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The Early Construction of Spatial Attention: Culture, Space, and Gesture in Parent-Child Interactions

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Abstract

American and Israeli toddler-caregiver dyads (mean age of toddler = 26 months) were presented with naturalistic tasks in which they must watch a short video (*N* = 97) or concoct a visual story together (*N* = 66). English-speaking American caregivers were more likely to use left-to-right spatial structuring than right-to-left, especially for well-ordered letters and numbers. Hebrew-speaking Israeli parents were more likely than Americans to use right-to-left spatial structuring, especially for letters. When constructing a pictorial narrative for their children, Americans were more likely to place pictures from left to right than Israelis. These spatial structure biases exhibited by caregivers are a potential route for the development of spatial biases in early childhood, before children have developed automatic reading and writing habits.

Keywords

space; number; gesture; culture

Humans, and many other non-human animals, lead a rich spatial life. In addition to everyday tasks which are explicitly spatial, such as navigating the environment, we also use this spatial awareness is more-subtle ways. The saying "A place for everything, and everything in its place", does not just apply to household organization; it captures the usefulness of space as a scaffold for non-spatial information, such as a string of to-be-remembered items (as in the ancient 'method of loci': Yates (1966)). This recruitment of space when conceptualizing other, non-spatial, sorts of information was first empirically documented in adults' use of a mental number line (Galton, 1880; Moyer & Landauer, 1967). In this phenomenon, educated adults associated small numbers with one side of space and large numbers with the opposite side (Bulf, Macchi Cassia, & de Hevia, 2014; Dehaene, Bossini, Giraux, 1993; Fischer, Castle, Dodd, & Pratt, 2003; Zorzi, Priftis, Meneghello, Marenzi, & Umilta, 2006). These spatial associations are not limited to number concepts; a large body of

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Author Contributions

K.M. developed the study concept. K.M and C.C. contributed to the study design. Testing and data collection were performed by C.C. and S.S. K.M. performed the data analysis and interpretation. K.M. drafted the manuscript, and C.C. and S.S. provided critical revisions. All authors approved the final version of the manuscript for submission.

evidence suggests that if information is well-ordered, such as days of the week or letters of the alphabet, it is likely to be placed onto a spatial frame of reference (Dodd, Van der Stigchel, Leghari, Fung, & Kingstone, 2008); Gevers, Reynvoet, & Fias, 2003, 2004; Previtali, de Hevia, & Girelli, 2010).

These spatial associations are often directionally biased in a manner that reflects the language of the participant (Dehaene et al., 1993; Shaki & Fischer, 2008; Shaki, Fischer, & Göbel, 2012; Zebian, 2005). Adults who read and write from left to right place initial information on the left side of space, and final information on the right (Dehaene et al., 1993; Previtali et al., 2010). However, adults whose dominant language is primarily read from right to left experience an attenuation or reversal of this bias (Dehaene et al., 1993; Shaki, 2009; Zebian, 2005). For example, some languages, such as Hebrew and Farsi, are written and read from right to left for words but left to right for any numbers embedded in this text. As a result, participants who speak these languages often exhibit non-directional or right-to-left spatial biases, especially when the dimension is non-numerical (Rashidi-Ranjbar, Goudarzvand, Jahangiri, Brugger, & Loetscher, 2014; Shaki, Petrusic, Leth-Steensen, 2012; Vallesi, Weisblatt, Semenza, & Shaki, 2013).

How, and when, these directional spatial biases develop is unclear. Several candidate explanations appear in the literature (see McCrink & Opfer, 2014 for a review). The first explanation emphasizes the role of visuo-motor feedback and embodied cognition during finger counting: the so-called “manumerical cognition” account (Fischer & Brugger, 2011). On this account, children learn to associate the left or right side of space with the left or right side of their hand as they extend each finger while stating the count list (“1… 2… 3…”). This account is intuitively appealing because there is an obvious one-to-one mapping, and a strong opportunity for immediate feedback, between the extended fingers and labels said aloud. Further, adults who count from left to right on their fingers exhibit stronger left-to-right spatial biases (Fischer, 2008), and finger-counting routines differ from culture to culture (Lindemann, Alipour, & Fischer, 2011). However, it is not well-supported as a developmental pathway to directional spatial associations; children who exhibit strong left-to-right biases for counting a set of objects also readily exhibit right-to-left finger counting routines (Knudsen, Fischer, & Ascherleben, 2014; Rinaldi, Galluci, & Girelli, 2015).

The second explanation draws on research on evolutionary psychology, and posits that – at least initially – a left-to-right spatial bias is present innately or with very little meaningful experience. This account has three components. First, infants exhibit a propensity to map number to space (de Hevia & Spelke, 2009; Lourenco & Longo, 2010). For example, infants who learn that a set of objects will appear from least to most numerous, also expect that a single line will appear from shortest to longest (de Hevia & Spelke, 2009). This early-developing commingling of space and number combines with an evolutionarily endowed attentional bias to orient to the left side of space (Vallortigara et al., 1996; Heilman & Van Den Abell, 1980). Finally, infants are more attentive to, and more readily learn, sequences of increasing quantity (de Hevia, Addabbo, Girelli, & Macchi Cassia, 2014; Macchi Cassia, Picozzi, Girelli, & de Hevia, 2012). This combination results in an association of small numbers (the first in an increasing series of quantities) with the left side of space (the first location to which they look).

Studies which find a left-to-right asymmetric mapping of number to space in non-human organisms who will never read or write, such as young chicks (Rugani et al., 2010, 2015) and monkeys (Drucker & Brannon, 2014), as well as very young infants (de Hevia et al., 2014; Bulf et al., 2015), bolster this view. Further support for this view comes from work that finds a privileged link between number and space over other dimensions (Bulf, Macchi Cassia, & de Hevia, 2014; Dodd et al., 2008), even in infancy (Bulf, de Hevia, & Macchi Cassia, 2015; de Hevia & Spelke, 2013). This account is incomplete, because in its strongest version it does not allow for cultural variations in spatial associations. Thus it must be paired with other mechanisms in a combination account, to fully capture the range of observed behaviors (Bulf et al., 2015; Neurk et al., 2015).

The third explanation highlights the driving role of formal writing systems. In this view, many years of reading and writing experience are needed to develop directional spatial biases. The habitual scanning from left to right, or right to left, leads readers to implement this structure for any ordered information that is placed onto their spatial scaffold (Berch et al., 1999; Dobel, Diesendruck, & Bolte, 2007; Tversky, Kugelmass, & Winter, 1991). A more-subtle version of this theory is that preliminary reading and writing skills drive spatial biases. For example, by 5 years of age, children given a reading task will reject everyday words whose initial letters are unexpected compared to final letters (Masonheimer, Drum, & Ehri, 1984; Ehri & Wilce, 1985; Share & Gur, 1999). When emergent readers view their own name, they exhibit this position sensitivity by 3 years and 9 months (Treiman, Cohen, Mulqueeny, Kessler, Schechtman, 2007). The awareness of orientation for self-generated writing comes in later, with children frequently mirror-reversing text until 6 years of age (Cornell, 1985), perhaps because reading and writing co-opt brain regions that are insensitive to mirror reversals (see Dehaene, Cohen, Sigman, Vinckier, 2005 for a review). Overall, this work on literacy points to a sense of text orientation that is prone to reversals, and most studies suggest it develops later (4–5 years of age on average) than spatial associations (Bulf et al., 2015; McCrink, Berkowitz, & Shaki, 2014; Shaki, Fischer, & Gobel, 2012). Although it is possible that self-directed reading and writing enhance spatial associations in childhood, they are unlikely to be the initial causal factor.

The final explanation, which is directly tested here, is a variant of this linguistic explanation. It hypothesizes that caregivers – most of whom read and write extensively – impose directionally biased spatial structure during everyday activities with their children, and act as early cultural transmitters of spatial orientation. For example, Shaki et al (2012) observed that counting routines, in which children point directionally while numerically labeling objects, occur from right to left for Hebrew-speaking children but from left to right for English-speaking children. Additionally, McCrink et al. (2014) found that preschool children exhibit better learning and memory for labels that are presented with a spatial structure that is consistent with the dominant language of their culture. These effects suggest that culturally sensitive spatial biases are already present before children exhibit self-directed reading and writing. Thus far, dyadic reading (Gobel, McCrink, Shaki, & Fischer, submitted) and visuo-motor games (Patro, Fischer, Nuerk, & Cress, 2015) have been studied as routines that contribute to this early cultural transmission. We believe that spatial structuring during caregiving is a spontaneous and pervasive way caregivers orient children to the culture’s spatial frame of reference.

