The dynamic effect of reading direction habit on spatial asymmetry of image perception

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Exploration of images after stimulus onset is initially biased to the left. Here, we studied the causes of such an asymmetry and investigated effects of reading habits, text primes, and priming by systematically biased eye movements on this spatial bias in visual exploration. Bilinguals first read text primes with right-to-left (RTL) or left-to-right (LTR) reading directions and subsequently explored natural images. In Experiment 1, native RTL speakers showed a leftward free-viewing shift after reading LTR primes but a weaker rightward bias after reading RTL primes. This demonstrates that reading direction dynamically influences the spatial bias. However, native LTR speakers who learned an RTL language late in life showed a leftward bias after reading either LTR or RTL primes, which suggests the role of habit formation in the production of the spatial bias. In Experiment 2, LTR bilinguals showed a slightly enhanced leftward bias after reading LTR text primes in their second language. This might contribute to the differences of native RTL and LTR speakers observed in Experiment 1. In Experiment 3, LTR bilinguals read normal (LTR, habitual reading) and mirrored left-to-right (mLTR, nonhabitual reading) texts. We observed a strong leftward bias in both cases, indicating that the bias direction is influenced by habitual reading direction and is not secondary to the actual reading direction. This is confirmed in Experiment 4, in which LTR participants were asked to follow RTL and LTR moving dots in prior image presentation and showed no change in the normal spatial bias. In conclusion, the horizontal bias is a dynamic property and is modulated by habitual reading direction.

Introduction

Attention is an integral part of human cognition. The focus of attention is in continuous movement between a subset of available sensory stimuli (James, 1890). Such shifts in attention are performed by overt eye movements as well as covert attentional shifts. The mechanisms of these two processes correlate tightly (Rizzolatti, Riggio, Dascola, & Umiltá, 1987). Factors such as the characteristics of stimuli and task guide this process (Buswell, 1935; Yarbus, 1967). Many models of human attention focus on the former stimulus-dependent aspects and rest upon the concept of a low-level "saliency map" (Koch & Ullman, 1985). Furthermore, the task at hand exerts a strong influence and is interpreted in terms of goal-oriented behavior (Betz, Kietzmann, Wilming, & König, 2010; Itti & Koch, 2001; Rothkopf, Ballard, & Hayhoe, 2007; Tatler, Hayhoe, Land, & Ballard, 2011). In addition, eye movements display temporal organization and spatial biases that add to the stimulus- and task-dependent factors (Kollmorgen, Nortmann, Schröder, & König, 2010). Moreover, eye movements have an influence on the oculomotor reflexes that is important for stabilizing the images and in shifting the gaze (Einhäuser et al., 2009). Finally, eye movements contribute to causal

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recognition following ambiguous object presentation (Kietzmann, Geuter, & König, 2011).

A prominent aspect of viewing spatial biases is the tendency to look at the center of visual stimuli during the free exploration of images (c.f. Tatler, 2007; Tseng, Carmi, Cameron, Munoz, & Itti, 2009). This central spatial bias was examined and proved to be rather a general effect. It is neither a result of a motoric system effect nor of a photographic bias by centering the objects' features toward the center of the images (Tatler, 2007).

Furthermore, there is some evidence for an asymmetric horizontal spatial bias. Eye-tracking studies of face perception have shown that perceptual biases are often accompanied by an initial exploratory bias to the left hemiface (from the viewer's perspective) (Barton, Radcliffe, Cherkasova, Edelman, & Intriligator, 2006; Butler & Harvey, 2005; Guo, Meints, Hall, Hall, & Mills, 2009; Guo, Tunnicliffe, & Roebuck, 2010; Leonards & Scott-Samuel, 2005; Mertens, Siegmund, & Grüsser, 1993; Phillips & David, 1997). This bias of spatial attention not only exists in adults, but also in 6-month-old infants. It is also found in other animals: Monkeys shift their gaze leftward when exploring humans, animal faces, and objects, and domestic dogs display the leftward bias only toward human faces (Guo et al., 2009). In addition to this viewing bias, when confronted with chimeric faces that are composed of two hemifaces showing different attributes and in the absence of eye movements, both children and adults show a congruent perceptual bias to the left side of the screen (Levine & Levy, 1986). Physiological studies observed a positive correlation between the magnitude of the left visual field bias and the asymmetric activation of the fusiform face area (Yovel, Tambini, & Brandman, 2008). Therefore, these and other exploratory and perceptual biases have been linked to the profile of hemispheric lateralization of the cortical areas involved in the processing of faces.

