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What the Attentional-SNARC and its (null) replications can and cannot tell us

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In response to a point raised by Fischer et al. (2020), we discuss the theoretical implications of both the original Attentional SNARC (Att-SNARC) and its recent failed multi-laboratory replication. In our view, the theoretical importance of the original Att-SNARC can be summarized in two points: (1) there is a conceptual link between numbers and space, which can be observed as Spatial-Numerical Associations, and (2) Spatial-Numerical Associations are involuntary and automatic. We conclude that convergent evidence from other paradigms saves the first point from being challenged in light of the failed replication; but, on the other hand, empirical evidence for the second point no longer holds.

Keywords: Attentional SNARC, Spatial-Numerical Associations, SNA, Automaticity

Introduction

In 2003 Fischer and colleagues demonstrated that in a Posner-like cuing paradigm, non-informative, centrally presented numerical cues cause spatial shifts of attention and facilitate detection of subsequently presented lateral visual targets, similarly to arrows. Small magnitude numbers lead to faster detection of left-side targets whereas large magnitude numbers lead to faster detection of right-side targets. This effect was called Attentional SNARC (Att-SNARC) and it is among the most influential studies in numerical cognition, even though it was demonstrated in a relatively small samples (n = 15 and n = 10 for Experiments 1 and 2 respectively). At the time of the writing of this sentence the original paper has been cited over 870 times. Direct and conceptual replication attempts of Att-SNARC have been made (Dodd et al., 2008; Fattorini et al., 2015; Galfano et al., 2006; Pellegrino et al., 2019; Ristic and Kingstone, 2006; van Dijck et al., 2013; Zanolie and Pecher, 2014) with mixed outcomes including successful replications, non-replications, or observing only neural but not behavioral signatures of the Att-SNARC (e.g., Salillas et al., 2008). Importantly, most of the successful replications enforced semantic processing of numerical cues, for instance, by introducing catch trials (Cipora, He, et al., 2020 for an overview). A recent multi-laboratory replication (Colling et al., 2020) following the original protocol (i.e., the processing of numerical cues was not enforced) failed to replicate Att-SNARC with a considerably larger sample (n = 1105 tested across 17 labs). On the basis of a recently developed framework for directional Spatial-Numerical Associations (SNAs; Cipora et al., 2018), we focus on (1) why the original study gained so much interest, or what Att-SNARC seemed to tell us about number processing that other SNAs did not, and (2) what new developments (including the multi-laboratory replication) can and cannot tell us in the context of Att-SNARC. At the same time, we challenge the statement made by the authors of the original Att-SNARC paper (Fischer et al., 2020) in their commentary on the multi-laboratory replication of Colling et al. (2020).

The two messages of Att-SNARC

In our opinion, there are two important messages of Att-SNARC as it was originally reported:

1. There is a conceptual link (association) between numbers and space. Such a link is expressed in different SNAs (Cipora, Haman, et al., 2020). In the case of Att-SNARC, this link is elicited neither by the spatial location of numbers nor the location of response keys. Moreover, Att-SNARC has no functional role in the context of the task: spatial mapping of numbers does not help one to complete the task. Importantly, this link is manifested by the alterations of the function of a basic cognitive process (i.e., spatial attention).

2. This SNA occurs fully automatically (i.e., it is involuntary; not related to any enforced processing).

These points are theoretically important to our understanding of the links between numbers and space, as was acknowledged by Fischer et al. (2020) in their commentary on the unsuccessful multi-laboratory replication of Colling et al. (2020). Fischer and colleagues point towards the purity and robustness of links between space and numbers. However, we argue that presence of the conceptual link and the automatic nature of the SNA are not the same and should not be treated as such. As we show below, the strength of empirical evidence for purity and automaticity is different. In particular, we disagree with and argue against Fischer and colleagues' claim that enforced numerical cue processing, or lack of thereof, should be treated as just one potential moderator of Att-SNARC.

The conceptual link between numbers and space

To understand the nature of the link between numbers and space it is important to establish whether such a link can be observed in the absence of perceptual and response related confounds between space and numbers (Fischer & Shaki, 2016; Shaki & Fischer, 2018). Att-SNARC provides strong evidence for this claim because the link is not primed by making salient either stimuli presentation (numerical cues are presented centrally and do not allow for the prediction of target location), or response side (participants respond with one, centrally located response key).

Crucially, the claim regarding the presence of the conceptual link is not only supported by the original Att-SNARC finding but also several other paradigms, including Att-SNARC studies that enforced numerical cue processing and thus observed the cuing effect. Similar evidence comes from studies on attentional biases in number comparison (Salvaggio et al., 2019) or mental arithmetic showing that conducting mental additions / subtractions leads to spatial biases to the right and left sides, respectively (Masson et al., 2018). Other spatial biases have been linked to response stage (e.g., Andres et al., 2020; Masson et al., 2020). Importantly, the recent failed multi-laboratory replication does not support the claim of an existence of a conceptual link; however, it does not disprove it completely at the theoretical level either, because, as pointed out by Fischer et al. (2020), there is convergent evidence for such a link from multiple studies and paradigms – such as those discussed above. Regarding the conceptual link between numbers and space, the original Att-SNARC study is not qualitatively different from studies that enforced numerical cue processing or other similar paradigms.

