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Weighted numbers: Commentary on "The Number Sense Represents (Rational) Numbers" by Sam Clarke and Jacob Beck

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In the current proposal, we intend to comment on the argument from congruency and the argument from confounds (*i.e.*, sections 3 and 4 in Clarke & Beck, 2021). We will specifically focus on the studies challenging the claim that the Approximate Number System (ANS) represents genuine numerical content based on the presence of congruency effects and interference from non-numerical confounds. A substantial amount of evidence for this claim has been observed and reported by our research group (see Expertise below).

To begin with, we believe that in their paper, Clarke and Beck somewhat misinterpret the findings obtained in the studies by Gebuis & Reynvoet (2012 a,b). Possibly, the misinterpretation originates in the claims made in the studies by Gebuis & Reynvoet (see also the review by Gebuis et al., 2016) — that the ANS does not "genuinely represent numbers" or "pure numerosity". However, in our opinion, and as we show below, the results of the latter studies can be reconciled with the indirect model proposed by Clarke and Beck.

In section 4, Clarke and Beck rightfully point out that researchers have always been aware of confounds between number and other non-numerical magnitudes. Precisely because of this, many different algorithms have been developed to control the visual confounds. By making these non-numerical magnitudes uninformative for the number decision, one could argue that the pure numerosity is measured. As a result, some studies have strongly claimed that the number is a primary feature — the processing of non-symbolic numbers (*i.e.*, numerosity) occurs directly and independently of non-numerical magnitudes (*e.g.*, Van Rinsveld *et al.*, 2021).

It is this strong interpretation of number as a primary feature that the studies by Gebuis and Reynvoet mainly contested: even when non-numerical magnitudes are made irrelevant, they still affect performance and lead to congruency effects, that may increase or decrease depending on sample and items (Defever, Reynvoet & Gebuis, 2013; Gebuis & Reynvoet, 2012b; Reynvoet *et al*., 2021). Therefore, it was proposed that decisions in non-symbolic number comparison tasks are – at least in some settings – can not be the result of only "pure numerosity" (i.e., only the discrete number of the set is used), but are also based on the information from non-numerical magnitudes of the set and combinations of these information

In its essence, the claims made in the studies of Gebuis and Reynvoet's proposal are not very different from an indirect model of the ANS as proposed by Clarke and Beck (p.6). However, an enormous contribution of this paper to the field is that the authors provide a substantial and valid argumentation for the claim that the computational outcome of integrating different sources of information (numerical and non-numerical) can/should be considered also as a representation of number. In this way, Clarke and Beck provide a framework that has the potential to be accepted widely, and may stimulate future research examining the computational factors that lead to these number representations.

References

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Expertise

Recently, the research group under my supervision (www.numcoglableuven.be) published several highly cited papers investigating the processes involved in non-symbolic number comparison (*e.g.*, Gebuis & Reynvoet, JEP:G, 2012 – cited 309 (Google scholar); Gebuis & Reynvoet, PLOS 2012 - cited 202 (Google Scholar); Smets, Szücs, Sasanguie & Reynvoet, Journal of Cognitive Psychology, 2015, cited 88 (Google Scholar). Based on the observation of congruency effects and the lack of appropriate controlled stimuli, we argued that it is unlikely that number is extracted directly and decisions in a non-symbolic number task may be based on a weighted combination of non-numerical magnitudes.