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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.

Keywords

space; learning; culture; order; cognition; SNARC effect

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-

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Numerical Association of Response Codes (SNARC) effect (Dehane, 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., 999999999; 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, Umiltà, & 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, & 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 & Zorzi (2013) found a dissociation with healthy participants as 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 degrees, 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 (deHevia, Vanderslice, & Spelke, 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, & Macchi-Cassia, 2014), 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, de Hevia, Macchi-Cassia, 2015).

There is clearly a large-scale cultural influence on spatial-ordinal mappings as well (see Gobel, 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; Vallessi, 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, Weisblatt, Semenza, & Shaki (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.

2.2 Design

Twenty subjects of each culture were randomly assigned to one of 3 conditions: Left-to-Right (LR), Right-to-Left (RL), or Centered (CTR). The shape-letter pairings were pseudo-randomized to create 20 different stimuli sets, yielding one unique pairing per subject for particular condition. This was a randomization process in which the strings were generated using a random generation function, and then altered slightly by hand so that no sequences displayed a block of increasing (A-B-C) or decreasing (G-F-E) order, creating a series of pairs that was always ultimately non-ordered according to the convention of the alphabet. This pairing was then held constant for the other conditions, in order to ensure identical difficulty and information presentation across LR, RL, and CTR. For example, the 5th subjects in the LR, RL, and CTR conditions would all hear the letter string “B – F – A – C – G – D – E “ or the Hebrew equivalent “ב – פ – א – צ – ג – ד – ה” paired with a square, rectangle, diamond, oval, triangle, circle, and polygon, respectively; the only experimental aspect that differed across conditions was the directional flow of incoming information. There were 7 shape-letter pairings to learn, and the subjects were presented with 3 identical training/testing sessions. In this way we are able to observe whether the spatial flow manipulation (LR, RL, or CTR) leads to differential learning curves as the subjects moved from the first to the last testing session.

2.3 Stimuli and Procedure

The stimuli were made in the presentation program Keynote and exported as Quicktime movies that could be advanced with a mouse click or key press when appropriate. The movies were presented on a 22" iMac (U.S.) or 17" View Sonic monitor (Israel); subjects sat approximately 70 cm / 60 cm from the screen with the experimenter in the same room. Subjects first saw the following instructions: “In this experiment, you will participate in 1. a training phase, and then 2. a testing phase. In the training phase, you will simply watch as some shapes appear on the screen. A letter will be spoken as each shape appears, and you need to remember the *letter/shape pairings*. You will go through this training/testing 3 times in total. Click the mouse to continue.” The subjects were then serially presented with seven shape-letter pairs, each of which appeared onscreen briefly for 2 seconds. The visual stimuli were comprised of seven distinct blue-colored shapes (a square, rectangle, diamond, oval, triangle, circle, and polygon) on a white background and the auditory stimuli paired with the shapes were the letters A through G (spoken in English for the Americans, and in Hebrew for the Israelis; See Figure 1). For the directional conditions, the first shape appeared in the first spatial position on either the left (LR) or right (RL) side of the screen, 1/7th of the screen's width in from the side. This shape disappeared after 2 seconds, at which point the next shape appeared an additional 1/7th of the screen from the position of the previous shape, in the corresponding flow of the condition (e.g., to the right of the previous shape for LR, to the left of the previous shape for RL), and so on until all 7 shape-letter pairings were presented. For the Centered condition, the shape-letter pairings appeared on the center of the screen for 2 seconds, then disappeared, followed by the next shape-letter combination until all 7 had been presented.

The letters were not presented in conventional order (A, B, C etc.); they were presented in random order for each subject of a condition. After the training session, subjects saw the instructions: “Next you will see the shapes individually. Please tell the experimenter which letter of the alphabet they were paired with, and then click the mouse to move onto the next trial. Click the mouse to continue.” Each shape appeared individually on the center of the screen for 1 second before disappearing, and the subject indicated their response to the experimenter before moving on to the next trial. This sequence (a training session, followed by a testing session) was repeated two more times, for a total of 3 training/testing blocks.