To test this hypothesis, we directly examined spontaneous caregiving behaviors that may be found in everyday interactions between parents and their children. We studied two types of dyadic interactions between English-speaking and Hebrew-speaking caregivers and their young toddlers, using materials designed to spontaneously elicit spatial structuring via gesture (Task 1, co-viewing task) or via an external set of pictures (Task 2, story construction task). In the first task, caregivers were asked to keep their child engaged while co-viewing a video that displayed both ordered and non-ordinal stimuli, and in the second task caregivers were asked to create and narrate a visual story for their child.

We put forth several hypotheses, from which we can generate predictions about within- and across-culture differences. The first three pertain to the co-viewing task, and the final hypothesis pertains to the story construction task. For across-culture comparisons, predictions refer to a certain type of directional point changing across cultures. For within-culture comparisons, predictions refer to the relative levels of each directional point within that culture. Note that within-culture predictions for Israelis are not predicted in advance. Hebrew exhibits mixed directionality for letters and numbers, and the effects of this mixed orthography for Israeli parents are hard to predict with rigor (Shaki, Fischer & Petrusic, 2009; Shaki & Fischer, 2014).

- Hypothesis 1: When parents view spatially structured scenes with their toddlers, they will be biased to provide spatial gestures that are culture-specific, as determined by their culture's reading and writing system. This hypothesis generates the following across-culture prediction: there will be an interaction between the pointing direction to these spatially structured scenes and the dyads' culture, with American parents exhibiting slightly higher levels of left-to-right points than Israeli parents, and Israeli parents exhibiting higher levels of right-to-left points than American parents (Hypothesis 1, Prediction 1: H1P1). This hypothesis also generates the following within-culture prediction: American parents will exhibit higher levels of left-to-right pointing than right-to-left (H1P2).
- Hypothesis 2: The degree to which we observe this culture-specific gesture bias will depend on the nature of the presented stimuli at that moment. This hypothesis generates the following across-culture prediction: there will be an interaction between the pointing direction to these different stimuli types and the dyads' culture, selectively driven by Israeli parents pointing from right to left more often than American parents when viewing letters (and not numbers: H2P1). This hypothesis also generates the following within-culture predictions: The American bias will be present for letters and numbers because they are read from left to right (H2P2).
- Hypothesis 3: The reading and writing system of the culture will result in a "spill-over" effect, in which parents impose structure on even very random scenes (non-ordinal stimuli, presented in a neutral spatial orientation) with a culture-specific bias. The degree to which this imposition of structure occurs will depend on how consistently directional the participant's written language is. This hypothesis generates the following across-culture prediction: there will be an

interaction between the pointing direction to these neutral scenes and the dyads' culture, driven by Israeli parents pointing from right to left more often than American parents for these neutral scenes, and Americans pointing left to right more often than Israeli parents (H3P1). This hypothesis also generates the following within-culture prediction: For Americans, there will be more left-to-right pointing than right-to-left pointing for these neutral scenes (H3P2).

- Hypothesis 4: This culture-specific structuring bias extends beyond gesture, and will be found in other domains – such as when parents construct a story for their child with pictures. This hypothesis generates the following across-culture prediction: there will be an interaction between structuring orientation and culture, with Israeli parents placing pictures from right to left more often than American parents, and Americans placing the pictures left to right more frequently than Israelis (H4P1). This hypothesis also generates a within-culture prediction: For Americans, there will be more left-to-right placements of story pictures than right-to-left placements (H4P2).

Method

Participants

One hundred and thirty caregiver-toddler dyads were recruited via flyers and word-of-mouth from the New York City metropolitan area or the Central district of Israel. The Americans participated at a children's museum or in a laboratory setting, and all Israelis participated in their homes. Both populations were screened to ensure the children's exposure to only left-to-right script (American sample) or right-to-left letter script (Israeli sample). In the sample of bilingual Americans, the other languages spoken were German, Spanish, French, Korean, and Tagalog. One hundred and sixteen dyads involved the mother of the child, 14 the father. In the co-viewing task, 33 dyads were excluded from the dataset, for fussiness and inability to complete the task ($n = 19$), caregiver or child interference ($n = 6$), and experimenter or equipment error, such as camera malfunction ($n = 8$). This yielded a final sample of 64 American dyads and 33 Israeli dyads. Of the American dyads, 34 participated in a laboratory and 30 in a children's museum.

In the story construction task, 39 dyads were excluded, for fussiness resulting in an inability to complete the task ($n = 19$), caregiver or child interference or failure to follow directions ($n = 13$), and experimenter or equipment error ($n = 7$). An additional 25 American dyads were run but not included in the final dataset; their experimental condition (in which the caregiver sat across from, not on the same side as, the toddler) was not implemented in Israel and therefore we do not have the relevant cross-cultural comparison to study our central claims. The main effects and interactions in the second task remain present even with this sample in the analyses. This yielded a final sample of 34 American dyads and 32 Israeli dyads. Of the American dyads, 19 participated at the children's museum and 15 in a laboratory setting. Maternal education levels and literacy measures were obtained for a subset of participants (39%: 16 of the 64 American dyads, and 22 of the 33 Israeli dyads). The sample size was drawn from looking at other experiments on early spatial associations (e.g., Shaki et al., 2012; Opfer et al. 2010), which had obtained and reported results with similar age groups, and data collection was stopped after reaching the targeted sample size. The characteristics of the final sample for both tasks (including age and demographic information) are summarized in Table 1.

Co-viewing Task

Stimuli and design—The dyads viewed a slideshow consisting of 12 images; the presentation order of these slides was counterbalanced across participants (Fig. 1). These images depicted letters (2), numbers (2), objects (2), or animals (6); the items within these images were spatially oriented in one of three directions. These directions were left to right (4: 2 animals, 1 set of letters, 1 set of numbers), right to left (4: 2 animals, 1 set of letters, 1 set of numbers), or neutral (4: 2 sets of animals, 2 sets of objects). Spatial orientation was determined by either the conventional order of the stimuli (where the initial or final letters or numbers are placed on the screen) or the head of the animals (head on the left for left-to-right orientation; caregivers showed a strong tendency in a previous study to use the head of the animal as a starting point.) The stimuli for American and Israeli dyads were identical with the exception of the letter slides; these slides used the English alphabet for the American sample (A, B, C, D, E), and each letter was changed to its Hebrew alphabet symbol for the Israeli sample (א, ב, ג, ד, ה).

Procedure—A 17″ Macbook Pro laptop or a 21.5″ screen iMac computer (America) or Asus 17.3″ (Israel) were used to present the stimuli; the exact computer depended on whether the child was tested in the children's museum or laboratory. The stimuli were presented via Keynote, with each slide shown for 15 seconds, along with a 2-second transitional slide displaying "Ready?". Children were asked to sit on their caregiver's lap, approximately 60 cm in front of the computer screen. A camera was positioned above the participants' head giving a bird's-eye view of the area between the participants and the computer screen. Caregivers were given the following instructions: "Please keep your child on your lap, and watch the video as you normally would. Try to keep them engaged, and explain the pictures."

Coding—The number and spatial structure of each point was coded from a recording of the dyad. Each point was defined as an outreach of the hand and ended as the caregiver pulled back his or her hand towards his or her body. A left-to-right point was any point in which the hand proceeded, without pulling back, to move towards the right after an initial brief pause in extension. A right-to-left point was coded for any hand extension in which the hand, without the arm pulling back, moved towards the left after an initial extension. A neutral point was a simple extension and pull back with no horizontal component. In order to code this and remain blind to the slide type, the sound was turned off during viewing of the study video, and the camera position did not reveal the image on the screen. A coder naïve to the hypotheses of the study, and particular on-screen stimulus, coded the number of each point type for each slide for a subset of the participants (~25%) from a recording. Given the continuous nature of the data we used Chronbach's α to compare the two sets of ratings; inter-rater reliability was substantial (α = .95).

