Spatial Organization of Magnitude in the Representation of Number and Emotion

Kevin J. Holmes (kevin.holmes@emory.edu)
Stella F. Lourenco (slouren@emory.edu)
Department of Psychology, Emory University
532 Kilgo Circle, Atlanta, GA 30322

Abstract

Converging behavioral and neural evidence suggests that numerical representations are spatially organized from left-to-right, the so-called *mental number line*. When judging parity (odd/even), for example, smaller and larger numbers produce faster left- and right-side responses, respectively (the *SNARC* effect). Three experiments revealed that this spatial organization of magnitude extends to the representation of emotion. In Experiment 1, participants made parity judgments to numbers (0 to 9) and gender judgments (male/female) to human faces whose expressions varied in happiness. Results showed similar patterns of spatial organization across the two dimensions, with right-side responses becoming increasingly faster as numerosity or happiness increased. Experiment 2 showed that magnitude, not valence, underlies this left-to-right organization, and Experiment 3 provided evidence for the flexibility and specificity of magnitude representation. Together, our findings suggest that people automatically extract information about magnitude, regardless of its instantiation, representing disparate dimensions of experience in common spatial (left-to-right) form. Number appears to be but one example of a more general representational system linking space and dimensions of magnitude.

Keywords: magnitude; spatial organization; SNARC effect; number; emotion.

Introduction

Space and number are richly correlated in the world. More numerous sets of items, for example, tend to occupy more space (provided item size remains constant). Associations between space and number have also been well established in the laboratory. Perhaps the classic demonstration of an association is the *SNARC* (Spatial-Numerical Association of Response Codes) effect, whereby smaller numbers (e.g., 1, 2) are associated with the left side of space and larger numbers (e.g., 8, 9) with the right. Dehaene, Bossini, and Giraux (1993), for example, found that participants asked to make parity (odd/even) judgments were faster to respond to smaller numbers with the left hand and to larger numbers with the right, suggesting that increasing numerical values show a left-to-right organization, the *mental number line*. Moreover, number processing has been found to elicit shifts in covert spatial attention, with smaller numbers speeding subsequent detection of peripheral stimuli in the left visual field and larger numbers speeding detection in the right (Fischer et al., 2003). This left-to-right spatial organization may not be unique to number, however. Spatial location has been shown to bias temporal judgments (Vallesi, Binns, & Shallice, 2008; Vicario et al., 2008), and SNARC-like effects have been observed for size (Bonny & Lourenco, in preparation).

Such findings lend support to the notion of a common representational code for magnitude across the dimensions of space, number, and time (Walsh, 2003). Moreover, neural evidence has pointed to posterior parietal cortex as a locus for the processing of magnitude, given its associations with spatial (e.g., Sereno, Pitzalis, & Martinez, 2001), numerical (e.g., Piazza et al., 2007), and temporal (e.g., Leon & Shadlen, 2003) processing. Recent developmental findings suggest that a general magnitude system may be operational from early in life. Lourenco and Longo (2009) showed that 9-month-old infants generalized learning across size, numerosity, and duration, suggesting early representations of magnitude that are, to some degree, abstracted from any specific dimension.

On a general magnitude account, evidence for the spatial organization of number (e.g., Dehaene et al., 1993; Fischer et al., 2003), duration (Vallesi et al., 2008; Vicario et al., 2008), and size (Bonny & Lourenco, in preparation) suggests that space may offer a representational template for organizing magnitude, regardless of dimension. Across all three magnitude dimensions, "more" (whether it be greater numerosity, longer duration, or larger size) tends to be processed more rapidly on the right side of space and "less" on the left. Thus, spatial organization may be a property of magnitude representation in general, rather than being specific to representations within a given dimension.

In theory, countless dimensions of experience may be characterized in terms of magnitude, from the clearly defined (e.g., number) to the more abstract (e.g., happiness). If magnitude representation is spatial in nature, a system that draws on magnitude as a common language of measurement (Lourenco & Longo, 2009) might recruit space to organize information within any dimension, so long as the information is defined in terms of more/less relations. This possibility suggests an even more general cognitive system that extends beyond the trio of dimensions – size, number, and duration – typically conceived as dimensions of magnitude. On this *über-general* account, even information that is ostensibly quite different from size, number, and duration might show left-to-right spatial organization.