3. Results: Experiment 1

The number of correct answers was tabulated for each subject in each session, and entered into a repeated measures ANOVA with session (1, 2, 3) as a within-subject variable and condition (LR, RL, CTR), culture (American, Israeli) as between-subjects variables. (There were no significant effects of or interactions involving gender; this variable is not considered further.) There was an expected main effect of session ($F(2, 228) = 91.24, p < .001, \eta_p^2 = .45$), with subjects increasing their performance significantly from the first session ($m = 3.2$), to the second ($m = 4.4$), and third ($m = 5.4$). This change in performance did not differ by culture or condition; Americans performed in LR an average of 4.5, RL 3.5, CTR 4.6, and Israelis performed 3.8 LR, 4.9 RL, and 4.5 CTR (all $SEMs = .33$; see Table 1 for detailed mean performance and SEM for each session, condition, and subject culture.)

There was a significant interaction between condition and culture ($F(2, 114) = 5.05, p = .008, \eta_p^2 = .08$). Follow-up analyses on the LR/RL trials Bonferroni-corrected for multiple comparisons reveal a significant effects of culture between American and Israeli participants in only the RL condition ($p = .004$; 95% CI of difference $[-2.3, -.43], \eta_p^2 = .10$). Significant effects of condition were impairment for Americans in RL (3.5 [.25]) compared to Americans in LR conditions ($M = 4.5$ [.36], $p = .04$; 95% CI of difference $[.04, 1.92], \eta_p^2 = .05$), and Israelis in LR (3.9 [.43]) compared to Israelis in RL conditions ($M = 4.9$ [.27]; $p = .04$; 95% CI of difference $[.08, 1.96], \eta_p^2 = .06$). Further, Americans performed slightly better in CTR than Americans in RL ($p = .05$, 95% CI of difference $[-.01, 2.21], \eta_p^2 = .06$), and Israelis in the CTR condition performed similarly to Israelis in LR or RL (Figure 2). There was no interaction between session $\times$ culture $\times$ condition ($F(4, 228) = 1.68, p = .16$), reflecting the finding that - while the subjects' performance was simultaneously modulated by culture and the spatial flow of information - these disparities were similar for each session.

4. Discussion: Experiment 1

This experiment illustrates privileged learning for commonly ordered information that was presented in a culturally consistent fashion. Hebrew speakers learned a shape-letter pairing better when it was presented from right-to-left relative to left-to-right, and the opposite was true for English speakers. Centrally presented information was recalled well, and similarly to directional information. With respect to cultural variation, the effect appears to be carried by

a benefit for RL information in Hebrew speakers relative to English speakers, and not a LR benefit in English speakers. This was not an emergent effect across the learning experience; it was equally present in the first testing session and the last. Thus we observe that spatial associations for even non-numerical stimuli are modulated by cultural factors (as in Shaki et al., 2009), with culturally relevant spatial flow of information enhancing memory for arbitrary information.

A central question raised by these data is how generalizable this phenomenon is. Is it possible to give *any* information to educated adults, and expect the culturally consistent spatial flow to enhance processing? Or will this effect be context-specific, and apply only to certain types of information? Work on young children suggests that the impact of spatial flow on information recall is specific only to commonly ordered stimuli such as the alphabet or numbers (McCrink et al, 2014; Opfer & Furlong, 2010), and does not hold for information such as color terms which are not commonly learned in a routine order (even though colors can be conceived of on a wavelength spectrum that is continuous and ordered). However, McCrink et al (2014) found that even though American children did not necessarily learn color term labels better when they were presented from left to right, they were significantly faster in this condition relative to a right-to-left presentation group. This confidence, coupled with increased facility with and exposure to reading and writing, may lead to adults experiencing a more-generic benefit of spatial flow that applies to even non-ordinal dimensions. To test this possibility, we performed a follow-up experiment wherein subjects were given an otherwise-identical learning task in which they must pair a less commonly ordered stimulus (a color term, after McCrink et al. (2014)) with each shape.

5. Methods: Experiment 2

5.1 Subjects

66 English-speaking (42 females and 24 males) and 64 Hebrew-speaking college students (46 females and 18 males) who had not participated in Experiment 1 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 enculturated language (e.g., Hebrew or Farsi for the Americans; English or Russian for the Israelis.) 10 subjects were removed from the sample and replaced (6 failure to follow instructions/ pay attention, 1 computer error, 2 bi-directional language fluency, 1 diagnosed learning disorder), for a total of 60 subjects of each culture.