Story Construction Task

Stimuli and design—Stimuli for the story construction task consisted of 10 mounted and laminated small pictures (6″ × 6″ each), each of which possessed a neutral orientation to not bias caregivers into displaying a particular structure when constructing their story. The pictures consisted of animals (a dog, squirrel, boy and girl), settings (a park, and beach), or objects (a car, basket, present, and cake). The dyads sat on the same side of the table.

Procedure—Caregivers were shown to a child-friendly table and chair set, and told: "Please use these tiles any way you like to create a story for your child." They were then handed the stack of tiles, with their order counterbalanced across dyads to control for possible confounds of agents, places, and objects being presented at differing points in the story. Because we were interested in the naturalistic manner in which caregivers interact with their children, we did not explicitly tell them to use all the tiles, or stop the story when all tiles were done. Caregivers were instructed to inform the experimenter when they had completed their story. Only parents placed the tiles. The average length of time caregivers used to tell their story was between 2.5 and 3 minutes. The interactions were recorded using a camera positioned to provide a bird's-eye view.

Coding—For each dyad a coder observed the study live, and measured how many times caregivers structured tiles left to right, right to left, vertically, or stacked on top of one another. Placing a tile to the right relative to a previously placed tile was scored as left to right (LR). Placing a tile to the left relative to a previously placed tile was scored as right to left (RL). Placing a tile above or below a previously placed tile was scored as vertical structuring (VRT). Stacking tiles on top of one another with no spatial direction was coded as neutral (NTL). All coding was considered from the viewpoint of the child. Although most caregivers used each tile once and only once, there was some variability in how often they repeated or used the tiles, and each placement of a tile was coded. To remain consistent across trials, only the initial three minutes were coded for each dyad. A coder naïve to the hypotheses of the study coded the number of placements of each type for a subset of the participants, from a recording (~25%). The inter-rater reliability between this coder and the original coder's ratings was high (Chronbach's α = .96).

Results

Co-Viewing Task

Each of the listed hypotheses has theoretically driven, culture-specific, predictions for the spatially structured points but not the spatially generic neutral points. For this reason we focus our analyses on these directional point types. In the supplementary online information for this article, the interested reader can view a table with the mean number with standard deviations of all point types, for each culture and scene type, and information on statistically significant Bonferroni-corrected post-hoc contrasts for within- and across-culture effects (S1). This information was derived from identical ANOVAs to those detailed below, with the sole addition of these neutral point types. The full dataset is available as supplementary information (S2).

Unless otherwise noted, all the post-hoc tests reported throughout the results sections are Bonferroni procedure pairwise comparisons, which corrects for multiple comparisons. Means are followed by their standard errors, and 95% confidence intervals of the difference are notated as CIoD. Note: Our American sample is larger than the Israeli sample; a set of analyses was done using a matched-*N* sample of Americans and Israelis (with children of the same age and gender), and the main effects and interactions were similar to those noted below.

Preliminary analyses—In the first analysis we examined directional gesture for stimuli that had a spatial orientation (e.g., were laid out left to right or right to left). The mean number of points was entered into a repeated-measures ANOVA with point type (LR, RL), stimuli type (number, letter, animal), and stimuli orientation (LR, RL) as within-participants factors and culture (American, Israeli), bilingualism (present, absent), maternal education (some high school, graduated high school, some college, college degree, post-graduate degree), gender (male, female), and age (1 y.o., 2 y.o.) as between-participants factors. These analyses indicated no significant main effects of, or meaningful interactions with: bilingualism ($p = .75$), maternal education levels ($p = .48$), gender ($p = .42$), or age ($p = .85$). An additional analysis was run over only the data from the American dyads, identical but with culture removed as a variable and location ran added (since this variable did not exist for the Israeli dyads). There was no effect or interaction with location ran (children's museum, or laboratory: $p = .08$). Thus these factors were not entered into the primary analysis of gesture for these oriented stimuli.

In a second analysis, we examined directional gesture for stimuli that were neutrally oriented. For these preliminary analyses, the mean number of points was entered into a repeated-measures ANOVA with point type (LR, RL) and stimuli type (objects, animals) as within-participants factors and culture (American, Israeli), bilingualism (present, absent), maternal education (some high school, graduated high school, some college, college degree, post-graduate degree), gender (male, female), and age (1 y.o., 2 y.o.) as between-participants factors. There were no significant main effects or interactions with pointing type (bilingualism ($p = .58$), maternal education ($p = .97$), gender ($p = .81$), or age ($p = .39$). An additional analysis was run over only the data from the American dyads, identical but with culture removed as a variable and location ran added (since this variable did not exist for the Israeli dyads). There was no main effect or interactions with location ran (children's museum, laboratory: $p = .07$). Accordingly, these factors were not considered further in the main ANOVA below, in which we analyzed gesture for these neutral stimuli.

Repeated Measures ANOVA analyzing spatial gesture during structured scenes

General effects of slide orientation: The mean number of points was entered into a repeated-measures ANOVA with point type (LR, RL), stimuli type (number, letter, animal), and stimuli orientation (LR, RL) as within-participants factors and culture (American, Israeli) as a between-participants factor. There was a main effect of slide orientation ($F(1,95) = 4.34$, $p = .04$, *partial* $\eta^2 = .04$); right-to-left oriented stimuli received more points overall than left-to-right oriented stimuli ($M = .64$, $SEM = 5.8$ vs. $M = .54$, $SEM = 5.4$], 95% CIoD

[.5, 19.7]). As would be expected if parents are paying attention to the slides, the orientation of the stimuli interacted with point type ($F(1,95) = 54.72$, $p < .001$, *partial* $\eta^2 = .37$), with parents exhibiting more right-to-left points than left-to-right points for right-to-left oriented stimuli ($M = .81$, $SEM = .08$] vs. $M = .19$, $SEM =.03$, $p < .001$, CIoD [.47, .79]) and more left-to-right points than right-to-left points for left-to-right oriented stimuli ($M = .89$, $SEM = .09$ vs. $M = .46$, $SEM = .07$, $p < .001$, CIoD [.70, 1.08). There was also a 3-way interaction between point type, stimuli type, and stimuli orientation ($F(2,190) = 16.55$, $p < .001$, *partial* $\eta^2 = .15$). Left-to-right oriented animals did not receive different amounts of left-to-right and right-to-left pointing ($p = .10$), but all other stimuli types and stimuli orientations did so in the expected manner (that is, more left-to-right points than right-to-left for stimuli oriented left to right, and vice versa.)

General effects of stimuli type: There was also a significant main effect of stimuli type ($F(2,190) = 35.34$, $p < .001$, *partial* $\eta^2 = .27$). Numbers ($M = .76$, $SEM = .08$) and letters ($M = .74$, $SEM = .07$) were pointed to more frequently overall than animals ($M = .27$, $SEM =.03$; both ps < .001, CIoD [.30, .67], [.32, .62] respectively). The type of stimuli interacted with culture ($F(2,190) = 9.52$, $p < .001$, *partial* $\eta^2 = .09$). Between-cultures, Americans were more likely than Israelis to point to numbers ($M = .97$, $SEM = .09$ vs. $M = .54$, $SEM = .13$, $p = .008$, CIoD [.12, .75]), and Israelis were more likely than Americans to point to animals ($M = .34$, $SEM = .05$] vs. $M = .20$, $SEM = .04$, $p = .03$, CIoD [.02, .26]). Within each culture, we observe that Americans provided more overall pointing to numbers ($M = .97$, $SEM = .09$) and letters ($M = .83$, $SEM = .08$) than animals ($M = .20$, $SEM = .04$; both ps < .001, CIoD [.55, .99], [.46, .81]). Israelis provided more overall pointing to letters ($M = .64$, $SEM = .11$) than animals ($M = .34$, $SEM = .05$; $p = .008$, CIoD [.06, .55]), with numbers in-between and not different than the other types of stimuli ($M = .54$, $SEM = .13$). Here we observed a relevant finding not detailed in the initial hypotheses: *Ordinal stimuli such as numbers and letters are more likely overall to evoke structured points, even those that are culturally non-specified, than non-ordinal stimuli such as animals.*

