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Common spatial organization of number and emotional expression: A mental magnitude line

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ABSTRACT

Converging behavioral and neural evidence suggests that numerical representations are mentally organized in left-to-right orientation. Here we show that this format of spatial organization extends to emotional expression. In Experiment 1, right-side responses became increasingly faster as number (represented by Arabic numerals) or happiness (depicted in facial stimuli) increased, for judgments completely unrelated to magnitude. Additional experiments suggest that magnitude (i.e., more/less relations), not valence (i.e., positive/negative), underlies left-to-right orientation of emotional expression (Experiment 2), and that this orientation accommodates to the context-relevant emotion (e.g., happier faces are more rightward when judged on happiness, but more leftward when judged on angriness; Experiment 3). These findings show that people automatically extract magnitude from a variety of stimuli, representing such information in common left-to-right format, perhaps reflecting a *mental magnitude line*. We suggest that number is but one dimension in a hyper-general representational system uniting disparate dimensions of magnitude and likely subserved by common neural mechanisms in posterior parietal cortex.

1. Introduction

The metaphor of the *mental number line* is often invoked to illustrate the deep mental connection between space and number (for review, see Hubbard, Piazza, Pinel, & Dehaene, 2005). In a classic demonstration, known as the *SNARC* (Spatial–Numerical Association of Response Codes) effect, Dehaene, Bossini, and Giraux (1993) found that parity (odd/even) judgments were faster when Western adult participants responded to smaller numbers (e.g., 1 and 2) on the left side of space (e.g., with their left hand) and to larger numbers (e.g., 8 and 9) on the right (e.g., with their right hand). It has also been shown that people randomly generate smaller numbers when facing leftward and larger numbers when facing rightward (Loetscher, Schwarz, Schubiger, & Brugger, 2008), and that numerical processing elicits shifts in spatial attention, with smaller and larger numbers speeding detection of left- and right-side visual stimuli, respectively (Fischer, Castel, Dodd, & Pratt, 2003). These findings suggest that representations of number are fundamentally spatial in nature, with increasing values mentally organized in left-to-right orientation.

Other recent studies suggest that spatial organization extends to temporal information. Duration is underestimated for left-side stimuli and overestimated for right-side stimuli (Vicario et al., 2008), and people are faster to respond to shorter and longer durations (Vallesi, Binns, & Shallice, 2008), as well as to judge earlier and later onset timing (Ishihara, Keller, Rossetti, & Prinz, 2008), with their left and right hands, respectively. Together, these findings suggest that left-to-right orientation is a property of both numerical and temporal representation: "less" time is represented on the left side of space and "more" time on the right, like smaller and larger numbers, respectively.

Evidence of common neural mechanisms in posterior parietal cortex, particularly the intraparietal sulcus (IPS), for number (Cohen Kadosh, Cohen Kadosh, Kaas, Henik, & Goebel, 2007; Piazza, Pinel, Le Bihan, & Dehaene, 2007), duration (Leon & Shadlen, 2003; Maquet et al., 1996), and spatial extent (Fias, Lammertyn, Reynvoet, Dupont, & Orban, 2003; Pinel, Piazza, Le Bihan, & Dehaene, 2004; Sereno, Pitzalis, & Martinez, 2001) is suggestive of a system of generalized magnitude representation (Walsh, 2003; see also Gallistel & Gelman, 2000; Lourenco & Longo, 2010), in which such dimensions share not only cerebral territory but also representational structure, including left-to-right orientation (for reviews, see Bueti & Walsh, 2009; Cantlon, Platt, & Brannon, 2009; Cohen Kadosh, Lammertyn, & Izard, 2008). Indeed, damage to right posterior parietal cortex, or more distributed parieto-frontal circuits, can produce representational deficits that extend across magnitude dimensions (Bisiach & Vallar, 2000). Patients with hemispatial neglect, for example, show significant rightward bias (i.e., ignoring the left side of space) not only when

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bisecting physical lines, but also when estimating the midpoint of numerical intervals (i.e., overestimating relative to the actual midpoint, consistent with a "rightward" bias on a left-to-right mental number line) (Zorzi, Priftis, & Umiltà, 2002; for evidence with healthy participants, see Longo & Lourenco, 2007, 2010; Lourenco & Longo, 2009). Similar findings when neglect patients judge temporal order for lateralized stimuli (Snyder & Chatterjee, 2004) suggest that impaired processing along the left–right spatial axis alters the mental organization of both number and time.

In the present research, we examine the extent to which such organization generalizes to less prototypical sources of magnitude information. Because of their clearly delineated more versus less relations, number and duration might be considered prototypical *prothetic* dimensions – that is, dimensions characterized by quantity, or "how much," often contrasted with *metathetic* dimensions such as pitch and hue, characterized by quality, or "what kind" (Stevens, 1957, 1975). However, countless other experiences can also be described in more/less terms, though perhaps not primarily. For example, the concept of happiness may be characterized, at least in part, in terms of degree – that is, how happy one is at a given moment. Might a system of generalized magnitude representation be so abstract as to encompass even socio-emotional cues such as facial expressions exhibiting happiness? If so, the representation of happiness, among other emotions, might also be expected to show the property of left-to-right orientation.