Importantly, the claim for the conceptual (i.e., independent from specific stimuli and response setups) link between numbers and space is supported by its bi-directionality. Not only does processing of numbers influence spatial processing, but directional actions in space affect number processing as well. Evidence from that comes from studies on random number generation while performing directional head movements (e.g., Loetscher et al., 2008; but see Moser et al., 2017 for a non-replication), or optokinetic stimulation affecting the number processing (e.g., Ranzini et al., 2015). In a similar vein, studies on patients with neglect show the impairment of number processing when spatial processing is distorted (e.g., Vuilleumier et al., 2004). Noteworthy, other studies do question the presence of the conceptual link and postulate that several boundary conditions need to be met for the link to occur (e.g., Pinto et al., 2021), however, this discussion goes beyond the dispute on the theoretical implications of the Att-SNARC and its null replication.

To sum up, the presence of the conceptual link between numbers and directional space seems to be quite well established, and comes from variety of paradigms. Therefore, failure to replicate the Att-SNARC does not challenge this claim considerably.

Automatic and spontaneous association

The other, in our view, equally important conclusion of the original Att-SNARC paper is that the association of numbers and space occurs spontaneously; as stated in the initial paper, the participants did not have to process the numerical cues. In fact, the cues could be ignored completely. Participants could still successfully perform the detection task even if the part of the display that presented the cues was occluded during the experiment. We know that in similar cuing paradigms both arrows and social cues such as symbolic drawings of faces gazing to the right or left cannot be ignored (Galfano et al., 2006). Furthermore, the direction of the effect caused by numbers can be reversed by the instruction (Galfano et al., 2006; Ristic et al., 2006). The finding of such an automatic effect for numbers in the original Att-SNARC report fits well into the discussion on the nature of the links between space and numbers. The automaticity of the association is what makes a qualitative difference between the original Att-SNARC and other studies. However, over the years and across multiple replications, including the multi-laboratory replication, the claim of automaticity has not been supported (see also Casarotti et al., 2007). The multi-laboratory replication as well as several prior studies (for a review see Pellegrino et al., 2019) clearly show that passive viewing of numbers does not cause attention to shift

as was implicated in the original Att-SNARC paper. At the same time, recent studies using the task irrelevant spatial cues did not show that spatial primes facilitate processing subsequently presented numbers (Clement et al., 2020), which further questions the spontaneity and automaticity of the space-number link. What can be seen as another argument against the spontaneity and automaticity of the link between numbers and space are studies showing that even semantic number processing is possible without evoking links to space (Nuerk et al., 2005), also within purely attentional paradigms (Pinto et al., 2019). Other recent studies further question the automaticity of Spatial-Numerical Associations (Pinto et al., 2021).

In our view, the spontaneity of Att-SNARC, or lack of thereof, is not only a matter of one or another unknown moderator (which was not considered either in the original Att-SNARC paper or in the multi-laboratory replication) as implied by Fischer et al. (2020). As we mentioned above, studies that enforce number processing are actually tackling only the conceptual link, and do not tell us anything about an automatic / spontaneous nature of the effect. In other words, these studies are providing evidence for only part of the claims of the original paper. At the same time, such studies either remain neutral about automaticity, or simply show that SNAs evoked by semantic processing are not automatically elicited in absence of enforced number processing (e.g., Weis et al., 2018). A growing body of evidence shows that selective attention directed towards numbers is important or even necessary to evoke directional spatial associations in different experimental setups (Cipora, He, et al., 2020 for a review), and it seems to be true for Att-SNARC as well.

Conclusion

We think that the convergent evidence from conceptual replications and other paradigms supports only one part of the story originally presented by Fischer et al. (2003): that a conceptual link between numbers and space exists and it is neither elicited by spatial location of numbers nor location of response keys. Even though Att-SNARC has not been replicated in a multi-laboratory study, other paradigms provide evidence for this theoretical assumption. However, the automaticity aspect is not warranted any more, at least in the Att-SNARC paradigm, and still lacks solid empirical evidence in other paradigms. Numbers, which are not semantically processed, do not seem to automatically direct attention towards a certain direction in space. Future efforts should focus on establishing boundary conditions and factors that amplify attentional biases caused by numbers and SNAs in general. What also needs to be looked at more closely are relations between attentional biases evoked by processing of numbers and Spatial-Numerical Associations in general.

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Author Contributions

KC wrote the first draft of the manuscript and discussed its main points with HCN who critically reviewed and improved the draft. Both authors approved final version of the manuscript.

Open Science Practices

This article is conceptual and is not eligible for Open Science badges. The entire editorial process, including the open reviews, are published in the online supplement.

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