Healthy human subjects also display a visuospatial attentional bias by the tendency to bisect lines toward the left in a line-bisection task (Bowers & Heilman, 1980). Similar to the hemispheric asymmetry for face processing, this "pseudoneglect" phenomenon has been associated with the lateralization of the attention system, with which both right and left hemispheres are involved in goal-directed attention, but only the right hemisphere is involved in the detection of behavior-relevant salient or unexpected events (Corbetta & Shulman, 2002).

During unrestricted free viewing of natural images, similar biases appear (Calen Walshe & Nuthmann, 2014; Engmann et al., 2009; Ossandón, König, & Heed, 2015; Ossandón, Onat, & König, 2014). These studies tested the spatial and temporal features of overt attention and the influence of tasks during visual exploration of static images. In these experiments, right-handed volunteers participated in an eye-tracking experiment and freely explored complex scenes. The average position for the first fixations started from the left side of the images from the participant's perspective and then shifted toward the right. Interestingly, this finding was not observed among a left-handed group, indicating that hemispheric asymmetries related to handedness are correlated with the lateralization of the attentional network (Ossandón et al., 2014). These results are in agreement with other studies of gaze bias in the viewing of complex images (Dickinson & Intraub, 2009; Engmann et al., 2009; Nuthmann & Matthias, 2014). Altogether, the presence of a spatial bias in face exploration and perception, a bias as in the line-bisection tasks, and a spatial bias during early exploration of scenes indicate the presence of a rather general visuospatial bias effect.

Moreover, this general spatial bias can also be modulated by other sensory modalities, such as auditory, visual, and irrelevant tactile stimulation (c.f. Kennett, Spence, & Driver, 2002; McDonald, Teder-Sälejärvi, & Hillyard, 2000; Ossandón, Kónig, & Heed, 2015). For instance, in a recent study of free viewing exploration, tactile stimulation was introduced to the left, the right, or to both hands in either a crossed hands or uncrossed hands position. The results showed a significant effect of the tactile stimulation to manipulate the spatial bias when it was introduced to the ipsilateral side with both crossed and uncrossed hands. This provides evidence that the crossmodal influence acts in an allocentric reference from—and not to—the location of the tactile stimulation on the body (Ossandón et al., 2015).

The cause of this general leftward spatial bias in healthy subjects is still unresolved. As described above, the bias has been associated with the lateralization of specific modules of visual processing and/or with the lateralization of the attentional cortical network. The asymmetry of the attentional network was first encountered in the study of hemispatial neglect patients, most of which present a pronounced attentional deficit over the left visual space secondary to a right hemisphere lesion and much less or not at all vice versa (c.f. Corbetta & Shulman, 2011). As demonstrated in neuroimaging studies, this pattern of deficits in patients is compatible with the patterns in brain activation of healthy subjects. These show a bias to right hemisphere activity in target detection tasks, unattended locations tasks, and changes in stimulus feature tasks (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000; Corbetta, Kincade, & Shulman, 2002). Functional and structural neuroimaging studies demonstrate that the attentional network covers a set of dorsal frontoparietal areas in both hemispheres, plus the right temporoparietal junction for stimulus-driven shifts of attention (Shulman et al., 2010). Furthermore, the superior longitudinal fasciculus, connecting frontal and parietal areas, is larger in volume in the right hemisphere than in the left, and its volume is positively correlated with measures of bias (de Schotten et al., 2011). In summary, a fair amount of work gives evidence that the lateralization of the attentional network is the major cause of viewing, perceptual, and motor spatial biases.

