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The order of magnitude:
Why SNARC-like tasks (still) cannot support a generalized magnitude system

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Absract

According to proponents of the Generalized Magnitude System proposal (GMS; Walsh, 2003), SNARC-like effects index spatial mappings of magnitude and provide crucial evidence for the existence of a GMS. Casasanto and Pitt (2019) have argued that these effects, instead, reflect mappings of ordinality, which people compute on the basis of differences among stimuli that vary either qualitatively (e.g., musical pitches) or quantitatively (e.g., dots of different sizes). In response to our paper, Prpic et al. (2021) argued that both magnitude and ordinality play a role in SNARC-like effects. Here we address each of their arguments and conclude that magnitude is relevant to these effects only insofar as it serves as a basis for ordinality. For this reason and others, SNARC or SNARC-like effects cannot provide evidence for the putative generalized magnitude system.

Keywords: Magnitude, Ordinality, SNARC effect, cross-domain associations, spatial cognition, metaphor

In a response to our paper, *The Faulty Magnitude Detector: Why SNARC-like tasks cannot support a generalized magnitude system* (Casasanto & Pitt, 2019), Prpic and colleagues (2021) argued that although some SNARC-like effects can be explained by ordinality, others can only be explained by magnitude. This argument rests on three claims: (1) magnitude can prevail on ordinality when they are pitted against each other; (2) some ordinality mappings can be ruled out on the basis of working memory constraints; and (3) ordinality is "culturally acquired." Here we challenge all three of these claims and clarify additional reasons why SNARC-like tasks cannot support the generalized magnitude system proposal (Walsh, 2003).

1. People can order stimuli according to their relative magnitudes

Much of Prpic et al.'s argument relies on the assumption that any spatial mapping that is organized according to magnitude, but not according to a canonical order, is a mapping of magnitude. This assumption is flawed because, critically, people can and do ordinalize stimuli *spontaneously* according to their relative magnitudes. Whenever things are arranged from smallest to largest, least to most, or shortest to longest, they are being ordered by magnitude. For example, when people say "small, medium, large," they are ordering words (in time) according to the sizes they denote. This tendency to ordinalize by magnitude is pervasive, and may be most pronounced when objects do not differ reliably in other ways (e.g. black circles that vary only in size, sounds that vary only in duration). Importantly, any time stimuli are ordered in space according to their relative magnitudes, the resulting 'magnitude mapping' is, in fact, a mapping of ordinal position.

People can order stimuli in space according to a newly learned sequence (e.g. 8-1-9-3-7), even when it contradicts their canonical order (van Dijk & Fias, 2011); this was the case in a

study of musical notes discussed by Prpic et al. (2021; 2016). In some conditions, participants ordered the stimuli according to their canonical order (i.e. as listed in speech); in other conditions, they mapped them according to their ordinal position (i.e. rank) from shortest to longest. This task-dependency has also been observed in people's luminosity associations, which *reversed* depending on the brightness of the background (Cohen Kadosh & Henik, 2006; Cohen Kadosh, Cohen Kadosh, & Henik, 2008; Fumarola et al, 2014; Ren et al., 2011). Such contextual cues do not change the magnitudes of the stimuli. Rather, they cause people to rank the same magnitudes in one order (e.g. from darkest to lightest) or another order (e.g. from lightest to darkest). Magnitude, therefore, is relevant to such mappings only insofar as it determines ordinal position; *ordinal position* is the stimulus feature that is being spatialized no matter whether the stimuli are being ordered from least to greatest magnitude or greatest to least magnitude.

2. People can order large, novel stimulus sets without taxing working memory

On Prpic et al.'s (2021) account, unless a stimulus set is overlearned (as in the verbal count list), it can only be ordinalized by holding it in working memory. Given the limits of working memory, they argue that SNARC-like effects for any large stimulus set (e.g. 48 object names) must reflect a mapping of magnitude and not ordinality. This argument is problematic for two reasons. First, there is no reason to believe that the working memory resources that are required to construct a spatial mapping on the basis of magnitude would be less than those required to construct one on the basis of ordinality. Second, people can spontaneously spatialize large sets of novel stimuli according to *qualitative* differences among them, even when this qualitative ordering *contradicts* differences in their magnitudes (e.g. 32 words that vary in emotional

valence and intensity; Pitt & Casasanto, 2018: Experiment 1b). Spatial mappings – even of large sets of unstudied stimuli – do not require that stimuli vary in magnitude.

