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Culturally inconsistent spatial structure reduces learning

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ABSTRACT

Human adults tend to use a spatial continuum to organize any information they consider to be well-ordered, with a sense of initial and final position. The directionality of this spatial mapping is mediated by the culture of the subject, largely as a function of the prevailing reading and writing habits (for example, from left-to-right for English speakers or right-to-left for Hebrew speakers). In the current study, we tasked American and Israeli subjects with encoding and recalling a set of arbitrary pairings, consisting of frequently ordered stimuli (letters with shapes: Experiment 1) or infrequently ordered stimuli (color terms with shapes: Experiment 2), that were serially presented in a left-to-right, right-to-left, or central-only manner. The subjects were better at recalling information that contained ordinal stimuli if the spatial flow of presentation during encoding matched the dominant directionality of the subjects' culture, compared to information encoded in the non-dominant direction. This phenomenon did not extend to infrequently ordered stimuli (e.g., color terms). These findings suggest that adults implicitly harness spatial organization to support memory, and this harnessing process is culturally mediated in tandem with our spatial biases.

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1. Introduction

It has long been noted in psychological science that numerical and spatial concepts are fundamentally associated (Galton, 1880), most often in the form of a horizontal continuum in which relatively small numbers are assigned to certain areas of space and relatively large numbers to the opposite areas of space (a "mental number line": Moyer & Landauer, 1967). This mental number line is thought to bias our spatial attention. Westernized adults are faster to respond to the left side of space after viewing centrally presented small numbers, and the right side of space after viewing centrally presented large numbers, the so-called Spatial-Numerical Association of Response Codes (SNARC) effect (Dehaene, Bossini, & Giraux, 1993). Fischer, Castel, Dodd, and Pratt (2003) found that central presentation of small numbers resulted in faster motor responses to leftward dot probes (and vice-versa for large numbers); recent work confirms that subjects experience quicker leftward visual saccades after viewing small numbers, and rightward saccades after viewing large numbers (Bulf, Macchi Cassia, & de Hevia, 2014). When adult subjects attempt to bisect in half a line, they will do so in a leftward manner for a line composed of small number symbols (e.g., 222222222) and a rightward manner for a line composed of large numbers (e.g., 99999999; Calabria & Rossetti, 2005; Fischer, 2001).

The propensity to map small and large numbers with opposing areas of a spatial continuum extend beyond the numerical, and exist in some form for other types of stimuli. A central factor driving the appropriation of a spatial continuum for representation of a dimension appears to be *ordinality*; if stimuli appear or are perceived as being in a consistent serial order (e.g., have an initial and a final point of reference), they exhibit a spatial bias in behavioral tasks. Spatial biases have been found for such varied stimuli as months of the year/days of the week (Gevers, Reynvoet, & Fias, 2003, 2004), letters of the alphabet (Gevers et al., 2003), pitch of a sound (Rusconi, Kwan, Giordano, Umilta, & Butterworth, 2006), and even newly-drilled arbitrary word sequences (Previtali, de Hevia, & Girelli, 2010; Van Opstal, Fias, Peigneux, & Verguts, 2009). In one such study (Previtali et al., 2010), subjects were given a list of nouns to learn in a particular order (e.g., "bow", then "tent", then "apple"). After being trained in the order, the subjects were required to answer with a leftward or rightward keypress a series of classification questions, some of which were relevant to ordinality (which word came first?), and some not (was there an "r" in this word?). For both order-relevant and order-irrelevant tasks, the subjects exhibited a spatial bias to respond more quickly to early-appearing words with the left side, and to late-appearing words the right side. It is not always the case that ordinality prompts directional spatial mapping; the dimension of number prompts such robust spatial biases because it has a sense of quantity as well as a sense of order, and processing non-quantitative stimuli can sometimes lessen spatial biases when the two are compared directly. For example, Zorzi, Priftis, Meneghello, Marenzi, and Umiltà (2006) report that neuropsychological patients with hemispheric neglect exhibit spatial biases in a line bisection task for numerical stimuli but not alphabetical stimuli. Di Bono and Zorzi (2013) found a dissociation with healthy participants as

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well; they exhibit different types of spatial biases when generating numbers vs. generating months of the year, and the subjects who exhibited directional biases for numbers were not necessarily the same subjects who exhibited these biases for letters. Thus, in many – but not all – cases, spatial biases associated with ordering stimuli are spontaneously drawn upon even when order is not a relevant or necessary aspect of a task.

Spatial-ordinal relationships are influenced by evolutionary factors, the immediate experimental context, and the culture and language of the subjects. Work on special populations with little or no interactive experience with the world (e.g., newly hatched chicks, human infants) has documented an untrained and spontaneous propensity to map quantitative information to a spatial continuum. Experimentally naïve young chicks (*Gallus gallus*), trained to find food at the 4th location from the bottom in a vertical array, will selectively go to the 4th location from the left when that array is surreptitiously transposed 90°, indicating a spatial bias to place initial stimuli on the left and progress towards the right for final stimuli (Rugani, Kelly, Szelest, Regolin, & Vallortigara, 2010). Further, chicks trained to peck a centrally presented panel displaying a intermediate number of dots (e.g., 8), are subsequently more likely to orient to a left-side panel display of a small number of dots (e.g., 2) than a right-side small-number display, a behavior that suggests conceptual congruency for small/left and large/right relations (Rugani, Vallortigara, Priftis, & Regolin, 2015; see Shaki & Fischer, 2015 and Rugani, Vallortigara, Priftis, & Regolin, 2016 for opposing viewpoints). Work by de Hevia and colleagues (Bulf, de Hevia, & Macchi Cassia, 2015; de Hevia, Izard, Coubart, Spelke, Streri, 2014; de Hevia & Spelke, 2010; de Hevia, Vanderslice, & Spelke, 2012) has documented an early-developing propensity in human infants to link numerical and spatial information (as well as temporal; see also Lourenco & Longo, 2010). For example, infants who are repeatedly shown an increasing number of objects expect this relationship to transfer to an increase of a spatial stimulus such as the length of a line (de Hevia & Spelke, 2010). In very early childhood, at least, spatial-ordinal mappings happen with a relatively constrained set of stimuli, as both infants and preschoolers neglect to map the dimension of brightness to space (de Hevia et al., 2012; de Hevia & Spelke, 2013). There is even evidence that the linkage between space and number may be asymmetrically oriented; infants learn to order a set of arrays if they are presented from smallest on the left to largest on the right (de Hevia, Girelli, Addabbo, & Cassia, 2014b), but not vice versa, and are quicker to attend to a left-side probe after central presentation of a small number vs. central presentation of a large number (Bulf et al., 2015).