However, there might be alternative explanations. Here, we consider the effect of reading direction habits. Given the ever-present use of text in our daily lives, the systematic bias of reading direction might result not only in biases for written content, but also a general motor-priming effect. We will consider in a series of experiments the role of reading habits and motor priming in the production of visuospatial bias. Specifically, we address the following questions: (a) Can the horizontal spatial bias be influenced dynamically by the habitual reading direction? (b) If there is an effect, is it due to the bilingualism? (c) Do we find the same effect after reading nonhabitual texts? (d) Can we modulate the natural spatial bias by introducing moving-dot primes?

Experiment 1a and b: The influence of reading direction on the spatial bias

Introduction

Although the leftward spatial bias is present in many different tasks, there is nevertheless also a concern when studying horizontal biases that they might be secondary or modulated by factors such as reading direction. Indeed, an influence of reading direction has been observed in a multitude of tasks, such as line bisection, chimeric faces, inhibition or return, spatial numeric association response code (SNARC), and perceptual span tests.

Reading habits from right to left (RTL) have an influence in line bisection tasks, and whereas left-to-right (LTR) readers usually show a bias to the left when asked to bisect a line (Bowers & Heilman, 1980), RTL readers show an opposite effect of bias to the right (Chokron & Imbert, 1993; Rashidi-Ranjbar, Goudarzvand, Jahangiri, Brugger, & Loetscher, 2014). On the other hand, performing a passive line bisection task, in which participants have to stop a moving marker on a monitor when it reaches the midpoint of a line, both RTL and LTR groups bisected the line toward the left with no significant difference in mean scores (Nicholls & Roberts, 2002).

Another example of the role of reading habits in attentional biases exists when evaluating chimeric faces. Two studies used these stimuli to test a variety of groups of subjects (LTR readers, LTR and RTL readers, illiterates, left-handed LTR readers, and left-handed RTL readers). The first study showed that the strongest bias to report the content presented at the left hemiface (from the participant's perspective) was among right-handed LTR readers, and the weakest effect was among right-handed RTL readers (Heath, Rouhana, & Ghanem, 2005; Vaid & Singh, 1989). A similar effect of reading habits was noticed in a second study with chimeric faces involving groups of native Hebrew speakers and a group of Arabic-Hebrew speakers (both groups' languages are read from RTL), in which no priority for the leftward spatial bias was noticed (Eviatar, 1997).

Reading habits also modulate biases on the phenomena of inhibition of return. In a study by Spalek and Hammad (2004) involving English-speaking subjects, it was shown that inhibition of return was smaller when the cue was projected to the right visual field. This contrasts a subsequent study, in which they showed that Arabic readers demonstrate the opposite effect to English readers, confirming the effect of reading habit direction in attentional bias (Spalek & Hammad, 2005).

The effect of reading direction is also seen in the research on the SNARC effect among RTL readers. In SNARC studies, it was found that English speakers mentally spatialize small numbers to the left side and larger numbers to the right side (Dehaene, Bossini, & Giraux, 1993). Two studies among Arabic readers demonstrated a reverse SNARC effect (Shaki, Fischer, & Petrusic, 2009; Zebian, 2005).

Similar results were observed in a study investigating the perceptual bias of LTR and RTL readers in a grayscale task. Here, the stimuli consisted of identical gradient pairs; one bar had the dark side toward the right, and the second bar had the dark side toward the left. Participants were asked to choose the darker bar (Nicholls, Bradshaw, & Mattingley, 1999). In one study, both RTL and LTR readers showed a bias to report a darker gradient with the dark edge located to the left (Nicholls & Roberts, 2002). However, in another experiment with a larger sample of subjects, RTL readers showed a weaker leftward bias in comparison to LTR readers (Friedrich & Elias, 2014). Furthermore, comparing viewing behavior over images that have a different direction of illumination, Smith and Elias (2013) reported that LTR readers fixated more to the left side of the images in contrast to RTL readers fixating more to the right. Jointly, these studies

	Experiments				
	1a	1b	2	3	4
No. of bilinguals	39	11	23	19	48
First language	Arabic/Urdu/Persian	German/English	German	English/German	German/English
Second language	German/English	Urdu/Arabic/Persian	English	English/German	German/English
First stimulus	RTL texts	LTR texts	LTR texts	LTR texts	LTR moving dots
Second stimulus	LTR texts	RTL texts	LTR texts	mLTR texts	RTL moving dots

Table 1. Number of participants in each experiment, their first and second language, and type of stimuli.

are consistent with an influence of reading direction of the native language on perception and attention.