5.2 Design, Stimuli, & Procedure

This experiment was identical to Experiment 1, with two exceptions: the auditory stimuli were color terms (instead of letters), and the shapes were plain white with a black outline (instead of blue with a black outline.) The color terms used were Yellow/ צהוב, Brown/ חום, Red/ אדום, Green/ ירוק, Black/ שחור, Purple/ סגול, and Blue/ כחול. All design features and apparatuses were identical; the directions were either identical or solely updated to reflect the substitution of color terms for letters.

6. Results: Experiment 2

The number of correct answers was tabulated for each subject in each session, and entered into a repeated measures ANOVA with session (1, 2, 3) as a within-subject variable and condition (LR, RL, CTR), culture (American, Israeli), and gender as between-subjects variables. There was an expected main effect of session ($F(2, 228) = 42.61, p < .001, \eta_p^2 = .28$), with subjects increasing their performance significantly from the first session ($m = 3.5$), to the second ($m = 4.5$), and third ($m = 5.2$). There were no significant effects of or interactions with condition, but there was a main effect of culture ($F(1, 108) = 6.01, p = .02, \eta_p^2 = .05$); Americans had a mean score of 4.8 ($SEM = .22$), and Israelis a mean score of 3.97 ($SEM = .27$; see Table 1 for both cultures' scores by condition and session, and Figure 3 for plotted means specific to Experiment 2). There was a significant main effect of gender ($F(1, 108) = 4.77, p = .03, \eta_p^2 = .04$), with women (4.77, $SEM = .18$) outperforming men (4.01, $SEM = .29$).

7. Discussion: Experiment 2

In this experiment, in contrast to Experiment 1, we observed no benefit for particular types of spatial directionality within or between the American and Israeli participants. Overall, both English-speaking participants and Israeli participants were able to learn arbitrary pairings of color terms and shapes equally well - within each culture - when these pairings were presented with a left-to-right directionality, right-to-left directionality, or in a neutral central manner. We believe this null result reflects a propensity for spatial biases in learning to arise only for stimuli with high ordinality. Because this conclusion is being drawn from a null effect, one must be cautious in interpreting it, as null effects are easy to obtain and can be less informative than positive effects. However, we did not necessarily predict a null effect; it was entirely possible that the confidence American children exhibited when spatially mapping color terms in McCrink et al. (2014) would have grown in time and been present here with adults as a learning benefit. Additionally, this null effect must be considered side-by-side with the positive effect from Experiment 2, which had nearly identical populations (and stimuli) and enough power to detect a positive effect.

In this Experiment 2 we document main effects of overall better learning in women compared to men, and Americans compared to Israelis. With respect to the gender differences, it is true that a "female advantage" in color-based tasks frequently arises in the psychological literature, and has been studied as far back as Eysenck (1941). The majority of these studies document sex differences in the preferences for particular colors (e.g., Al-Rasheed, 2015; Hurlburt & Ling, 2007). However, there are also findings that women in many cultures possess a higher willingness and ability to map a more-varied set of color terms to a stimulus (for example, the term 'periwinkle' instead of 'blue'; Green & Gynther, 1995; Thomas, Curtis, & Bolotn, 1978; Wijk, Berg, Sivik & Steen, 1999) and even some evidence that women have finer-tuned color discrimination (Abramov, Gordon, Feldman, & Chavarga, 2012). With respect to this particular study, then, it is possible that the ease in which the color terms were encoded, and the evocativeness of these terms with respect to forming a representation as input to the color term-shape matching process, were occurring

more readily for women than men. This benefit for the color component of the pairing thus may have led to higher overall performance for the women. This is a speculative hypothesis, and the question of whether women have a learning benefit for color-relevant stimuli is still an open and interesting one (albeit distinct from the aims of the current study.) However, it is important to note that this overall effect cannot explain the lack of modulation by the specific spatial flow of the information; neither the women nor the men were at ceiling, and still no effects pertaining to spatial flow or interactions between spatial flow and culture appeared.

