view has trouble explaining this, as magnitudes are first-order properties.

I disagree. On the view where the ANS represents pure magnitudes one can easily appeal to the idea of a sensory integration mechanism to account for this phenomenon. Pure magnitudes are ratios of quantities (e.g. 2 cm : 3 cm, which can also be obtained by 2 kg : 3 kg) and fit in naturally with the idea of a system that integrates the information from different sensory modalities, as they are not specific to any one modality. So, to return to the elephant study, it fails to show that they have an ANS since the task can be solved with specific magnitude representations (for smell) and doesn't require the use of pure magnitudes (which result from an integration across modalities). In this way it can be just as easily explained why the lack of confounds is problematic for studies that aim to establish the use of an ANS. The

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sensory integration mechanisms accounts for this, just as it can answer Clarke and Beck's charge that the argument from confounds is ad hoc. If the ANS is best viewed as a sensory integration mechanism representing pure magnitudes, then we would expect that precisely this mixture of confounding quantities is what drives the responses in different tasks.

The dumbbell studies (He et al., 2009; Franconeri et al., 2009) are trickier to explain on the basis of the sensory integration mechanism. Clarke and Beck already point out that non-numerical confounds are nearly identical whether the dots are connected or not, so that such an appeal is implausible. Yet a different kind of confound should be researched. The stimuli used in both studies have a relatively small number of connected dots/squares, which may readily be picked up by the Object Tracking System (OTS, cf. Feigenson et al, 2004), which can inform numerical judgements. For example, the fourth experiment of Franconeri et al (2009) has four circles, and in the connected format these form two dumbbell shapes. Since the connected items are visually far more salient than the remaining dots/squares, it could be that the OTS's processing of these connected items interferes with the target estimation of the four circles. Franconeri et al (2009) do have a few experiments where the number of connected squares is above the OTS threshold, but in these specific cases there is a significant difference between the connected and non-connected stimuli, re-introducing non-numerical confounds (as Franconeri et al, 2009 already note as motivation for their fourth experiment). He et al (2009) have more dots, but only ever connect up to two pairs of them, keeping the possible OTS confound. Studies controlling for non-numerical confounds with more connected dots, possibly combined with research on the role of the OTS in these cases, will clarify the situation.

The dumbbell studies, then, might have picked up interference from another (numer-related) system that is known to involve object detection, the second-order characteristic that Clarke and Beck focus on. The remaining second-order aspects are readily explained by a sensory integration mechanism. Yet they also appeal to the second-order character to argue that the number-representing view satisfies their weak sensitivity principle, which states that the ANS should be sensitive to at least some of the essential properties of what it is said to represent. Does the quantical/pure magnitude view similarly satisfy weak sensitivity? As I discuss in Buijsman (2021) all the essential features of quantities, as formalized in measurement theory (ordering, concatenation, choice of measurement), fit the ANS data. Specifically, its approximate character fits with the formally established flexibility in choice of measurement scale. So, indeed, the sensitivity requirement is satisfied by the magnitude-based view.

If the magnitude-based view can't be ruled out on this basis, what should the next steps be? As discussed, more clarity on whether systems that involve object identification interfere with the dumbbell studies might give more clarity. In Buijsman and Tirado (2019) we've outlined ways in which this issue might be resolved based on spatial-numerical associations, specifically by studying whether the representations of the ANS are amodal (and shared with symbolic number representations) or modality-specific. Furthermore, all of the future work suggested by Clarke and Beck can proceed without the need to settle this issue of the representations. Yet, just as they argue that it was too early to rule out the hypothesis that the ANS represents numbers, they were too eager to dismiss the quantity view.

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