All the previously mentioned studies investigated the effect of reading direction as a static factor. That is, the independent variable investigated was the reading direction in the native language, but no actual reading was required in these experiments. A few studies explored the dynamic properties of the spatial bias. For example, in one study, the spatial bias when exploring images was studied in three different conditions: normal image viewing, a right-gaze-contingent window, and a left-gaze-contingent window. The results showed a flexibility of the participants to make saccades in the same direction of the contingent window applied (Foulsham, Gray, Nasiopoulos, & Kingstone, 2013). In another study, bilinguals who can read RTL and LTR texts were instructed to read RTL or LTR sentences that were enclosed in a window mask. This mask could be symmetrical or asymmetrical and moved simultaneously with the eye, allowing measuring of perceptual span. When subjects read LTR texts, the perceptual span became more pronounced toward the right, and when the subjects read RTL texts, toward the left (Jordan et al., 2013). This test produced a similar effect when performed on Hebrew readers (Pollatsek, Bolozky, Well, & Rayner, 1981) and on Urdu readers (Paterson et al., 2014). Finally, in the SNARC task, Hebrew students who were native in Russian were tested in two conditions: after reading Russian texts and after reading Hebrew texts. They showed the SNARC effect after reading Russian texts, but the effect was reduced after reading Hebrew texts (Shaki & Fischer, 2008). In summary, it seems that there is not only a static effect of the direction of reading habits on perceptual biases, but that the act of reading prior to a given test can modify biases.

Therefore, Experiment 1 tested the dynamic role of reading direction. Subjects read texts in different languages with either RTL or LTR reading direction. Directly afterward, we characterized the spatial bias in a free visual exploration of complex scenes. We tested two groups: one with native RTL readers who have mastered a second LTR language and one with native LTR readers who learned an RTL language.

Methods

Participants

Informed consent was obtained for all participants in the following experiments. Experimental procedures conformed to the Declaration of Helsinki and national guidelines. All participants were right-handed with normal or corrected-to-normal vision and participated either for money (5–15 euros) or study credits. They performed a handedness test (Edinburgh Test; Oldfield, 1971), vision accuracy test, and dominant eye test (Miles Test; Miles, 1929).

In Experiment 1a, 39 bilinguals (31 males and eight females; age range 21–60 years) that were native in an RTL language (Arabic, Urdu, or Persian) and fluent in a secondary LTR language (German and/or English) participated. In Experiment 1b, 10 Germans and one Pakistani (seven males and four females; age range 14–30 years) who were native in an LTR language and who learned to read and write an RTL language later in life, either in school or from one of their parents, participated. Table 1 summarizes the number of bilinguals in each experiment, the different languages they speak, and the different types of stimuli used for each experiment.

Stimuli

We used two different types of visual stimuli: images and texts. The images were selected from three different categories: urban scenes, natural scenes, and artificial fractal images. The urban category included 60 high-resolution photos of public spaces around Zürich (taken with a Nikon D2Z, Japan) (Onat, Açık, Schumann, & König, 2014). The natural category included 60 scenes from the calibrated color image database (Olmos & Kingdom, 2004) depicting outdoor scenes without man-made objects. The artificial fractal category included 60 self-similar computer-generated shapes with second-order statistics similar to real-world images from three different web databases: Chaotic N-Space Network (http://www.cnspace.net/html/fractals.html), Elena's Fractal Gallery (http://www.elena-fractals.it/ in http://web.archive.org), and Maria's Fractal Explorer Gallery (http://www.mariagrist.