With respect to the overall performance differences between the two cultures, is the case that there are national variations in IQ (Lynn & Meisenberg, 2010); intelligence tests are highly variable but usually possess a spatial component as well as a verbal working memory component, both of which are relevant here. In some national measures, Americans do score slightly higher on IQ than Israelis on a population level (Lynn & Meisenberg, 2010; Lynn & Mikk, 2007). Further, the American population here was drawn from an university with a higher admission standard than the one in Israel, which may have exacerbated these differences – though we did not take any measures to confirm this possibility. As one can imagine, the work on IQ and culture has been surrounded by controversy, with explanations ranging from the political to the evolutionary to the climatic atmosphere of the tested population and beyond (Lynn & Vanhanen, 2012; Eppig, Fincher, & Thornhill, 2010.) For the purposes of this experiment, this overall main effect may have dampened a possible subtle interaction of spatial directionality and culture. Critically, however, we still obtained a positive result in Experiment 1, even though Experiments 1 and 2 were of similar overall difficulty ($M_s = 4.3$ and 4.5 , $p = .48$). Taken together, these aspects of the data speak against an overall main effect trumping a more-subtle interaction effect, since any impact of IQ or overall processing capacity as a function of culture would be equally present in both experiments.

8. General Discussion

In this set of experiments, American and Israeli adults were tasked with recalling information from arbitrary pairings that occurred without spatial structure (in the center of the screen), or with spatial structure that was consistent or inconsistent with the reading and writing system of the surrounding culture (left to right for Americans, right to left for Israelis). Both populations recalled more information when it was embedded in a culturally consistent spatial flow, compared to a culturally inconsistent spatial flow. This phenomenon was limited to pairings which harnessed information that was considered ordinal by the participant (e.g., letters of the alphabet), and did not extend out to information that is not normally processed ordinally such as color. These findings support the position that spatial biases alter learning patterns, and do so in a way that reflects the spatial emphases of the learner's environment.

An important but subtle aspect to these findings is that this spatial bias emerged – for the Americans, at least – as a detriment to learning information presented with cultural incongruence, rather than a bonus for learning information presented with congruence. This may be for two distinct reasons. The first is that the phenomenon studied here reflects a

flexible and adaptive spatial structuring system; after all, information is rarely perfectly structured in space, so we need to be able to accommodate uninformative spatial information in our environment (and via years of practice do very well at it.) However, we rarely observe spatial information that is perfectly ordered- but *not* what we expect, and in this case a learning deficit arises. Note that this is likely why we do not have a complete reversal of the effect for the Israeli population; their language already exhibits mixed directionality with respect to letters (right-to-left) and numbers (left-to-right), which would dampen this effect of perfectly ordered but unexpected stimuli since Hebrew writing is less directionally inconsistent. The second potential reason this pattern of relative strength for central presentation arises is because the center condition has less information to encode relative to either of the left-to-right or right-to-left conditions. Either explicitly or implicitly, the subjects here may have been tracking the absolute location of the objects in addition to their relative flow, and this additional information resulted in lower overall scores for those conditions. Although it is difficult to exactly tease apart these alternatives, one could imagine theoretically telling performance profiles for subjects who saw the information presented vertically. If the relatively high performance for the central condition was due to no additional spatial information needing to be encoded, the subjects would do worse on this vertical condition relative to the central condition, but if this profile was due to other factors (such as familiarity of flow, which is fairly high for vertical information), the subjects would do the same or even better than those in the center condition. Recent work by McCrink and Galamba (2015) supports this latter possibility; in this study, English-speaking adults given a series of random spatial locations recalled these positions at a significantly lower rate than those provided with spatial flow of either direction, and were especially impaired at recalling unstructured information when the locations were embedded with numerical information (which is highly ordinal.)

The study detailed here goes beyond the question of where humans mentally place static concepts in space, a topic that has a rich documentation of culturally mediated directional mapping preferences (Dehaene et al., 1993; Shaki & Fischer, 2012; Zebian, 2005). The items presented here were jumbled, with stimuli conventionally considered to be “initial” (e.g., the letter A) appearing equally on the left or right side of the screen. Yet, spatial biases still exerted an effect on this very basic encoding of information, and this effect was limited to conventionally-ordered stimuli; thus this phenomenon reflects the active nature of how we shoehorn stimuli we have grown accustomed to ordering into available spatial structures, even if they are culturally maladaptive. An open question is whether the phenomenon documented here will extend to sequences that are newly ordered to a subject (e.g., Previtali et. al’s (2010) novel word sequences), or whether it takes years of ingrained ordering to prompt the observed pattern. If the former is the case, one could imagine that this type of attention to spatial structure could be beneficial in a variety of educational and practical situations.