Analyses for Hypothesis 1: Viewing spatially structured scenes prompts culture-specific spatial gesture: There was a significant main effect of point type ($F(1,95) = 8.37$, $p = .005$, *partial* $\eta^2 = .08$). Overall, the sample of parents exhibited higher levels of left-to-right pointing than right to left pointing ($M = .68$, $SEM = .07$ vs. $M = .50$, $SEM = .05$; CIoD [.06, .30]). Confirming Hypothesis 1 Prediction 1 (H1P1), point type interacted with culture ($F(1,95) = 26.6$, $p < .001$, *partial* $\eta^2 = .22$). Between cultures, American parents exhibited significantly higher amounts of left-to-right pointing than Israeli parents ($M = .92$, $SEM = .08$ vs. $M = .44$, $SEM = .06$, $p = .001$, CIoD [.20, .75]), and American and Israeli parents exhibited similar overall amounts of right-to-left pointing ($M = .42$, $SEM = .06$ vs. $M = .58$, $SEM = .08$, $p = .10$). Within-culture, Americans were more likely to provide left-to-right points than right-to-left points ($p < .001$, CIoD [.35, .64]), confirming H1P2. Israelis were equally likely to point left to right and right to left ($p = .17$). *These two findings support the hypothesis that the directionality of spatial gestures in a parent-toddler dyad when viewing spatially structured scenes is influenced by the culture of the parent.*

Analyses for Hypothesis 2: Stimuli that are ordinal, and consistent with the orthography of the culture, will elicit more culture-specific gesture than stimuli that are not: The ANOVA run above also quantified a three-way interaction of point type × stimuli type × culture ($F(2,190) = 9.39$, $p < .001$, *partial* $\eta^2 = .09$). There were significant effects across culture for left-to-right pointing behavior to letters and numbers, but not animals. There were significant effects across culture for right-to-left pointing behavior for letters and animals, but not numbers. (See Figure 2 for means and standard errors for pointing behavior, as a function of culture and scene type.) Americans exhibited significantly higher rates of left-to-right pointing for the number and letter stimuli than Israelis (*p*s = .001, < .001; CIoD [.32, 1.24], [.35, 1.18]). Israelis, on the other hand, exhibited significantly higher rates of right-to-left pointing than the Americans for letter stimuli ($p = .004$; CIoD [.12, .65]) and animals ($p = .03$; CIoD [.02, .30]). These results confirm H2P1, that there is stimulus-specificity for these cross-cultural directional gesture differences.

Within each particular culture, the Americans were on the whole more “directional”; they were more likely to point left to right than right to left for letter and number stimuli (both *p*s < .001; CIoD [.59, 1.09], [.37, .92] respectively) but not animals. These results confirm H2P2, that higher rates of left-to-right pointing than right-to-left would be found in American parents for letters and numbers. Americans exhibited more left-to-right and right-to-left points for ordinal stimuli than the animals (all *p*s < .05). Israelis tended to point left to right and right to left with similar frequency regardless of stimuli type (numbers, letters, and animals: *p*s = .81, .07, .49 respectively). Israelis did not change their overall level of left-to-right points according to the nature of the stimuli. They instead changed their level of right-to-left points, providing more right-to-left points for letters than animals ($p = .001$, CIoD [.16, .72]). *These analyses support the hypothesis that the presence of culture-specific gesture is dependent on the nature of the stimulus being observed by the dyad.*

Repeated Measures ANOVA analyzing spatial gesture during neutral scenes

Analyses for Hypothesis 3: Viewing scenes without intrinsic structure continues to evoke culture-specific spatial gesture: In our final co-viewing analysis we examined the pointing behavior for the non-oriented slides with non-ordinal stimuli (objects, or animals). The mean number of points was entered into a repeated-measures ANOVA with point type (LR, RL) and stimuli type (objects, animals) as within-participants factors and culture (American, Israeli) as a between-participants factor.

There was a significant main effect of stimulus type ($F(1,95) = 10.25$, $p = .002$, *partial* $\eta^2 = .10$); the parents pointed more overall to objects than to animals. There was an interaction of point type with the culture of the participants ($F(1,95) = 18.87$, $p < .001$, *partial* $\eta^2 = .17$). The right-to-left pointing, but not the left-to-right pointing, significantly differed between the two populations. Americans and Israelis were equally likely to point left to right ($M = .45$, $SEM = .06$ American, $M = .29$, $SEM = .08$ Israeli), but Israelis ($M = .42$, $SEM = .04$) were nearly three times more likely to point right to left than Americans ($M = .15$, $SEM = .03$; $p < .001$, CIoD [.17, .39]). This pattern partially confirms H3P1; the significant interaction indicates that cultural modulation of pointing type for these neutral scenes is occurring, but this effect is driven by the difference in only right-to-left pointing behavior.

Within each culture, Americans showed higher levels of left-to-right pointing than right-to-left pointing ($p < .001$; CIoD [.15, .38]). This confirms H3P2, that even spatially neutral scenes with non-ordinal stimuli will be preferentially structured with culture-specific directionality. Israelis did not exhibit different amounts of these two types of directional points. (Figure 3.) Finally, there was a three-way interaction between point type, stimuli type, and culture ($F(1,95) = 7.07$, $p = .009$, *partial* $\eta^2 = .07$). This reflects the fact that the two populations exhibited their culture-specific pointing patterns for different types of stimuli. The Americans were more likely to point left to right than right to left for object stimuli ($M = .64$, $SEM = .10$) compared to animal stimuli ($M = .26$, $SEM = .04$, $p < .001$; CIoD [.24, .61]), while their right-to-left pointing did not differ by stimuli type. Israelis were more likely to point right to left for animals ($M = .55$, $SEM = .06$) than objects ($M = .35$, $SEM = .14$, $p = .01$; CIoD [.07, .34]), but their left-to-right pointing did not differ by stimuli type. *Overall, these results support the hypothesis that parents structure random scenes with non-ordinal stimuli in a manner that is consistent with the culture's reading and writing system.*

Story Construction Task

A percentage was calculated for how many placements were made of each type (left-to-right, right-to-left, vertical, or stacking of the tiles); because some parents re-used tiles in the course of the narrative, this normalized for slightly different amounts of overall placements. As with the first task, we had a series of predictions regarding the amount of directional placements (left-to-right or right-to-left) used by parents when constructing a pictorial narrative for their toddler. Thus we do not analyze spatially generic or irrelevant placements. Those data, along with directional placements, can be found in the Supplementary Data 1. Note that this presentation of data results in placement totals of less than 100%.

Preliminary analyses—The percentage of placements was analyzed in a repeated-measures ANOVA with placement type (left-to-right, right-to-left) as a within-subjects variable and culture (American, Israeli), bilingualism (present, absent), maternal education (some high school, graduated high school, some college, college degree, post-graduate degree), gender (male, female), and age (1 y.o., 2 y.o.) as between-subjects variables. These preliminary analyses indicate that bilingualism ($p = .14$), maternal education ($p = .99$), age ($p = .69$), and gender ($p = .26$) had no significant main effects or interactions with placement and are therefore not included in the main analysis. An additional analysis was run over only the data from the American dyads, identical but with culture removed as a variable and location added (since this variable did not exist for the Israeli dyads). There was no main effect of location ran for the American participants, but there was a significant interaction of location with placement type ($F(1,32) = 5.13$, $p = .03$, *partial* $\eta^2 = .14$). Parents at the children's museum were 33% more likely to place from left to right than right to left ($p = .001$), while parents in the laboratory exhibit only a 3% difference ($p = .74$). (This variable is specific to only the Americans and cannot be included in the critical cross-cultural analysis.)

