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Numerical representations are neither abstract nor automatic

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Abstract

Here, I support and augment the argument put forth by Cohen Kadosh & Walsh (CK&W) that numerical representations are not abstract. I briefly review data that support the nonabstract nature of the representation of numbers between zero and one, and I discuss how a failure to test alternative hypotheses has led researchers to erroneously conclude that numerals automatically activate their semantic meaning.

There exists in the numerical cognition literature what I call the triple tautology: That numerical representations are (1) *automatically activated*, (2) *abstract*, and (3) *analogue*. Cohen Kadosh & Walsh (CK&W) present a convincing argument that numerical representations are not abstract. Although CK&W focus on the numerical representation of integers, strong evidence also exists for the nonabstract nature of the numerical representation of quantities between zero and one (Cohen et al. 2002). My colleagues and I have shown that, although most college students understand the correct ordinal relation of numbers expressed in a single numerical format (e.g., decimals), they do not understand the correct ordinal relation of numbers expressed in different formats (e.g., comparing decimals to relative frequencies). If the numerical representation of numbers between zero and one were abstract, the students should have been able to compare the semantic meaning of numbers expressed in different numerical formats once the numbers were converted into the abstract representation. Although researchers may discount this evidence for nonabstract representation of numbers as unique to those between zero and one, CK&W reveal that it is consistent with the evidence for the representation of integers.

The crux of CK&W's argument is that correlations should not be confused for causal mechanisms - no matter how intuitive the causal relations may appear. Further on, I describe how the remaining two tautologies (automatic activation and analogue representation) also rely heavily on correlational evidence.

It can be argued that Moyer and Landauer (1967) started the modern study of numerical cognition with their discovery of the *numerical distance* effect. In short, the authors presented two integers side-by-side and asked participants to judge which integer was the larger of the two. The authors found that reaction time (RT) varied as a function of the numerical distance between the two presented integers. The robust nature of the finding, together with its appeal to our intuition about the importance of numerical distance, has made this finding one of the bedrocks of the numerical cognition literature. The numerical

distance effect was the foundation of the first tautology of numerical cognition: the analogue nature of the representation.

The numerical distance effect is not only the foundation of the first tautology, but it is also a foundation of *automaticity*. A strong test of the automatic activation hypothesis is a simple task in which participants are to judge whether two numerical symbols are the same or different. In previous versions of this task, researchers dichotomized the stimuli into “close” and “far” groups by choosing numbers that are numerically “close” (e.g., 8 and 9) and numbers that are numerically “far” (e.g., 1 and 9). If semantic meaning is automatically activated, it will interfere with participants’ same/different judgments and evidence for the numerical distance effect should be present in the RT data. Specifically, the time for participants to judge two numerically close numbers as different (i.e., the “close” group) should be longer than the time it takes them to judge two numerically distant numbers as different (i.e., the “far” group). This is exactly what researchers found (Dehaene & Akhavein 1995; Ganor-Stern & Tzelgov 2008), and they reasonably concluded that numerical symbols automatically activated their semantic meaning.

Researchers should remember that, despite its name, the *numerical distance effect* is correlational. That is, numerical distance is one of several features that are correlated with the order of the numbers on the number line. Therefore, although numerical distance is correlated with participants’ RTs, it may not be the controlling factor of participants’ RTs. As with all correlational data, there may be a third variable that (1) is correlated with numerical distance and (2) is the true controlling factor of participants’ responses. The first step in determining whether a third variable exists is to test alternative hypotheses. Unfortunately, in numerical cognition research, researchers rarely (if ever) consider plausible alternatives to the numerical distance hypothesis. Recently, I did just that when I tested whether numerical symbols automatically activate their representation.

I ran the numerical same/different task with two simple changes: (1) I did not dichotomize the stimuli and (2) I tested an alternative hypothesis. By not dichotomizing the levels of the independent variable, I reduced the number of plausible alternative hypotheses that could explain the data. The plausible alternative I tested was simple: RT increased as a function of the *physical similarity* between the two numbers to be distinguished. See Cohen (2009) for the operational definition of the physical similarity function. The data were clear: Physical similarity was the controlling factor in participants’ RTs, not numerical distance. Because the semantic meaning did not interfere with participants’ response, the data demonstrated that integers do not automatically activate their semantic meaning. Because the numerical distance function correlates highly with the physical similarity function ($r = .62$), researchers may easily confuse the effects of physical similarity for those of numerical distance if they do not actively test both.

CK&W benefit the numerical cognition community by reviewing the literature addressing the abstract nature of numerical representations. The authors remind us not to confuse correlations for causal mechanisms. I echo that sentiment and remind readers that the numerical distance effect is, at its essence, simply a correlation. By challenging the

tautologies of the field with plausible alternative hypotheses, researchers like Cohen Kadosh & Walsh keep the numerical cognition field moving forward.

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