The current results illuminate how our mind negotiates between high-level environmental variables (such as the daily distribution of spatial attention to the left, or to the right, as a function of culture and literacy) and low-level fundamental mechanisms of encoding and recall, with the likely interface of the working memory system. An emerging body of literature suggests that working memory - long held to be responsible for general processes

of encoding and maintaining information for later recall or storage (Baddeley, 2000; Cowan, 1999) – is the workspace in which our spatial-ordinal biases are constructed (Ginsburg, van Dijck, Previtali, Fias, & Gevers, 2014; Herrera, Macizo, & Semenza, 2008; van Dijck, Gevers, & Fias, 2009; van Dijck & Fias, 2011; van Dijck, Abrahamse, Majerus, & Fias, 2013). For example, van Dijck and Fias (2011) found that the ordinal position of an item in working memory (e.g., encoded first, second, third) drives spatial biases in responding, and not whether that item was simply being judged as large or small. Work on this *positional WM* account has established that serial order in working memory has a direct link to spatial selective attention; when retrieving earlier/later items stored in a sequence, Westernized subjects experience attentional shifts to the left/right ((van Dijck, Abrahamse, Majerus, & Fias, 2013).

These results directly implicate cultural influences as a mediator in this link between spatial attention and ordinal position in working memory, and illustrate that this mediation is specific to the case of highly ordinal stimuli that has cultural relevance (e.g., the alphabet). To our knowledge, this is the first study to document a critical factor in the spatial bias literature (reading direction) as it exerts its influence on a popular and well-supported model of how spatial biases are constructed. Further, in contrast to the majority of studies on spatial biases, our central measure did not draw upon lateralized responding as an action that must be produced by the subject (e.g., manual response to one side of space) upon retrieval or whilst making an immediate judgment. In this way we are able to look at the impact of this culturally-driven spatial attention as it occurs primarily at the time of encoding – that is, entry into the working memory system - with a spatially neutral retrieval scenario. The fact that subjects experienced a learning differential for information that was congruent or incongruent to their typical orthography suggests that in addition to spatial biases generated by retrieval (e.g., Ginsburg et al. 2014) there are also spatial biases generated by the initial encoding process (see also Opfer et al. (2011) for a developmental version of this claim.)¹ Taken together, these two pieces of information highlight the important role that culture plays on the generation of spatial biases as commonly ordered information is being placed into a working memory sequence for later recall.

The current study uses as the two populations of interest American and Israeli students, but it should be noted that – although a successful cultural modulation was documented – the effect was likely weakened by the use of Hebrew-speakers, who have a writing system that flows mainly from right-to-left but does occasionally flow from left-to-right (when transcribing numerals). This mixed writing system does result in Hebrew speakers exhibiting a flexible set of spatial biases depending on which type of stimulus is being tested (See Shaki & Fischer, 2008; Shaki & Gevers, 2011). A testable prediction is that speakers whose reading and writing system is exclusively right-to-left will show an even greater effect of spatial flow than the Hebrew speakers in our study (who were actually similar to English speakers with respect to prowess for left-to-right mappings overall.) The results obtained

¹It is possible that at retrieval the subjects were explicitly re-enacting their encoding and doing so in an ordered sequential fashion, at which point the spatial bias could arise. A subset (N = 10) of subjects were interviewed after completing the study and asked to discuss their recall strategy. Of the 10 subjects, all mentioned the simple strategy upon recall of visualizing the letter – shape pair, and only 1 mentioned any use of stringing together the encoded information at retrieval to form an ordinal sequence.

here also raise a set of developmental questions; if this tendency to modulate learning based on spatial flow is found in both children (McCrink et al., 2014; Opfer & Furlong, 2010) and adults (current study), is it to some extent a fundamental feature of our learning system? Or does it arise with experience, and strategic encoding decisions? The role of spatial structure, and culturally specific structure, on learning in infancy is currently unexplored but may yield answers to these questions.