How do people spatialize novel stimuli without holding all of the stimulus items in working memory? Research in visual and auditory cognition shows that, when presented with complex stimuli (e.g., arrays of images or sequences of words), people spontaneously construct summary representations of those stimuli, without taxing working memory (Brady, Konkle, & Alvarez, 2011; Whitney & Yamanashi Leib, 2018). For example, people accurately compute the average size in an array of shapes, the average pitch in a sequence of tones, and the average emotional expression in a crowd of faces (and their variances), even when people cannot recognize the individual stimuli that were presented (and even for stimulus sets that number in the hundreds). As these examples illustrate, people can compute summary representations for features that vary *quantitatively* (e.g., size) or *qualitatively* (e.g., pitch). If participants can construct a summary representation of the distribution of the relevant stimulus feature (e.g., the typical sizes of various animals), then they should be able to relate an unstudied stimulus (e.g. beetle) to other stimuli in a set (e.g. bear, bat, brontosaurus, etc.) without holding each stimulus in working memory, rehearsing the set in a temporal sequence, or knowing in advance the limits of the set.

3. Ordinality need not be culturally acquired

Prpic et al. (2021) argued that space-number association observed in infants and non-human animals must rely on magnitude; they cannot be explained by ordinality because ordinality is "culturally acquired." However, we are unaware of any evidence that supports this claim. The *direction* of people's mental mappings (e.g. left-to-right vs. right-to-left) varies across cultures

and contexts (e.g. Shaki, Fischer, & Petrusic, 2009; Pitt & Casasanto, 2020), but the tendency to ordinalize objects or events appears to be universal: Children and adults from non-industrialized cultures order novel stimuli according to their relative number, size, or age with little or no cultural support (Cooperrider, Marghetis, & Núñez, 2017; Pitt et al., 2021). This ability is not specific to magnitudes: People spatialize unstudied stimuli whether they vary quantitatively (i.e. a *prothetic* domain like size and brightness) or qualitatively (i.e. a *metathetic* domain like pitch and emotional valence). For example, people implicitly associate negative emotions with the left and positive emotions with the right, even though positive emotions are not necessarily greater in 'magnitude' (i.e., emotional intensity) than negative ones (Pitt & Casasanto, 2018; Stevens, 1957; Stevens & Galanter, 1957).[1] In short, people do not need variation in magnitude to construct ordered spatial mappings, and they construct these mappings in the absence of relevant cultural conventions (Pitt et al., 2021) or even in contradiction to these conventions (de la Fuente, Casasanto, Román, & Santiago, 2015).

4. Magnitude does not have direction

In their reply, Prpic et al. (2021) do not address one of the fundamental challenges to the claim that SNARC-like effects reflect magnitude mappings, and to the GMS proposal more broadly: *SNARC-like effects have direction but magnitude does not*. On the GMS proposal, SNARC-like effects reflect interactions between two magnitudes: spatial magnitude and the magnitude of whatever domain is being spatialized. Yet, all magnitudes (including size, length, brightness, and duration) are scalars and therefore have extent but no direction. In light of this physical fact,

[1] Like sounds and colors, emotions vary along both prothetic and metathetic dimensions. For example, *happy* and *ecstatic* differ in emotional intensity (prothetic) whereas *happy* and *sad* differ in emotional valence (metathetic), even if they are of equal intensity.

people may associate more in one domain with more in another domain (e.g. more in number - larger in size; de Hevia et al., 2014; Srinivasan & Carey, 2010) but such an association among magnitudes alone cannot in principle produce a directional mapping like those indexed by the SNARC effect (e.g. small-left, big-right).[2] Rather, the aspect of space that underlies SNARC-like effects is spatial *position*, which can vary in a particular direction (e.g. left-to-right) but does not vary in magnitude (e.g. right is not "more space" than left; Stevens & Galanter, 1957). The GMS proposal only obtains for "those dimensions that were described as *prothetic* by Stevens (1957), meaning dimensions that can be experienced as more than or less than" (Walsh, 2003, p. 484). If the spatial basis of SNARC-like effects is metathetic (i.e., position), then these effects cannot reflect mappings among two magnitudes, no matter what domain is being spatialized. Rather, they appear to reflect mental mappings between a metathetic source domain (e.g. left-right spatial position) and a metathetic target domain (e.g. ordinal rank in number, time, size, etc.), neither of which varies in magnitude.

5. Conclusion

SNARC-like effects reflect spatial mappings of ordinal relations among stimuli that can vary along either prothetic or metathetic dimensions. Even when a prothetic property is being spatialized, the spatial mapping indexes ordinal relations among the stimuli: In these cases, the ordinal relations happen to be determined on the basis of magnitude. People implicitly spatialize ordinal relations among stimuli whether or not these relations are overlearned, and whether or

[2] Some may suggest that magnitude mappings can gain direction when anchored to a position: Longer lines would extend farther to the right than shorter lines, if they were left-aligned to the same lateral starting point. This proposal, which combines spatial magnitude (i.e. size) with position (i.e. a shared starting point), is inconsistent with empirical findings. For example, educated adults associate longer temporal durations with longer spatial distances, whether those distances are traversed left-to-right or right-to-left (Casasanto & Boroditsky, 2003).

not every stimulus in the set can be held in working memory at once. Rather than supporting a putative Generalized Magnitude System, SNARC-like effects provide evidence for a broader theory of how people use space to organize their knowledge in both prothetic and metathetic domains (Casasanto, 2017).

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