To investigate this possibility, we selected the domain of emotion, which includes dimensions such as happiness, angriness, surprise, etc. If space serves to organize dimensions for which magnitude information may be extracted, stimuli that denote "less" and "more" of a given emotion (e.g., facial expressions that range from less happy to more happy) should be processed more rapidly on the left and right side of space, respectively. This pattern of spatial organization would support the notion that magnitude serves as a shared vocabulary linking representations of seemingly disparate dimensions of experience.

Experiment 1: Number & Happiness

This experiment explored whether the dimension of happiness, as indexed by facial expression, would show spatial organization similar to that of number. Participants completed both a number and a face task. The number task was a replication of Dehaene et al. (1993, Exp. 1); participants made parity (odd/even) judgments to numbers ranging from 0 to 9. In the face task, participants made gender judgments (male/female) to images of human faces whose expressions ranged from neutral to extremely happy. In both tasks, response choices were paired with left- and right-side response keys. If spatial organization is not specific to the dimensions of number, duration, and size, but instead reflects an even more general representational system for magnitude, the two tasks should produce analogous response patterns. Specifically, faster right-side responses should be observed as happiness increases in the face task, mirroring faster right responses as numerosity increases in the number task.

Method

Participants. 18 Emory University undergraduates participated for course credit.

Materials. Number stimuli were Arabic numerals (0 to 9), presented centrally on a computer screen in black on a white background (Arial font, 25 x 15 mm). Face stimuli were selected from the NimStim Face Stimulus Set (Tottenham et al., in press). Images of six models (three male, three female), each making four distinct facial expressions (labeled *neutral*, *happy*, *very happy*, and *extremely happy*; see Figure 1), were selected, for a total of 24 digital grayscale images. Face stimuli (90 x 65 mm) were presented centrally on a white background.

Procedure. Each participant completed both a number and a face task (order counterbalanced). In the number task, participants made odd or even judgments to numbers by pressing one of two response keys on the computer keyboard. Participants completed two blocks of trials: one in which the even response was assigned to the left key and the odd response to the right key, and one with the reverse assignment (order counterbalanced). Each block began with 10 practice trials, with each number presented once. On test trials, each number was presented nine times, for a total of 90 trials per block (random order).

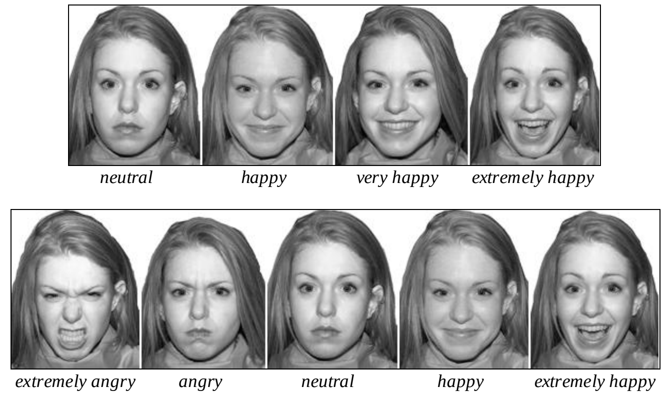

Figure 1: The range of faces used in Exp. 1 (top row) and Exp. 2 and 3 (bottom row), shown for one of the models. Experiment 3 omitted the *neutral* face.

In the face task, participants made male or female judgments to human faces varying in happiness by pressing left and right response keys. For one block of trials, the male response was assigned to the left key and the female response to the right key; a second block used the reverse assignment (order counterbalanced). Each block began with 12 practice trials, with each of the four facial expression categories presented 3 times (with different models). On test trials, each of the 24 unique face images was presented 4 times, for a total of 96 randomly ordered trials per block (24 trials of each facial expression category).

In both tasks, instructions emphasized speed and accuracy. Each trial began with a fixation cross presented centrally for 500 ms. The target stimulus (number or face) followed and remained on screen until a response was made.

Results and Discussion

The overall error rates were 5.0% in the number task and 2.2% in the face task. Trials in which participants made an incorrect response or in which the RT was greater than 2.5 SD from the participant's mean were not included in the analyses.