In sum, the current study extends the literature on spatial-ordinal biases to examine how these phenomena alter our encoding and recall of information from the environment. As adults, we possess a readiness to learn information that is congruent with our previous experience, reflecting an adaptive attunement to our environment that optimizes learning. In this way, we make use of a natural bias to place information onto an intuitive and readily available spatial scaffold.

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References

- Abramov I, Gordon J, Feldman O, Chavarga A. Sex and vision II: color appearance of monochromatic lights. *Biology of Sex Differences*. 2012; 3:21. [PubMed: 22943488]
- Al-rasheed AS. Categorical perception of color: evidence from secondary category boundary. *Psychology Research and Behavior Management*. 2015; 8:273. [PubMed: 26648764]
- Alloway TP, Gathercole SE, Pickering SJ. Verbal and Visuospatial Short-Term and Working Memory in Children: Are They Separable? *Child Development*. 2006; 77:1698–1716. [PubMed: 17107455]
- Baddeley A. The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences*. 2000; 4:417–423. [PubMed: 11058819]
- Bulf H, de Hevia MD, Macchi Cassia V. Small on the left, large on the right: numbers orient visual attention onto space in preverbal infants. *Developmental Science*. 2015
- Bulf H, Macchi Cassia V, de Hevia MD. Are numbers, size and brightness equally efficient in orienting visual attention? Evidence from an eye-tracking study. *PLoS One*. 2014; 9:1–6.
- Calabria M, Rossetti Y. Interference between number processing and line bisection: a methodology. *Neuropsychologia*. 2005; 43:779–783. [PubMed: 15721190]
- Cowan N. An embedded-processes model of working memory. *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*. 1999; 20:506.
- de Hevia MD, Girelli L, Addabbo M, Cassia VM. Human Infants' Preference for Left-to-Right Oriented Increasing Numerical Sequences. *PLoS One*. 2014; 9doi: 10.1371/journal.pone.0096412
- de Hevia MD, Izard V, Coubart A, Spelke ES, Streri A. Representations of space, time, and number in neonates. *Proceedings of the National Academy of Sciences*. 2014; 111:4809–4813.
- de Hevia MD, Spelke ES. Number-space mapping in human infants. *Psychological Science*. 2010; 21:653–660. [PubMed: 20483843]
- de Hevia MD, Spelke ES. Not all continuous dimensions map equally: Number-Brightness mapping in human infants. *PLoS ONE*. 2013; 8doi: 10.1371/journal.pone.0081241
- de Hevia MD, Vanderslice M, Spelke ES. Cross-dimensional mapping of number, length and brightness by preschool children. *PLoS One*. 2012; 7doi: 10.1371/journal.pone.0035530
- Dehaene S, Bossini S, Giraux P. The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*. 1993; 122:371–396.