There is clearly a large-scale cultural influence on spatial-ordinal mappings as well (see Göbel, Shaki, & Fischer, 2011 for a review), mainly driven by the linguistic milieu of the subject. Left/small and right/large spatial-numerical mappings are attenuated, or even reversed, in populations whose reading and writing system is consistently oriented from right to left instead of left to right (Dehaene et al., 1993; Shaki, Fischer, & Petrusic, 2009), and subjects who are illiterate show no reliable spatial mapping biases (Zebian, 2005). This cultural modulation applies to other types of spatial-ordinal biases as well (Shaki & Gevers, 2011; Shaki, Petrusic, & Leth-Steensen, 2012; Vallesi, Weisblatt, Semenza, & Shaki, 2014). Shaki and Gevers (2011) presented bilingual Hebrew-English speakers with the ordinal stimuli of letter sequences in either the English alphabet (read from left to right) or Hebrew alphabet (read from right to left). They found that these bilinguals exhibited both left-to-right and right-to-left spatial mapping biases, depending on the particular language invoked for that block of the experiment (English or Hebrew, respectively). Further documentation of this cultural mediation comes from Vallesi et al. (2014), who found attenuated left-short and right-long spatial-temporal mappings in Israeli subjects relative to Italian subjects.

Taken together, the findings indicate that spatial biases are a fundamental and multiply determined aspect of our cognitive lives. Yet, we have little information as to how these spatial biases impact our everyday interactions with, and encoding of, the world around us. What are the ramifications of spatial associations on learning and memory, and how do they vary according to the culture of the subject? There is some work from the cognitive development literature which suggests that the presentation of stimuli in a culturally congruent spatial manner allows for better encoding and recall in a later memory task (McCrink, Shaki, & Berkowitz, 2014; Opfer & Furlong, 2011; Opfer, Thompson, & Furlong, 2010). For example, Opfer et al. (2010) asked English-speaking American kindergarteners to learn a numbering system for a set of boxes, and use that number sequence when performing a spatial mapping task. The experimenter provided verbal number labels to spatial locations in either a left-to-right or right-to-left manner (e.g., "this is box number 1, this is box number 2…" as they tapped each location), and the children had to transfer (i.e., map) these labels to a new set of boxes in order to locate a desirable object. The subjects were most likely to remember a spatial mapping when the numbering had occurred in a left-to-right fashion, congruent with the culture of the child. McCrink et al. (2014) found a similar spatial bias on memory in American children who were given a series of letter labels, but not when they were given color labels, indicating the effect comes about mainly for ordered stimuli with a clear initial/end point. Further, these mapping benefits were reversed in Israeli children, whose Hebrew alphabet is written from right to left.

This phenomenon may reflect a temporary scaffold used by children and later discarded, as the transition from childhood to adulthood results in large gains in working memory span (Alloway, Gathercole, & Pickering, 2006) and strategic memory techniques (e.g., verbal rehearsal; Hagen, Jongeward, & Kail, 1975). Alternately, it may be the case that even as adults we are implicitly harnessing spatial organization, and this harnessing process is culturally mediated in tandem with our spatial biases. To address these alternatives, we studied a population of American and Israeli young adults, whose reading and writing systems exhibit opposite directionality of spatial flow for letters. The subjects were required to learn arbitrary pairings of shapes with auditorially presented letters (Experiment 1) or color names (Experiment 2). The shapes appeared serially in either a left-to-right manner, right-to-left manner, or on the center of the screen. If adults experience a learning benefit as a result of their spatial-ordinal mapping biases, and if this effect is dependent on the nature of the stimulus (e.g., ordinal vs. non-ordinal) and subject's culture (predominantly left-to-right for English speakers, and right-to-left for Hebrew speakers), we would expect to see two patterns emerge in the data. First, any spatial biases that come about for ordinal stimuli in the Americans (better learning for left-to-right relative to right-to-left) will be attenuated or reversed in the Israeli group, because Americans have a consistent left-to-right spatial mapping in their reading and writing system, and Israelis do not (Experiment 1). Second, spatial biases will be lessened or non-existent for the less-ordinal stimuli (color names, which – although they can be conceived of on an ordered wavelength spectrum – occur in this specific order infrequently: Experiment 2).

2. Method

2.1. Subjects

67 English-speaking (33 females and 27 males) and 62 Hebrew-speaking college students (51 females and 11 males) were recruited from Introductory Psychology subject pools and word of mouth on their respective college campuses. The subjects were screened for fluency in non-native languages of the opposite writing directionality to their native language (e.g., Hebrew or Farsi for the Americans; English or Russian for the Israelis.) 9 subjects were removed from the sample and replaced (3 computer error, 6 bi-directional language fluency), for a total of 60 subjects of each culture.