Following Dehaene et al. (1993), number magnitude was collapsed across digit pairs: 0-1, 2-3, 4-5, 6-7, and 8-9. Mean RTs for each participant were computed for left and right responses separately for each digit pair in the number task and for each facial expression category in the face task. RT differences were computed by subtracting the mean RT for the left response from the mean RT for the right response. For the number task, these RT differences were regressed on digit magnitude to determine the unstandardized slope coefficient of the best-fitting linear regression. If increasing numerosity shows a left-to-right organization, smaller numbers should elicit relatively faster left responses and larger numbers should elicit relatively faster right responses, resulting in a negative slope.

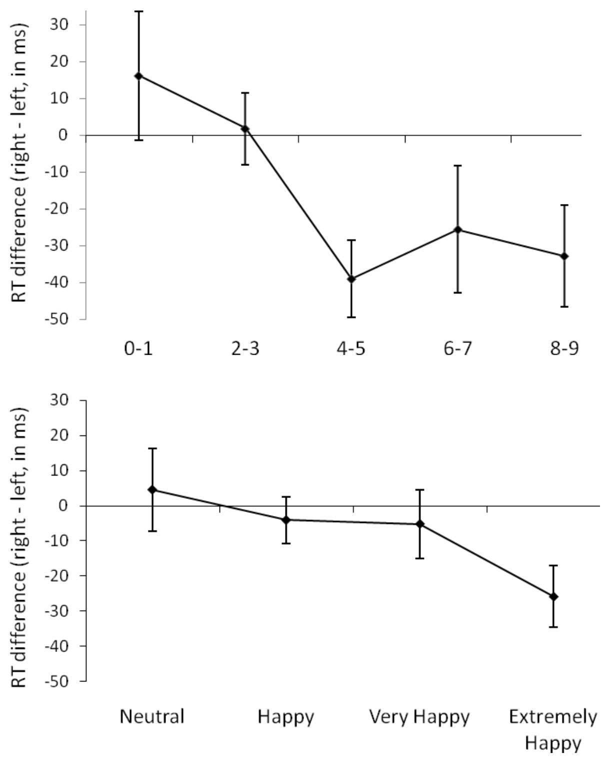

Figure 2: Mean RT difference between right and left responses for the number (top panel) and face (bottom panel) tasks in Exp. 1. Negative values indicate faster right than left responses.

For the face task, the facial expression categories were assigned increasing values from 1 to 4 (1 = *neutral*, 2 = *happy*, 3 = *very happy*, 4 = *extremely happy*). RT differences were regressed on these values, since the "psychological distance" between differing degrees of happiness is unknown.[1] If the dimension of happiness shows a similar left-to-right organization to that of number, less happy faces should elicit relatively faster left responses and more happy faces should elicit relatively faster right responses, again resulting in a negative slope.

The average slope coefficients for the two tasks were compared against zero. The slopes were -6.26 ms/digit (*SD* = 10.18) for number and -9.19 ms/category (*SD* = 14.83) for happiness.[2] Both values reflect reliable mappings between space and magnitude, $t(17) = 2.61$, $p < .05$ for number and $t(17) = 2.63$, $p < .05$ for happiness (see Figure 2), indicating that participants mapped values corresponding to "less" and "more" onto left and right space, respectively, for both number and happiness. A 2 (dimension: number or happiness) × 2 (task order) ANOVA showed no significant main effect of task order or interaction (*p*s > .3).

The results of Experiment 1 suggest that the dimension of happiness shows a similar pattern of spatial organization to that of number. Rather than being specific to number (or other traditional dimensions of magnitude, such as size and duration), spatial organization may be invoked in the processing of other dimensions for which differences in magnitude may be a defining attribute. Intriguingly, spatial organization was observed for happiness even though participants' responses were irrelevant to emotion. This finding suggests automatic extraction of magnitude during the processing of everyday stimuli such as numbers or faces, and supports the notion of a highly general representational system linking spatial orientation and magnitude.