We use emotional expression as the test case of generalization because there are clear reasons why such a domain might be excluded from a general magnitude system, and hence not mentally organized in any consistent spatial orientation. Unlike for number, other features (e.g., valence) may be equally, if not more, salient than degree of emotion (e.g., Bradley & Vrana, 1993; Nakashima et al., 2008), and representations of emotion have often been regarded as categorical, rather than graded, in nature (e.g., Ekman, 1992). Moreover, while cultural tools such as rulers reinforce left-to-right orientation for number, emotional expression has no obvious spatial instantiation in the physical world. Happier people, for example, do not tend to congregate on the right side of space. Given the substantive differences between number and emotional expression, a common pattern of spatial organization would provide compelling support for a hyper-general system of magnitude representation, encompassing dimensions both prototypical and otherwise.

2. Experiment 1

This experiment examined whether happiness, as indexed by facial expression, is mentally organized in left-to-right orientation, like number. Participants completed both Number and Face tasks in which response choices were paired with left- and right-side response keys. The Number task used the canonical SNARC paradigm (e.g., Dehaene et al., 1993, Experiment 1), with participants making parity (odd/even) judgments to numbers 0–9. Because parity judgments are irrelevant to magnitude (i.e., a larger number is no more likely to be odd or even than a smaller number), reliable left-to-right orientation in this paradigm suggests that spatial organization is relatively automatic (Fias & Fischer, 2005). Indeed, left-to-right orientation of number has been observed using other types of magnitude-irrelevant judgments as well (e.g., Fias, Lauwereyns, & Lammertyn, 2001). The Face task was designed to mirror the Number task in this respect. Participants were presented with images of human faces whose expressions varied in happiness, and were asked to judge the gender (male/female) of each face. Thus, judgments in both tasks involved no explicit consideration of magnitude, whether numerical or emotional.

2.1. Method

2.1.1. Participants

Eighteen Emory University undergraduates (12 female) participated for course credit. As measured by the Edinburgh Handedness Inventory (EHI; Oldfield, 1971), the majority of participants (14) were right-handed ($M = 49$; range: -53 to 100). All had normal or corrected-to-normal vision and gave written consent to participate. Procedures were approved by the local ethics committee.

2.1.2. Stimuli

Number stimuli were Arabic numerals (0–9), presented centrally on a computer screen in black font on a white background (Arial font, 25×15 mm, $2.9° \times 1.7°$). Face stimuli (90×65 mm, $10.3° \times 7.4°$), also presented centrally on a white background, were from the NimStim Face Stimulus Set (Tottenham et al., 2009). Images of six models (three female), each exhibiting four distinct expressions (which we labeled *neutral*, *happy*, *very happy*, and *extremely happy*; see Fig. 1a), were selected based on validity ratings, for a total of 24 grayscale images.

2.1.3. Procedure

Each participant completed both Number and Face tasks (order counterbalanced). In the Number task, participants made parity judgments on each trial by pressing left ("Q") and right ("P") computer keys. Participants completed two blocks of trials: one in which even responses were assigned to the left key and odd responses to the right key, and the other with the reverse assignment (order counterbalanced). Each block consisted of 10 practice trials and 90 test trials (each number presented nine times; random order). In the Face task, participants made gender judgments on each trial by pressing the same left and right keys. As in the Number task, participants completed two blocks of trials: one in which male responses were assigned to the left key and female responses to the right key, and the other with the reverse assignment (order counterbalanced). Each block consisted of 12 practice trials and 96 test trials (24 face stimuli presented four times each, with 24 trials of each expression; random order). Each trial began with a fixation cross presented centrally for 500 ms. The target stimulus (number or face) followed, remaining onscreen until participants made a response. The intertrial interval was 500 ms. Instructions emphasized both speed and accuracy.

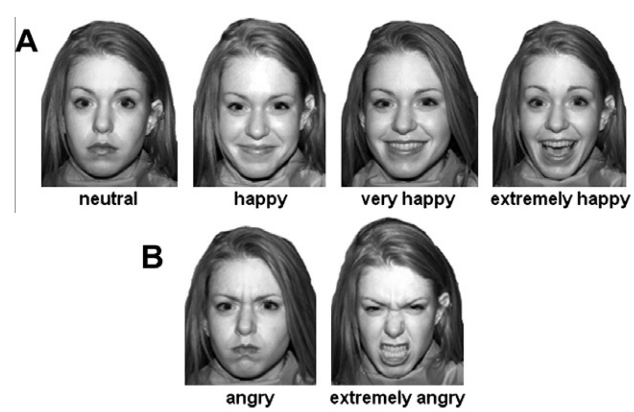

Fig. 1. (A) Range of facial expressions used in Experiment 1. (B) Angry facial expressions used in Experiments 2 and 3; these experiments also included *neutral* (Experiment 2 only), *happy*, and *extremely happy* expressions. All face stimuli were selected from Tottenham et al. (2009).