- Di Bono MG, Zorzi M. The spatial representation of numerical and non-numerical ordered sequences: insights from a random generation task. *The Quarterly Journal of Experimental Psychology*. 2013; 66:2348–2362. [PubMed: 23574588]
- Eppig C, Fincher CL, Thornhill R. Parasite prevalence and the worldwide distribution of cognitive ability. *Proceedings of the Royal Society of London B: Biological Sciences*. 2010; 277:3801–3808.
- Eysenck HJ. A critical and experimental study of colour preferences. *The American Journal of Psychology*. 1941:385–394.
- Fischer MH. Number processing induces spatial performance biases. *Neurology*. 2001; 57:822–826. [PubMed: 11552011]
- Fischer MH, Castel AD, Dodd MD, Pratt J. Perceiving numbers causes spatial shifts of attention. *Nature Neuroscience*. 2003; 6:555–556. [PubMed: 12754517]
- Galton F. Visualized numerals. *Nature*. 1880; 21:252–256.
- Gevers W, Reynvoet B, Fias W. The mental representation of ordinal sequences is spatially organized. *Cognition*. 2003; 87:B87–B95. [PubMed: 12684205]
- Gevers W, Reynvoet B, Fias W. The mental representation of ordinal sequences is spatially organized. Evidence from days of the week. *Cortex*. 2004; 40:171–172. [PubMed: 15174454]
- Ginsburg V, van Dijck JP, Previtali P, Fias W, Gevers W. The impact of verbal working memory on number – space associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 2014; 40:976.
- Göbel SM, Shaki S, Fischer MH. The cultural number line: a review of cultural and linguistic influences on the development of number processing. *Journal of Cross-Cultural Psychology*. 2011; 42:543–565.
- Greene KS, Gynther MD. Blue versus periwinkle: Color identification and gender. *Perceptual and Motor Skills*. 1995; 80:27–32. [PubMed: 7624204]
- Hagen JW, Jongeward RH, Kail RV. Cognitive perspectives on the development of memory. *Advances in Child Development and Behavior*. 1975; 10:57–101. [PubMed: 1101662]
- Herrera A, Macizo P, Semenza C. The role of working memory in the association between number magnitude and space. *Acta psychologica*. 2008; 128:225–237. [PubMed: 18295166]
- Hurlbert AC, Ling Y. Biological components of sex differences in color preference. *Current Biology*. 2007; 17:R623–R625. [PubMed: 17714645]
- Lourenco SF, Longo MR. 2010 General magnitude representation in human infants. *Psychological Science*.
- Lynn R, Meisenberg G. National IQs calculated and validated for 108 nations. *Intelligence*. 2010; 38:353–360.
- Lynn R, Mikk J. National differences in intelligence and educational attainment. *Intelligence*. 2007; 35:115–121.
- Lynn R, Vanhanen T. National IQs: A review of their educational, cognitive, economic, political, demographic, sociological, epidemiological, geographic and climatic correlates. *Intelligence*. 2012; 40:226–234.
- McCrink K, Galamba J. The impact of symbolic and non-symbolic quantity on spatial learning. *PLoS One*. 2015; 10doi: 10.1371/journal.pone.0119395
- McCrink K, Shaki S, Berkowitz T. Culturally driven biases in preschoolers' spatial search strategies for ordinal and non-ordinal dimensions. *Cognitive Development*. 2014; 30:1–14. [PubMed: 24771964]
- Moyer RS, Landauer TK. Time required for judgments of numerical inequality. *Nature*. 1967; 215:1519–1520. [PubMed: 6052760]
- Opfer JE, Furlong EE. How numbers bias preschoolers' spatial search. *Journal of Cross-Cultural Psychology*. 2011; 42:682–695.
- Opfer JE, Thompson CA, Furlong EE. Early development of spatial-numeric associations: evidence from spatial and quantitative performance of preschoolers. *Developmental Science*. 2010; 13:761–771. [PubMed: 20712742]