Repeated measures ANOVA analyzing cultural variation in directional placement—Here we perform analyses for Hypothesis 4: The culture-specific structuring bias will extend to a task in which parents must construct a story for their child using pictures. The percentage of placements was analyzed in a repeated-measures ANOVA with placement type (left-to-right, right-to-left) as a within-subjects variable and culture (American, Israeli) as a between-subjects variable. There was no significant main effect of placement type ($F(1,64) = 3.58$, $p = .06$). There was a significant interaction between placement type and culture ($F(1,64) = 8.04$, $p = .006$, *partial* $\eta^2 = .11$). Culture influenced the extent to which left-to-right placements occurred (M = 31%, SEM = 4.6 for Americans and M = 8%, SEM = 4.7 for Israelis, $p = .001$, CIoD [10.3, 36.6]), but not right-to-left placements (M = 11%, SEM = 4.1 for Americans and M = 12%, *SEM* = 4.3 for Israelis, $p = .87$). This pattern partially confirms H4P1, with an interaction signifying that the visual construction of stories is different between the cultures, but this interaction is driven by a difference in only the left-to-right placements. Americans were more likely to place slides left to right than right to left ($p = .002$, CIoD [8.4, 32.3]), confirming H4P2. (See Figure 4.) Thus we observe partial evidence for our final hypothesis: *there is a culture-specific structuring bias that goes beyond gesture, that is found when parents arrange pictures to tell a story to their child*.

Discussion

Overview

The current findings illustrate that caregivers of very young toddlers consistently and spontaneously provide particular types of spatial structure, and this structure is dictated by the cultural surround of the child and parent. When tasked with engaging their child while viewing a video together, caregivers' gestures embodied the structure of the linguistic surround. This cross-cultural *spatial gesture bias* was persistent for both traditionally ordered scenes (letters and numbers, arranged in a horizontal continuum) and unordered scenes (objects and animals, placed randomly on the screen), though high levels of ordinality and transparent structure did exacerbate the phenomenon. In the second task, caregivers used a set of visual stimuli to supplement a verbal story, and when American parents provided structure it was preferentially in a left-to-right manner. The caregivers were not explicitly told to use spatial gesture or structure; they spontaneously and reliably recruited gesture and spatial structure as methods of controlling their child's attention and engagement. These findings support the hypotheses that a) parents exhibit a spontaneous spatial gesture bias that is culture-specific, and b) this bias is found most prominently for stimuli that are consistent with the direction of their culture's reading and writing system, such as the alphabet.

Below we summarize the findings, and discuss the support for each of the hypotheses detailed in the introduction. These hypotheses predicted distinct types of across- and within-culture effects of the parents' language on how they structured scenes and stories for their children.

Hypothesis 1: Culture Modulates the Direction of Gesture for Spatially Structured Scenes

When viewing scenes of ordinal stimuli (such as letters, or numbers) that were well laid out (on a horizontal line, arrayed from right to left or left to right), American parents exhibited significantly higher amounts of left-to-right pointing than Israeli parents. Israeli parents did not exhibit higher amounts of right-to-left pointing than the American parents, suggesting a dilution of this cross-cultural spatial gesture bias brought on by the mixed directionality of the Hebrew language. American parents were also more likely overall to point from left to right than right to left, but the complementary within-culture directional tendency did not exist for the Israeli parents. Overall, these findings support the hypothesis that, when viewing scenes of well laid-out, commonly ordered stimuli, parents who read and write a language with consistently directional gesture (such as English) will direct their child's attention with a spatial gesture bias in accord with their language's orthography. If consistent directionality is not present, as with the Hebrew speakers, there is no overall within-culture spatial gesture bias.

Hypothesis 2: Cultural Modulation of Gesture is Stimuli Specific

Further, we found that this cultural modulation of spatial gesture varied depending on what sort of stimuli the parents were co-viewing with their children. Israelis were more likely to point right to left than American parents when viewing scenes composed of letters. This is likely due to the Hebrew writing system's consistent right-to-left spatial orientation for non-numerical text. Americans were more likely than Israelis to point left to right for letters. Interestingly, Americans were also more likely to point left to right for numbers than Israelis. This suggests that when the framing orthography of the language is right-to-left (as in Hebrew), this suppresses left-to-right structuring even for the subset of the language that is printed left-to-right (here, numbers). Thus we find partial support for the hypothesis that ordinal stimuli will reliably elicit structuring that parallels their print direction. This is generally the case, but the effects for directional stimuli that are embedded within an opposing spatial frame (such as the numbers in Hebrew writing) are attenuated.

Hypothesis 3: Consistent Directionality Results in a Gesture Bias to Neutral Scenes

American parents who viewed non-ordinal stimuli, such as animals or objects, presented with no intrinsic structure (e.g., scattered or facing forward), were overall more likely to gesture from left to right than right to left. Israeli parents who viewed these same scenes showed no tendency to prefer one type of directional point over the other. However, these Israeli parents were far more likely to point from right to left than the American parents, with left-to-right points showing no cultural differences for these neutral scenes and stimuli. These results illustrate that a carryover effect from the culture's orthography exists, wherein parents impose a culturally specific spatial gesture bias. This bias is only found for the Americans, indicating that the language that the adults read and write must be highly consistent to generalize to unstructured scenes of non-ordinal stimuli. The finding that the across-culture differences came about only for right-to-left points is likely due to the mixed directionality of the Hebrew language. Both Hebrew speakers and English speakers are accustomed to pointing from left to right, but Hebrew speakers are far more accustomed than English speakers to directing their attention from right to left in everyday interaction with text. These results support the hypothesis that spatial structuring by parents does not solely occur for scenes that are already well laid-out, but rather this phenomenon generalizes to unstructured scenes. A minimal comparison between these results and the structured scene results (which show no left-to-right pointing bias by the Americans for non-ordinal stimuli like animals) suggests that this blank-slate scenario is exactly when parents impose structure on non-ordinal stimuli (e.g., when there is none to be had).

Hypothesis 4: Parents Exhibit a Spatial Structure Bias When Constructing a Narrative

Parents' spatial biases were also on display during the second task, in which they had to construct a story for their child using pictures and words. This was especially true for our English-speaking sample, in which the writing system is consistently left-to-right for letters and numbers. American caregivers preferentially structured their story left to right over right to left, and this pattern was attenuated – but not reversed - in the Israeli caregivers. There was a significant interaction between the culture of the dyad and the relative amount of each directional placement, with right-to-left (but not left-to-right) layouts more common amongst Israeli parents than American parents. Thus we find partial evidence for the hypothesis that parents will exhibit culturally determined spatial structure in ways that go beyond simple hand gestures. This effect replicates and extends in a developmental context the *spatial agency bias* (Maass & Russo, 2003), in which adults mentally and physically map agents to the left or right side of space, and action in a scene or story flows from left to right or right to left, as a function of their native language's script orientation and the order in which the participant and object appear in sentences (Maass, Suitner, & Nadhmi, 2014). The phenomenon documented here may be an avenue of cultural transmission for this spatial agency bias.

Spatial Structure Bias and Visual Attention

In addition to the explicitly hypothesized effects, unexpected findings also emerged. First, there was the preference by American caregivers to exhibit a greater overall amount of directional pointing to symbols, such as letters and numbers, than to pictures of animals. This greater overall amount of structural pointing even happened with culturally inconsistent gesture (e.g., parents were more likely to point right to left for letters and numbers than animals and objects). Second, the use of visual structure during narration was found primarily in the group of Americans who participated in the children's museum, and not in the laboratory. We believe these two findings may be tapping into the same phenomenon: Parents are more directional in their structure when feel that they need to get, and sustain, their child's attention.

With respect to the effects of differing stimuli in the co-viewing task, the presented symbols were probably less interesting than the animals for the children. Thus, parents may feel more compelled to direct and hold their child's attention to them with more extensive and structured pointing. With respect to the difference in structuring behavior between the participants in the museum and laboratory, the story construction task took place in the second half of the study, when children were more likely to be restless and distracted by their environment. This restlessness is heightened in the museum, where there are often siblings around and the children are in the midst of an environment that has more stimulating options than a simple set of pictures. This is turn may have led parents to be more directional in the museum context, either because they have noticed that this broad structure heightens their child's attention, or because their own biases are exaggerated when they are trying to be compelling and enthusiastic. Taken together, this evidence leads us to speculate that parents are more likely to exhibit spatial gesture and structure biases under conditions of distraction or inattention.