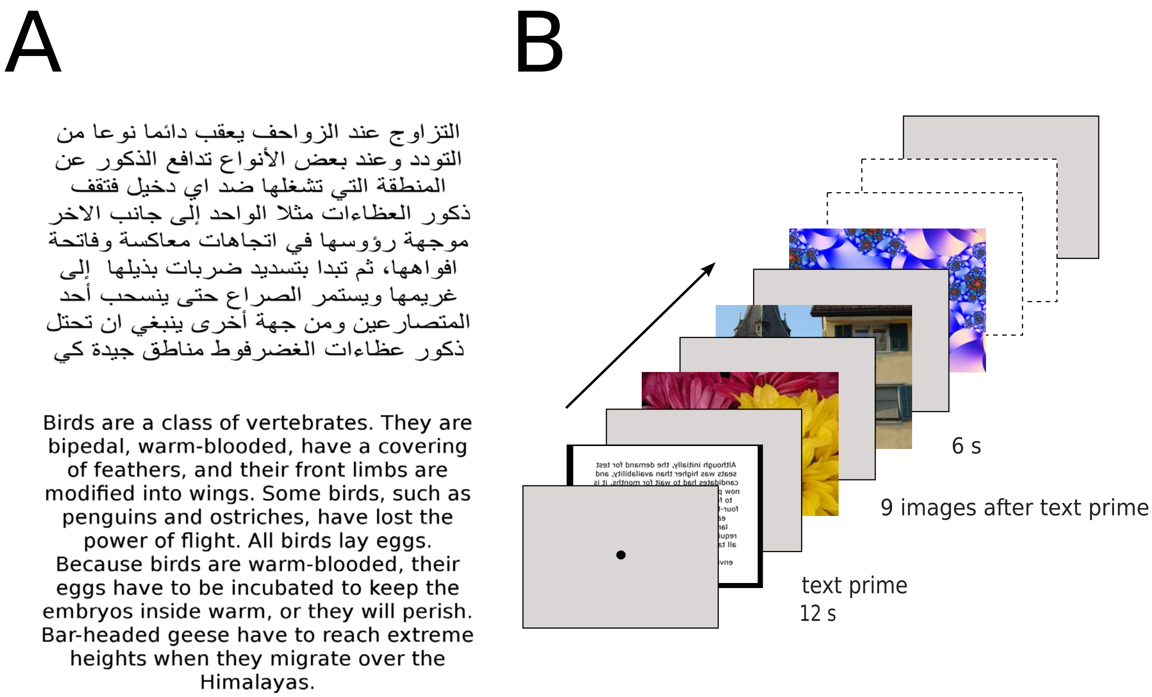

Figure 1. (A) Example of different language texts used as primes for Experiment 1. The upper text is an RTL Arabic text, and the lower text is an LTR English text. (B) An experimental block; before each presentation, a drift correction point appears in the middle of the screen. The block started with presentation of a text prime for 12 s, followed by nine images from all categories (naturals, urban, and fractals). Each image was presented for 6 s.

net/fegal). We presented the images in either original or mirrored condition to eliminate bias secondary to image content distribution (Ossandón et al., 2014). Text written in languages of either RTL or LTR reading direction (Arabic, Urdu, or Persian and German or English, respectively) served as primes before each set of pictures. We chose them from neutral excerpts of Wikipedia the Free Encyclopedia, the British Broadcasting Corporation, and the German newspapers *die Zeit* and *Süddeutsche Zeitung*. The stimuli were viewed on a 21-in. CRT monitor (Samsung SyncMaster 1100 DF, Samsung Electronics, Suwon, South Korea) at a refresh rate of 85 Hz and a resolution of 1280 × 960 pixels.

Experimental setup

A fixation point in the middle of a gray screen preceded each stimulus presentation. A complete experimental trial included a text stimulus as a prime, followed by a total of nine test pictures (Figure 1) that were presented in either original or mirrored condition. Five sequences of primes of the same language and test stimuli constituted one experimental block. A total of 20 primes with 180 test images were presented in four blocks. The sequence was balanced with respect to first and second language across participants.

Procedure

All experiments were performed in the eye-tracking laboratory at the Institute of Cognitive Science of the University of Osnabrück in a windowless room with lights off. All the participants completed questionnaires regarding their native and second language proficiencies and the age at which they learned to read. During the experiments, the participants set comfortably 80 cm away from the monitor. The participants in Experiment 1a and b were presented with two types of text stimuli: LTR texts and RTL texts. For the prime stimuli, we instructed the participants to read the texts silently and to avoid moving the head. We also instructed them to read in their normal reading speed and to continue reading until the texts disappeared or until they finished reading. The participants were aware that there were no questions about the texts after the experiment was finished. Afterward, images were presented once subjects had fixated on a fixation point that appeared in the middle of the screen. We randomized the order of presentation of the images and articles across all subjects. All pictures shown in original condition for one participant appeared in the mirrored condition for another participant. The whole experiment lasted between 30 and 40 min in total. Eye movements were recorded by a head-mounted video-based eye-tracker system with binocular pupil tracking at 500 Hz

(EyeLink II, SR Research Ltd., Mississauga, ON, Canada).