An alternative explanation for the results of the face task counters this conclusion. Since the facial expressions differed not only in magnitude but also in emotional valence, participants may have mapped values corresponding to relatively more negative and relatively more positive emotion to left and right space, respectively. This possibility is consistent with recent findings of mental associations between emotional valence and space (Casasanto, in press).[3] If faces were organized in terms of valence, rather than magnitude, it might be concluded that different factors underlie the spatial organization of number and faces. Such a conclusion would argue against the prediction that magnitude underlies the spatial organization of dimensions other than number, duration, and size. Experiment 2 was designed to discriminate between these two possibilities.

Experiment 2: Number & Happiness/Angriness

Experiment 2 examined more closely the pattern of spatial organization of emotion observed in Experiment 1. As in the first experiment, participants made gender judgments to faces by pressing left and right response keys, but this time the range of faces included both positive and negative emotional expressions. If the left-to-right organization of faces is due to the processing of magnitude information, faster right responses should be observed as the magnitude of either positive or negative emotion increases. If, however, the observed pattern of spatial organization is due to associations between valence and space, more negative expressions should produce faster left responses and more positive expressions should produce faster right responses. To enable comparison of findings for number

[1] While the values selected may not capture the true psychological distance between points along the happiness continuum, it should be noted that digit magnitude may similarly be an imperfect measure of psychological distance for number. In accordance with Weber's law, the discriminability of two numbers decreases as their magnitude increases (Moyer & Landauer, 1967).

[2] When slopes in the face task were calculated as a function of model, there was a negative slope for each of the six models, suggesting that the effects observed were not due to specific items.

[3] Casasanto's *body-specificity hypothesis* predicts that handedness moderates associations between valence and space. There was no correlation, however, between slope coefficients and handedness, as measured by the Edinburgh Handedness Inventory, in any of the three experiments reported here (all *p*s > .3). The results of Exp. 2, showing that emotion is organized spatially in terms of magnitude rather than valence, are also inconsistent with Casasanto's proposal.

and emotion, participants also completed the same number task as in Experiment 1.

Method

Participants. 30 Emory University undergraduates participated for course credit.

Materials and Procedure. The number task was identical to that in Exp. 1. The face task used images of the same six models as in Exp. 1, but the facial expressions were *extremely angry*, *angry*, *neutral*, *happy*, and *extremely happy* (see Figure 1), for a total of 30 images.

As in Exp. 1, there were two blocks of trials, across which response (male or female) and side of response (left or right) were counterbalanced. Each block began with 10 practice trials, with each of the five facial expressions presented twice (once with a male model and once with a female model). On test trials, each of the 30 face images was presented three times, for a total of 90 randomly ordered trials per block (18 trials of each facial expression category). All other aspects were identical to Exp. 1.

Results and Discussion

The overall error rate was 5.1% in the number task and 2.5% in the face task. Data were trimmed and RT differences calculated using previous criteria (see Exp. 1).

For the face task, the facial expression categories were assigned values from -2 to 2 (-2 = *extremely angry*, -1 = *angry*, 0 = *neutral*, 1 = *happy*, 2 = *extremely happy*). These values enabled discrimination between two accounts: (a) that angriness and happiness are processed as symmetrical dimensions organized by magnitude; or (b) that they are processed as a single dimension organized by valence. RT differences (right minus left) were regressed on these values. The average slope coefficients were -4.19 ms/digit (SD = 6.62) for number and 3.27 ms/category (SD = 11.13) for emotion. These values were significantly different from zero in the case of number, $t(29) = 3.47$, $p < .01$, but not emotion, $t(29) = 1.61$, $p > .1$.

To examine the pattern of spatial organization within each dimension individually, the average slope coefficients for angriness (*extremely angry* to *angry*) and happiness (*happy* to *extremely happy*) were computed. Whereas the slope for angriness was positive (29.35; SD = 51.78), the slope for happiness was negative (-2.87; SD = 62.23), indicating that right-side responses became faster with both increasing angriness and increasing happiness (see Figure 3). These findings suggest that participants treated happiness and angriness separately, responding to emotion on the basis of magnitude within each dimension rather than valence (positive vs. negative). A 3 (dimension: number, happiness, or angriness) × 2 (task order) ANOVA revealed no significant main effects or interaction (ps > .05).