Implications for the Time-course of Spatial Bias Development

As noted in the introduction, there is a debate in the literature as to when exactly culturally consistent spatial biases develop. Some authors (Dobel et al., 2007; Tversky et al., 1991) find that they develop fairly late, in early childhood and well after toddlerhood. More recent studies find evidence as early as 3 years of age for culturally modulated spatial-numerical biases (Opfer et al., 2010; Shaki et al., 2012) and more-general spatial biases (McCrink et al., 2014). The current results suggest that the early-developing, culturally attuned biases in toddlerhood recently documented in the literature are explicable via enculturation, given the divergent and specific actions of caregivers in each culture. Insofar as the early development of culturally variable spatial biases emerges early, one testable hypothesis is that that biases would be linked to how reliably and frequently parents gestured with cultural specificity. With respect to exactly how early this structuring could have an effect, one must turn to work with infants, which has documented spatial biases as early as eight months of age (Bulf et al., 2015; de Hevia et al., 2014). However, given that these infant biases are theorized to be due to innate properties of brain lateralization (Rugani & de Hevia, in press), they are likely to be culturally invariant, and consistently of the left-initial and right-final format. Work with infants from multiple cultures, and under multiple types of caregiver structure levels, would serve to further illuminate the developmental course of these culturally sensitive directional biases.

Future Directions

Given that we observe this cultural modulation of spatial structuring, a key next step is to determine if the degree and nature of this parental spatial structuring will prompt the development of particular spatial biases in the children themselves. In these young toddlers, markers of spatial associations are difficult to come by; it is a challenge for them to readily sit still for a well-controlled video presentation (a technique used with infants; Bulf et al., 2015) without the parents motivating or influencing them, but they are too young to possess the verbal mastery of the count list to reliably count and point to a set of objects in a line (as in Opfer et al., 2010; Shaki et al., 2012). Regardless, this is a critical piece of knowledge, and a potential area for early intervention, since robust spatial skills predict the early development of useful number-line knowledge - which in turn assists in the development of more-complex math skills (Gunderson, Ramirez, Beilock & Levine, 2012). As such, one can develop in-lab navigation tasks for spatial associations based on those used with non-human animals (e.g., Rugani et al., 2010), which may be suitable for children as soon as they can start to move on their own.

Another realm of future work on this phenomenon lies in examining the fundamental cognitive outcomes of providing different types of structure to children early in life. Given work in adults (Maass & Russo, 2003; McCrink & Shaki, 2016) and preschoolers (McCrink et al., 2014; Opfer et al., 2010), which finds facilitated processing when events unfold in a culturally-consistent manner, one would predict that individual differences in the level and type of parental structuring would lead to individual differences in each child's content memory. This type of measure was attempted in the present study, with a set of simple slide recognition probes after the co-viewing task. However, these children were extremely young, and the majority of them either could not comprehend the probe questions, or refused to answer the questions. Going forward, research on spatial associations in very early childhood would do well to employ a more-subtle measure, which does not require interaction or linguistic competence from these young children (such as a preferential looking paradigm).

Finally, one additional future direction is to examine more closely the literacy environment of toddlers, and map how this relates to parental structuring behavior as well as children's development of spatial associations. The dyads studied here were drawn from a pool of participants with relatively high maternal education, which is associated with a high level of literacy (Rodriguez & Tamis-LeMonda, 2011). One could examine whether the amount of picture book engagement (in which gesture and pointing features prominently) is correlated with culture-specific directionality of spatial biases. Given new pediatric guidelines that infants should be read to daily (American Academy of Pediatrics, 2014), the shaping of spatial associations through gesture and narrative may happen at an earlier age than ever before, and vary with factors such as maternal education and socio-economic status.

Limitations

The first limitation to note is that, despite endeavoring to fully match our American and Israeli samples, they differed slightly. The average maternal education level was slightly higher for the American parents than the Hebrew parents, and the dyads tested in America represented a more-diverse pool in terms of ethnic background than the Israeli dyads. Further, the Hebrew-speaking sample size was smaller, partially due to the screening for fluent bilingualism (which is common in Israel). The unequal sample sizes may have led to an exaggerated difference between the Americans and Israelis, due to lower variability in the American sample. This concern is mitigated by an analysis which finds equal (if not stronger) effects when comparing a randomly drawn, smaller, set of Americans to the Israelis. An additional limitation is that the low levels of attention in toddlerhood influenced how long we could observe and test the dyads, and this time limitation resulted in a co-viewing task design that was missing potentially informative cells. Specifically, no numbers or letters were presented in a randomized, neutral spatial layout, which would have allowed for more-nuanced insight into how parents impose structure on random scenes of ordinal stimuli.

Conclusion

Caregivers of young children regularly use the time spent with their child describing everyday scenery, as well as communicating to them stories about their environment. This guidance is necessary in order for children to grow up understanding the content of their world. Yet, these spontaneous behaviors also exert their influence in more fundamental ways. Understanding how mental organizational processes develop in the context of everyday caregiving provides a clear benefit when considering optimal parenting and teaching practices. This study found that when caregivers structure scenes, images, and stories in a discrete direction, they do so in a direction that is uniform with the orientation of their culture's reading and writing. Taken together, these caregiver-behaviors suggest a route by which very early child-caregiver interactions prime spatial organizational processes that continue to develop into adulthood.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

American Academy of Pediatrics: Council on Early Childhood. Literacy promotion: An essential component of primary care pediatric practice. Pediatrics. 2014; 134:404–409. DOI: 10.1542/peds.2014-1384 [PubMed: 24962987]

Berch D, Foley E, Hill R, Ryan P. Extracting parity and magnitude from Arabic numerals: Developmental changes in number processing and mental representation. Journal of Experimental Child Psychology. 1999; 74:286–308. [PubMed: 10552920]

Bowman M, Treiman R. Relating print and speech: The effects of letter names and word position on reading and spelling performance. Journal of Experimental Child Psychology. 2002; 82:305–340. [PubMed: 12225758]

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.doi: 10.1371/journal.pone.0099499

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; Advance online publication. doi: 10.1111/desc.12315

Macchi Cassia V, Picozzi M, Girelli L, de Hevia MD. Increasing magnitude counts more: Asymmetrical processing of ordinality in 4-month-old infants. Cognition. 2012; 124:183–193. DOI: 10.1016/j.cognition.2012.05.004 [PubMed: 22676954]

Chatterjee A, Southwood MH, Basilico D. Verbs, events and spatial representations. Neuropsychologia. 1999; 37:395–402. [PubMed: 10215086]

Cornell J. Spontaneous mirror-writing in children. Canadian Journal of Experimental Psychology. 1985; 39:174–179.

de Hevia MD, Spelke ES. Spontaneous mapping of number and space in adults and young children. Cognition. 2009; 110:198–207. DOI: 10.1016/j.cognition.2008.11.003 [PubMed: 19095223]

de Hevia MD, Spelke ES. Not all continuous dimensions map equally: Number-brightness mapping in human infants. PloS One. 2013; 8:e81241.doi: 10.1371/journal.pone.0081241 [PubMed: 24278402]

de Hevia MD, Girelli L, Addabbo M, Macchi Cassia V. Human infants' preference for left-to-right oriented increasing numerical sequences. PLoS One. 2014; :9.doi: 10.1371/journal.pone.0096412

Dehaene S, Bossini S, Giraux P. The Mental representation of parity and number magnitude. Journal of Experimental Psychology: General. 1993; 122:371–396. DOI: 10.1037/0096-3445.122.3.371

Dehaene S, Cohen L, Sigman M, Vinckier F. The neural code for written words: a proposal. Trends in Cognitive Sciences. 2005; 9:335–341. [PubMed: 15951224]

Dobel C, Diesendruck G, Bolte J. How writing system and age influence spatial representations of actions. Psychological Science. 2007; 18:487–491. [PubMed: 17576259]

Dodd MD, Van der Stigchel S, Leghari MA, Fung G, Kingstone A. Attentional SNARC: There's something special about numbers (let us count the ways). Cognition. 2008; 108:810–818. DOI: 10.1016/j.cognition.2008.04.006 [PubMed: 18538756]

Drucker C, Brannon E. Rhesus monkeys map number onto space. Cognition. 2014; 132:57–67. DOI: 10.1016/j.cognition.2014.03.011 [PubMed: 24762923]

Ehri LC, Wilce LS. Movement into reading: Is the first stage of printed word learning visual or phonetic? Reading Research Quarterly. 1985; 20:163–179.