- Previtali P, de Hevia MD, Girelli L. Placing order in space: the SNARC effect in serial learning. *Experimental Brain Research*. 2010; 201:599–605. [PubMed: 19888566]
- Rugani R, Kelly DM, Szelest I, Regolin L, Vallortigara G. Is it only humans that count from left to right? *Biology Letters*. 2010; 6:290–292. [PubMed: 20071393]
- Rugani R, Vallortigara G, Priftis K, Regolin L. Number-space mapping in the newborn chick resembles humans' mental number line. *Science*. 2015; 347:534–536. [PubMed: 25635096]
- Rugani R, Vallortigara G, Priftis K, Regolin L. Response: "Newborn chicks need no number tricks. Commentary: Number-space mapping in the newborn chick resembles humans' mental number line". *Frontiers in Human Neuroscience*. 2016; 10doi: 10.3389/fnhum.2016.00031
- Rusconi E, Kwan B, Giordano BL, Umiltà C, Butterworth B. Spatial representation of pitch height: the SMARC effect. *Cognition*. 2006; 99:113–129. [PubMed: 15925355]
- Shaki S, Fischer MH. Reading space into numbers – A cross-linguistic comparison of the SNARC effect. *Cognition*. 2008; 108:590–599. [PubMed: 18514179]
- Shaki S, Fischer MH. Multiple spatial mappings in numerical cognition. *Journal of Experimental Psychology: Human Perception and Performance*. 2012; 38:804–809. [PubMed: 22428673]
- Shaki S, Fischer MH. Newborn chicks need no number tricks. Commentary: Number-space mapping in the newborn chick resembles humans' mental number line. *Frontiers in Human Neuroscience*. 2015; 9
- Shaki S, Fischer MH, Petrusic WM. Reading habits for both words and numbers contribute to the SNARC effect. *Psychonomic Bulletin & Review*. 2009; 16:328–331. [PubMed: 19293102]
- Shaki S, Gevers W. Cultural characteristics dissociate magnitude and ordinal information processing. *Journal of Cross-Cultural Psychology*. 2011; 42:639–650.
- Shaki S, Petrusic WM, Leth-Steensen C. SNARC effects with numerical and nonnumerical symbolic comparative judgments: Instructional and cultural dependencies. *Journal of Experimental Psychology: Human Perception and Performance*. 2012; 38:515–530. [PubMed: 22288694]
- Thomas LL, Curtis AT, Bolton R. Sex differences in elicited color lexicon size. *Perceptual and Motor Skills*. 1978; 47:77–78. [PubMed: 740470]
- Vallesi A, Weisblatt Y, Semenza C, Shaki S. Cultural modulations of space–time compatibility effects. *Psychonomic Bulletin & Review*. 2014; 21:666–669. [PubMed: 24163172]
- van Dijck JP, Abrahamse EL, Majerus S, Fias W. Spatial attention interacts with serial-order retrieval from verbal working memory. *Psychological Science*. 2013; 24:1854–1859. [PubMed: 23863755]
- van Dijck JP, Fias W. A working memory account for spatial–numerical associations. *Cognition*. 2011; 119:114–119. [PubMed: 21262509]
- van Dijck JP, Gevers W, Fias W. Numbers are associated with different types of spatial information depending on the task. *Cognition*. 2009; 113:248–253. [PubMed: 19726035]
- Van Opstal F, Fias W, Peigneux P, Verguts T. The neural representation of extensively trained ordered sequences. *Neuroimage*. 2009; 47:367–375. [PubMed: 19376245]
- Wijk H, Berg S, Sivik L, Steen B. Colour discrimination, colour naming and colour preferences among individuals with Alzheimer's disease. *International Journal of Geriatric Psychiatry*. 1999; 14:1000–1005. [PubMed: 10607966]
- Zebian S. Linkages between number concepts, spatial thinking, and directionality of writing: The SNARC effect and the reverse SNARC effect in English and Arabic monoliterates, biliterates, and illiterate Arabic speakers. *Journal of Cognition and Culture*. 2005; 5:1–2.
- Zorzi M, Priftis K, Meneghello F, Marenzi R, Umiltà C. The spatial representation of numerical and non-numerical sequences: evidence from neglect. *Neuropsychologia*. 2006; 44:1061–1067. [PubMed: 16356515]

Highlights

- American and Israeli adults were tasked with learning arbitrary stimuli pairs.
- The to-be-recalled information was presented from left-to-right, right-to-left, or centrally.
- Learning was decreased when information was presented in a direction opposite of the culture's dominant reading and writing system.
- This effect appears only when learning information that is typically ordinal to the subjects.

Figure 1.
Schematic of the Experiment 1 left-to-right condition, as presented to American subjects.

Figure 2. Accuracy on the recall task as a function of culture and spatial flow of the presented stimuli for Experiment 1. Error bars represent the standard error of the mean. Significant between-culture effects are highlighted with an asterisk (alpha level of $< .05$).

Figure 3.

Table 1

Mean performance in each testing session (1st, 2nd, 3rd), condition (Left-to-Right (LR), Right-to-Left (RL), or Centered (CTR)), and culture (American, Israeli) for Experiments 1 and 2.

Experiment 1: Letter-Shape Pairs							
Session 1			Session 2			Session 3	
Condition	LR	CTR	RL	LR	CTR	RL	RL
Americans	3.4 [.38]	3.5 [.38]	2.5 [.38]	4.4 [.40]	5.3 [.40]	3.5 [.40]	5.2 [.40]
Israelis	3.0 [.38]	3.6 [.38]	3.6 [.38]	3.8 [.40]	4.5 [.40]	5.1 [.40]	5.6 [.40]
							6.1 [.40]
Experiment 2: Color-Shape Pairs							
Session 1			Session 2			Session 3	
Condition	LR	CTR	RL	LR	CTR	RL	RL
Americans	3.5 [.44]	3.5 [.46]	4.2 [.46]	5.0 [.49]	5.0 [.51]	5.1 [.51]	5.9 [.43]
Israelis	3.1 [.44]	3.1 [.43]	3.7 [.70]	3.8 [.49]	3.5 [.47]	4.7 [.78]	4.4 [.41]
							5.5 [.66]