The results of Exp. 2 suggest that participants mapped values of "less" and "more" onto left and right space, respectively, for number, happiness, and angriness. The findings counter the possibility that valence underlies the

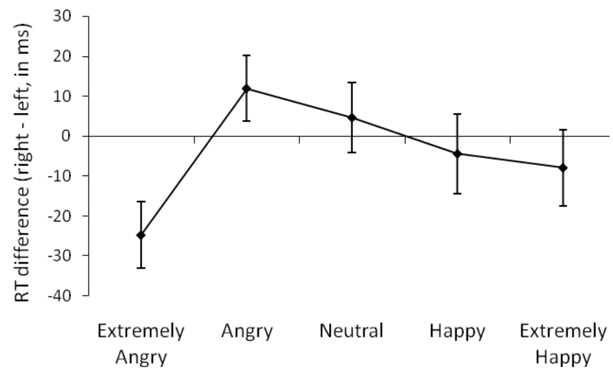

Figure 3: Mean RT difference between right and left responses for the face task in Exp. 2.

spatial organization of emotion. Instead, they suggest that by default, people extract magnitude information across different dimensions and organize this information spatially. Even when multiple dimensions were intermixed, as in the face task, people seemed to unpack them, mentally organizing each in terms of "less" and "more."

What factors determine how one conceptualizes "more"? Not all contexts support the processing of magnitude across multiple dimensions (e.g., happiness and angriness). In everyday life, we often reason or make judgments within the parameters of a single dimension. For example, a doctor confronted with a room full of sick patients must decide which are sickest in order to allocate her time appropriately. In making this decision, other magnitude-related information (e.g., patients' varying levels of hunger, self-esteem, etc.) is irrelevant and should be ignored. Whereas default conditions, like those in Experiment 2, might support the extraction of magnitude across multiple dimensions, contexts that suggest magnitude should be conceptualized in terms of a single dimension might promote dimension-specific processing. In this latter case, only magnitude information relevant to the dimension in question should show spatial organization. Experiment 3 addressed this prediction within emotion dimensions.

Experiment 3: Dimension-Specific Processing of Magnitude

Experiment 3 was designed to examine how the spatial organization of emotion is affected by context. As in the first two experiments, participants were presented with faces of varying emotional expression, but this time they made explicit judgments about emotion, designed to promote dimension-specific processing of magnitude. Across two tasks, participants judged either happiness or angriness for the same facial expressions. If, as predicted, the spatial organization of magnitude is flexible and depends on how magnitude is conceptualized, different patterns should be observed for the two types of judgments. For happiness judgments, participants should show relatively faster left responses to angrier faces and relatively faster right responses to happier faces; for angriness judgments, the reverse pattern should be observed. If, however, the spatial organization of magnitude is impervious to such contextual factors, the findings should resemble those of the previous experiment, with right responses becoming relatively faster as either happiness or angriness increases.

Method

Participants. 20 Emory University undergraduates participated for course credit.

Materials and Procedure. The same face stimuli as in Exp. 2 were used (see Figure 1), except that the *neutral* expression was omitted (since it is unlikely to be treated as happy or angry), leaving a total of 24 images. Each participant completed both a "happy = more" task and an "angry = more" task (order counterbalanced). In the "happy = more" task, participants judged whether each face was "happy" or "not happy" by pressing left and right response keys. In one block, the "happy" response was assigned to the left key and the "not happy" response to the right key; the other block used the reverse assignment (order counterbalanced). The "angry = more" task was identical, except that the responses were "angry" and "not angry." As in Exp. 1, there were 12 practice trials and 96 test trials.

Results and Discussion

The overall error rate was 5.6% in the happiness task and 5.5% in the angriness task. Data were trimmed and RT differences calculated using previous criteria (see Exp. 1).

Across both tasks, the facial expression categories were assigned values from 1 to 4 (1 = *extremely angry*, 2 = *angry*, 3 = *happy*, 4 = *extremely happy*).[4] If the spatial organization of emotion changes depending on one's dimension-specific representation of magnitude (e.g., whether one conceives of "more" as being "more happy" or "more angry"), angrier faces should elicit relatively faster left responses and happier faces should elicit relatively faster right responses in the "happy = more" task. The reverse pattern should be observed in the "angry = more" task.