Fischer MH. Finger counting habits modulate spatial-numerical associations. Cortex. 2008; 44:386–392. DOI: 10.1016/j.cortex.2007.08.004 [PubMed: 18387569]

Fischer MH, Brugger P. When digits help digits: spatial–numerical associations point to finger counting as prime example of embodied cognition. Frontiers in Psychology. 2011; 2:41–47. DOI: 10.3389/fpsyg.2011.00260 [PubMed: 21738516]

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. Visualised numerals. Nature. 1880; 21:252–256.

Gevers W, Reynvoet B, Fias W. The mental representation of ordinal sequences is spatially organized. Cognition. 2003; 87:87–95.

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. DOI: 10.1016/S0010-9452(08)70938-9 [PubMed: 15174454]

Gunderson E, Ramirez G, Beilock S, Levine S. The relation between spatial skill and early number knowledge: The role of the linear number line. Developmental Psychology. 2012; 48:1229–1241. DOI: 10.1037/a0027433 [PubMed: 22390659]

Heilman K, Van Den Abell T. Right hemisphere dominance for attention: The mechanism underlying hemispheric asymmetries of inattention (neglect). Neurology. 1980; 30:327–327. [PubMed: 7189037]

Knudsen B, Fischer MH, Aschersleben G. Development of spatial preferences for counting and picture naming. Psychological Research. 2015; 79:939–949. DOI: 10.1007/s00426-014-0623-z [PubMed: 25326847]

Lindemann O, Alipour A, Fischer MH. Finger counting habits in middle eastern and western individuals: an online survey. Journal of Cross-Cultural Psychology. 2011; 42:566–578. DOI: 10.1177/0022022111406254

Logothetis N, Pauls J. Psychophysical and physiological evidence for viewer-centered object representations in the primate. Cerebral Cortex. 1995; 5:270–288. [PubMed: 7613082]

Lourenco SF, Longo MR. General magnitude representation in human infants. Psychological Science. 2010; 21:873–881. DOI: 10.1177/0956797610370158 [PubMed: 20431048]

Maass A, Russo A. Directional bias in the mental representation of spatial events: Nature or culture? Psychological Science. 2003; 14:296–301. [PubMed: 12807400]

Maass A, Suitner C, Nadhmi F. What drives the spatial agency bias? An Italian–Malagasy–Arabic comparison study. Journal of Experimental Psychology: General. 2014; 143:991–996. DOI: 10.1037/a0034989 [PubMed: 24219024]

Masonheimer P, Drum P, Ehri L. Does environmental print identification lead children into word reading? Journal of Reading Behavior. 1984; 16:257–271.

McCrink K, Opfer J. Development of spatial-numerical associations. Current Directions in Psychological Science. 2014; 23:439–445. DOI: 10.1177/0963721414549751 [PubMed: 26166955]

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. DOI: 10.1016/j.cogdev.2013.11.002 [PubMed: 24771964]

McCrink K, Shaki S. Culturally inconsistent spatial structure reduces learning. Acta Psychologica. 2016; 169:20–26. [PubMed: 27208418]

Moyer RS, Landauer TK. Time required for judgements of numerical inequality. Nature. 1967; 215:1519–1520. DOI: 10.1038/2151519a0 [PubMed: 6052760]

Nuerk H, Patro K, Cress U, Schild U, Friedrich C, Göbel S. How space-number associations may be created in preliterate children: six distinct mechanisms. Frontiers in Psychology. 2015; 6:215.doi: 10.3389/fpsyg.2015.00215 [PubMed: 25798116]

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. DOI: 10.1111/j.1467-7687.2009.00934.x [PubMed: 20712742]

Patro K, Fischer U, Nuerk H-C, Cress U. How to rapidly construct a spatial-numerical representation in preliterate children (at least temporarily). Developmental Science. 2015; doi: 10.1111/desc.12296

Patro K, Haman M. The spatial–numerical congruity effect in preschoolers. Journal of Experimental Child Psychology. 2012; 111:534–542. DOI: 10.1016/j.jecp.2011.09.006 [PubMed: 22153910]

Previtali P, de Hevia MD, Girelli L. Placing order in space: The SNARC effect in serial learning. Experimental Brain Research. 2010; 201:599–605. DOI: 10.1007/s00221-009-2063-3 [PubMed: 19888566]

Rashidi-Ranjbar N, Goudarzvand M, Jahangiri S, Brugger P, Loetscher T. No horizontal numerical mapping in a culture with mixed-reading habits. Frontiers in Human Neuroscience. 2014; :8.doi: 10.3389/fnhum.2014.00072 [PubMed: 24478674]

Rinaldi L, Gallucci M, Girelli L. Spatial-numerical consistency impacts on preschoolers' numerical representation: Children can count on both peripersonal and personal space. Cognitive Development. 2016; 37:9–17. DOI: 10.1016/j.cogdev.2015.10.006

Rodriguez ET, Tamis-LeMonda CS. Trajectories of the home learning environment across the first 5 years: Associations with children's vocabulary and literacy skills at prekindergarten. Child Development. 2011; 82:1058–1075. DOI: 10.1111/j.1467-8624.2011.01614.x [PubMed: 21679179]

Rugani R, de Hevia MD. Number-space associations without language: Evidence from preverbal human infants and non-human animal species. Psychonomic Bulletin and Review. (in press).

Rugani R, Kelly D, Szelest I, Regolin L, Vallortigara G. Is it only humans that count from left to right? Biology Letters. 2010; 6:290–292. DOI: 10.1098/rsbl.2009.0960 [PubMed: 20071393]

Rugani R, Vallortigara G, Priftis K, Regolin L. Number-space mapping in the newborn child resembles humans' mental number line. Science. 2015; 347:534–536. DOI: 10.1126/science.aaa1379 [PubMed: 25635096]

Shaki S, Fischer M. Removing spatial responses reveals spatial concepts - even in a culture with mixed reading habits. Frontiers in Human Neuroscience. 2014; :8.doi: 10.3389/fnhum.2014.00966 [PubMed: 24478674]

Shaki S, Fischer MH. Reading space into numbers–a cross-linguistic comparison of the SNARC effect. Cognition. 2008; 108:590–599. DOI: 10.1016/j.cognition.2008.04.001 [PubMed: 18514179]

Shaki S, Fischer MH, Göbel SM. Direction counts: a comparative study of spatially directional counting biases in cultures with different reading directions. Journal of Experimental Child Psychology. 2012; 112:275–281. DOI: 10.1016/j.jecp.2011.12.005 [PubMed: 22341408]

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. DOI: 10.3758/PBR.16.2.328 [PubMed: 19293102]

Share DL, Gur T. How reading begins: A study of preschoolers' print identification strategies. Cognition and Instruction. 1999; 17:177–213.

Treiman R, Cohen J, Mulqueeny K, Kessler B, Schechtman S. Young children's knowledge about printed names. Child Development. 2007; 78:1458–1471. [PubMed: 17883442]

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Tversky B, Kugelmass S, Winter A. Cross-cultural and developmental trends in graphic productions. Cognitive Psychology. 1991; 23:515–557. DOI: 10.1016/0010-0285(91)90005-9

Vallesi A, Weisblatt Y, Semenza C, Shaki S. Cultural modulations of space–time compatibility effects. Psychonomic Bulletin & Review. 2014; 21:666–669. DOI: 10.3758/s13423-013-0540-y [PubMed: 24163172]

Vallortigara G, Regolin L, Bortolomio G, Tommasi L. Lateral asymmetries due to preferences in eye use during visual discrimination learning in chicks. Behavioral Brain Research. 1996; 74:135–43.