The average slope coefficients were -27.15 ms/category (SD = 59.16) for the "happy = more" task and -11.58 ms/category (SD = 51.35) for the "angry = more" task, with no significant difference between them. A 2 (task: "happy = more" or "angry = more") × 2 (task order) ANOVA revealed a significant main effect of task order, $F(1, 18) = 8.04$, $p = .011$, but no interaction, $F(1, 18) = .05$, $p > .8$, indicating that participants' patterns of performance on the first task carried over to the second task. Focusing only on the first task completed, the average slope coefficients were -44.15 (SD = 68.40) for the "happy = more" task and 11.67 (SD = 49.69) for the "angry = more" task, with a significant difference between slopes, $t(18) = 2.44$, $p < .05$. Thus, participants who completed the "happy = more" task first

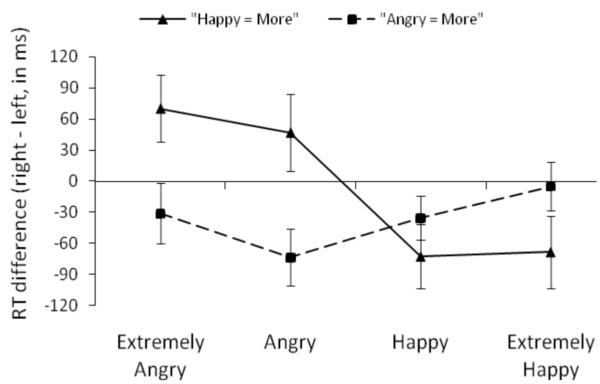

Figure 4: Mean RT difference between right and left responses in Exp. 3, for the first task completed.

organized the face continuum from angry (left) to happy (right). In contrast, those who completed the "angry = more" task first showed the opposite pattern of spatial organization (see Figure 4).

Whereas the first two experiments suggested a left-to-right organization of magnitude across different dimensions, the findings of Experiment 3 highlight the flexibility of this organization. When context promotes dimension-specific processing of magnitude, spatial organization adjusts accordingly to the dimension in question. When making judgments about happiness, for example, participants conceptualized "more" specifically as "more happy," and the mapping of magnitude to space reflected this representation. The findings suggest that representing magnitude spatially may offer a flexible tool for the context-specific mental organization of experience. Disparate dimensions may be linked through extraction of their common denominator: magnitude.

General Discussion

The mental number line has been regarded as a useful metaphor for highlighting the spatial nature of numerical representation. The present research suggests that the spatial organization of number has in some sense been unjustifiably privileged. Spatial organization appears not to be specific to number, but rather a property of magnitude representation more generally. The findings of three experiments revealed a left-to-right organization of magnitude across dimensions, mirroring similar findings for duration (Vallesi et al., 2008) and size (Bonny & Lourenco, in preparation). What distinguishes the present experiments from prior work is the demonstration that spatial organization is recruited in the processing of emotion, a domain strikingly unlike those studied previously. Our findings suggest that vastly different dimensions of experience may be processed more similarly than previously thought, with magnitude perhaps serving as a link between them. Moreover, spatial organization may be deployed quite flexibly in magnitude representation, across different dimensions and spatial frames of reference. While the current paradigm specifically examined left-to-right organization, it is possible that other spatial frames (e.g.,

[4] Without the *neutral* category, there is no obvious reason to split the angry and happy categories, as would have occurred had the values from Exp. 2 (-2, -1, 1, 2) been used instead.

up/down, front/back) may also be recruited in the processing of magnitude (Schwarz & Keus, 2004).

What are the origins of these commonalities in processing? One possibility is that the relation between space and number is prepotent to some extent, with other dimensions of magnitude taking their spatial structure from number. External spatial representations of number, such as those on rulers and telephone keypads, are ubiquitous, and left-to-right counting direction predicts SNARC-like effects in preschoolers (Opfer & Thompson, 2006). In contrast, there would seem to be little external support for placing happier stimuli on the right side of space. This observation suggests that there may be differences in the strength of spatial organization across dimensions of magnitude. While the present experiments did not allow for cross-dimension comparisons of this type, such comparisons will be an important avenue for future research.

Despite the wealth of evidence suggesting that representations of number are spatially organized, an alternative account – termed *polarity correspondence* – argues that apparent associations between space and number (or any dimension) merely reflect task-specific stimulus-response (S-R) compatibility (e.g, Landy, Jones, & Hummel, 2008). This account suggests that paradigms like that of the SNARC effect promote the binary coding of dimensions (e.g., "small/large" for number, "left/right" for space), with one value more "dominant" than the other; on this account, facilitation occurs when dominant stimulus values (e.g., "large") map onto dominant response values (e.g., "right"). While polarity correspondence may be sufficient to explain the canonical SNARC effect, it cannot account for other robust associations between space and number that do not rely on S-R compatibility, such as the finding that number processing elicits involuntary shifts in spatial attention (Fischer et al., 2003), and it is unclear how binary codes would be assigned to information spanning multiple dimensions (as with happy and angry in Exp. 2).

Magnitude is pervasive in everyday experience. It is a property not only of information gleaned from the senses, but also of facets of experience that are more elusive. The findings reported here suggest that distinct dimensions of experience may share the common representational format of space, with magnitude as their organizing factor. Consistent with accounts of the spatial representation of abstract concepts (e.g., Lakoff & Johnson, 1980), our findings suggest that space may offer a representational template for making sense of the seemingly intangible.

Acknowledgments

We thank Phil Wolff for comments on the paper, Laura Namy for valuable discussion, and Lulu Kaiali and Jeong Min Lee for help with data collection. This research was supported by a William Orr Dingwall Fellowship to KJH.

References

Bonny, J., & Lourenco, S. F. (in preparation). The association of size and number in space.

Casasanto, D. (in press). Embodiment of abstract concepts: Good and bad in right and left handers. *Journal of Experimental Psychology: General*.

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*, *122*, 371-396.

Fischer, M. H., Castel, A. D., Dodd, M. D., & Pratt, J. (2003). Perceiving numbers causes spatial shifts of attention. *Nature Neuroscience*, *6*, 555-556.

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. Chicago, IL: University of Chicago Press.

Landy, D. H., Jones, E. L., & Hummel, J. E. (2008). Why spatial-numeric associations aren't evidence for a mental number line. In B. C. Love, K. McRae, & V. M. Sloutsky (Eds.), *Proceedings of the 30th Annual Conference of the Cognitive Science Society* (pp. 357-362). Austin, TX: Cognitive Science Society.

Leon, M. I., & Shadlen, M. N. (2003). Representation of time by neurons in the posterior parietal cortex of the macaque. *Neuron*, *38*, 317-327.

Lourenco, S. F., & Longo, M. R. (2009, under review). General magnitude representation in human infants.

Moyer, R. S., & Landauer, T. K. (1967). Time required for judgments of numerical inequality. *Nature*, *215*, 1519-1520.

Opfer, J. E., & Thompson, C. A. (2006). Even early representations of numerical magnitude are spatially organized: Evidence for a directional magnitude bias in pre-reading preschoolers. In R. Sun & N. Miyake (Eds.), *Proceedings of the 28th Annual Conference of the Cognitive Science Society* (pp. 639-644). Mahwah, NJ: Erlbaum.

Piazza, M., Pinel, P., Le Bihan, D., & Dehaene, S. (2007). A magnitude code common to numerosities and number symbols in human intraparietal cortex. *Neuron*, *53*, 293-305.

Schwarz, W., & Keus, I. M. (2004). Moving the eyes along the mental number line: Comparing SNARC effects with saccadic and manual responses. *Perception & Psychophysics*, *66*, 651-664.

Sereno, M. I., Pitzalis, S., & Martinez, A. (2001). Mapping of contralateral space in retinotopic coordinates by a parietal cortical area in humans. *Science*, *294*, 1350-1354.

Tottenham, N., Tanaka, J., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., et al. (in press). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*.

Vallesi, A., Binns, M. A., & Shallice, T. (2008). An effect of spatial-temporal association of response codes: Understanding the cognitive representations of time. *Cognition*, *107*, 501-527.

Vicario, C. M., Pecoraro, P., Turriziani, P., Koch, G., Caltagirone, C., & Oliveri, M. (2008). Relativistic compression and expansion of experiential time in the left and right space. *PLoS ONE*, *3*, e1716.

Walsh, V. (2003). A theory of magnitude: Common cortical metrics of time, space and quantity. *Trends in Cognitive Sciences*, *7*, 483-488.