Yates FA. The art of memory Chicago: University of Chicago Press; 1966

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; 5:165–190. DOI: 10.1163/1568537054068660

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. DOI: 10.1016/j.neuropsychologia.2005.10.025 [PubMed: 16356515]

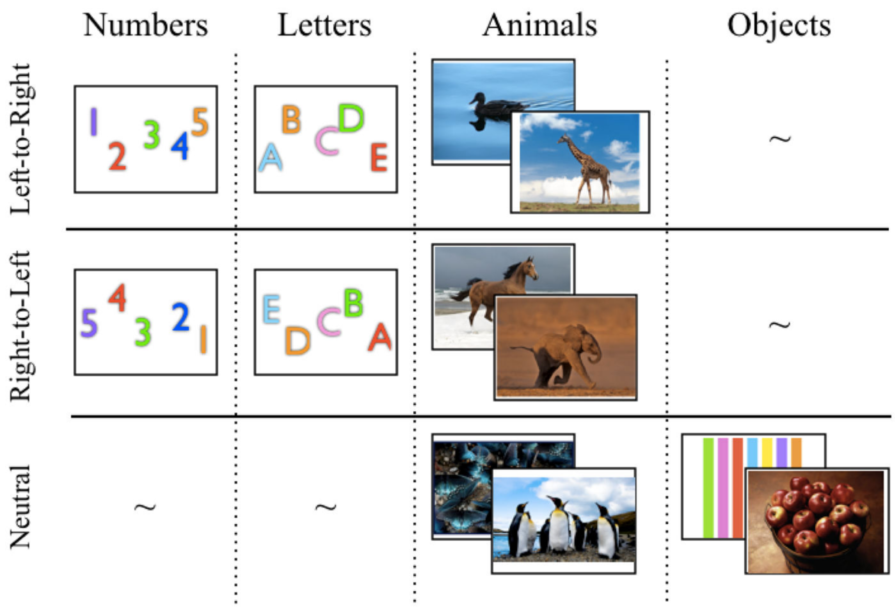

Figure 1.

Stimuli presented during the co-viewing task. The images were of a conventionally ordinal (numbers, letters) or non-ordinal (objects, animals) nature, oriented from left to right, right to left, or neutrally. The symbol ~ indicates there were no stimuli of that type and orientation combination.

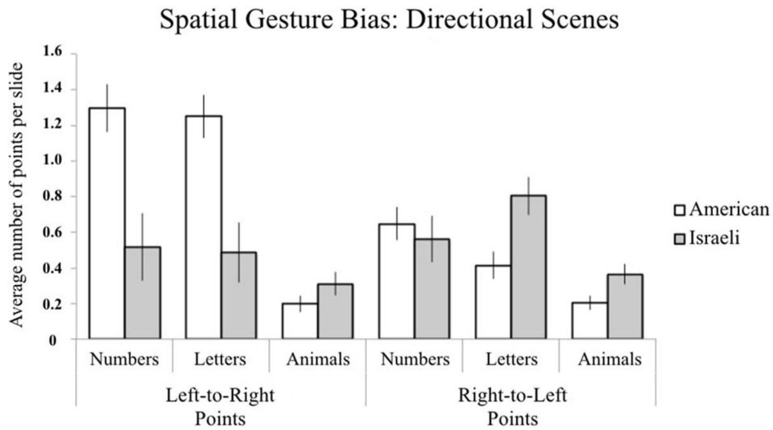

Figure 2.

Modulation of left-to-right and right-to-left structured points in the co-viewing task, collapsed over left-to-right or right-to-left orientation of the scene. The estimated marginal means are plotted a function of the type of stimulus and culture. Error bars represent +/− one *SEM*.

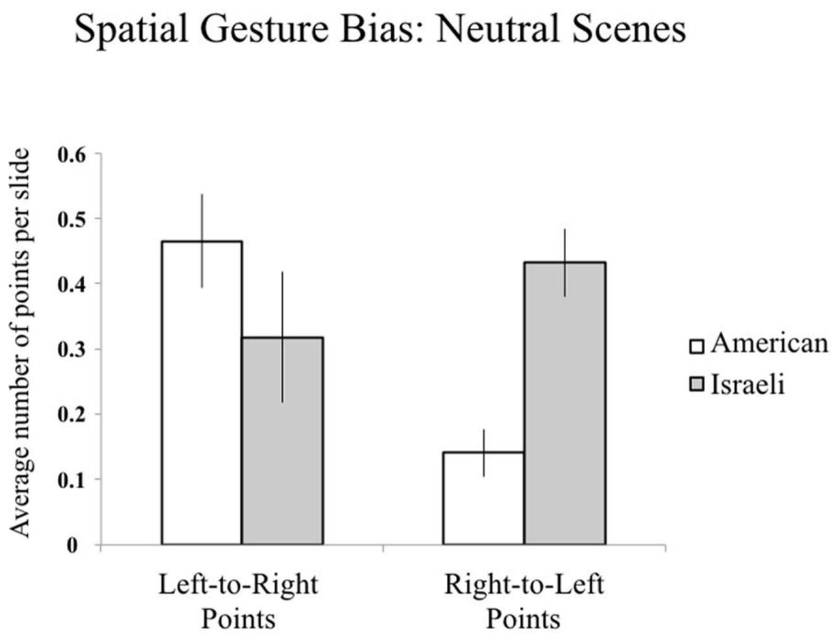

Figure 3.

Modulation of point type during the co-viewing task for neutrally structured, non-ordinal scenes, collapsed over stimuli type (objects, or animals.) Estimated marginal means are plotted. Error bars represent +/− one *SEM*.

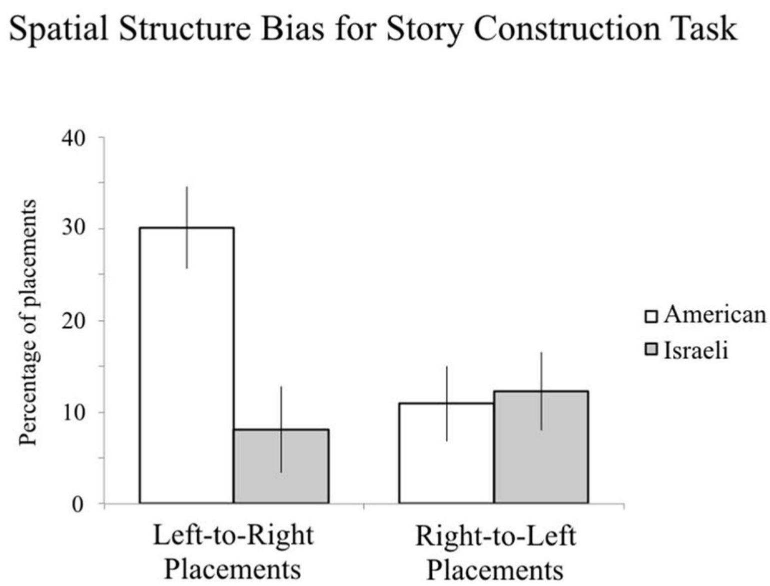

Figure 4.
Results from the story construction task. The percentage of placements is plotted for each horizontal spatial structure type (left-to-right or right-to-left), as a function of the dyad's culture. Error bars represent +/− one *SEM*.

Table 1

Characteristics of Participants

	Task 1: Co-Viewing		Task 2: Story Construction	
	American	**Israeli**	**American**	**Israeli**
Recruiting Timeframe	2011–2013	2014	2011–2013	2014
Number of Boy Toddlers	29	20	20	12
Number of Girl Toddlers	35	13	14	20
Mean Age (in months)	27	25	27	26
Age Range (in months)	14 – 36	12 – 37	16 – 36	12 – 37
Maternal Education[a, b]	4.4 out of 5	3.6 out of 5	4.3 out of 5	3.7 out of 5
Literacy Rate [c]	100%	100%	100%	100%
Bilingualism	31%	0%	35%	0%
Prevalence [b]				
Ethnic (Israel) or Racial (America) Background [d]	18% Asian, 15% Black, 50% White, 17% Other	90% Jewish, 5% Arabic, 5% Other [d]	18% Asian, 15% Black, 50% White, 17% Other	90% Jewish, 5% Arabic, 5% Other [d]

[a]As indicated on a scale ranging from 1 (No Education) to 3 (Some College) to 5 (Advanced Graduate Degree).

[b]This figure was calculated from a subset (~40%) of the sample who responded to a survey.

[c]Percentage of responding parents who said they could read well or very well.

[d]Value obtained from publicly available demographic information, and not directly from pool of participants.