Data analysis

In this study, we were interested in the horizontal position of fixation points. We used custom-made Matlab and Python scripts to extract, analyze, and visualize the data. In the following paragraphs, we explain data analysis in detail.

Fixation density maps

Fixation density maps were created to visualize the global effect of reading direction. The spatial distribution of fixation points over the stimuli was transformed to a probability distribution. To avoid binning artifacts, the distribution was smoothed using a convolution with a circular 2-D Gaussian kernel of 0.5° full width at half maximum. The resulting heat maps show bright and dark colors. The brighter the color, the higher density of fixation points on a specific stimulus. They are distributed in different spots that represent the location of the fixation points on the respective stimulus.

Time course diagrams

To investigate how the bias developed over time, we created time course diagrams. See Ossandón et al. (2014) for a full description of how these diagrams are constructed. In brief, the horizontal coordinate of fixation points were extracted from viewing original and mirrored images, separately. Then, they were placed in a matrix in the exact horizontal position order. The matrix of fixation points from mirrored images was flipped. After that, these matrices were convoluted with spatial and temporal filters. Spatial (Gaussian kernel of full width at half maximum = 2°) and temporal filters (Gaussian kernel of full width at half maximum = 20 ms) were applied to reduce the amount of high-frequency noise on the images. After smoothing the data, flipped mirrored image matrices were subtracted from the original image matrices to obtain the difference in bias as the function of time. Positive values were presented in red colors, indicating the bias to the indicated position in the original images, and negative values were presented in blue colors, indicating the bias in the indicated position in the mirrored images.

The difference between left and right horizontal coordinates of fixation points

For each text prime condition (LTR or RTL) and time interval (1-s width, equally spaced from 0 to 6 s), the difference between the left and right coordinates of fixation points were calculated after pooling across all subjects. For each original image, the horizontal position of the fixations right to the center of the screen were added to the horizontal position of the fixations left to the center of the screen for the mirrored image. After that, the horizontal fixation points from the left side were added to the horizontal fixation points from the right side of the mirrored ones. Then, the results of the two summations were subtracted from each other, divided by the total number of horizontal fixation points, and multiplied by 100%. This result represents a fraction of the difference between left and right coordinates of fixation points.

Statistical analysis

The data used for statistical analysis were the values of the difference between fixation points in the left and right half of the images. These data were distributed in 12 groups based on two independent variables: text prime variables (two levels) and time variables (six levels). We analyzed the effect of time and the effect of text prime separately. In addition, we tested the interaction effect between time and prime (Prime × Time) by two-way repeated measures ANOVA. We checked normality with the D'Agostino-Pearson test and sphericity with Mauchly's test. All the groups were tested for normality. When it was violated, we corrected it through outlier removal by using the outlier labeling rule (Tukey, 1977).

Results

In Experiment 1a, we investigated the effect of reading direction habit in bilingual speakers of a native RTL language (Urdu, Persian, or Arabic) and a secondary LTR language (English or German). In both cases, participants fixated more at the beginning of each sentence (Figure 2A), and in general, they could read most of the texts written in their native language. In contrast, for the texts in the second language, they fixated mostly in the upper half of the texts. This effect is likely due to higher fluency in their native language compared to the secondary language (Pollatsek et al., 1981). The time course diagrams (Figure 2B, C) show an early rightward bias after reading RTL text primes in the exploration of complex scenes. In contrast, we observed an early leftward bias of fixation points after reading LTR texts.

Two-way repeated-measures ANOVA within subjects revealed a significant main effect of prime, $F(1, 175) = 17.4$, $p < 0.001$. The factor time was not significant, $F(5, 875) = 1.6$, $p \sim 0.15$. However, we

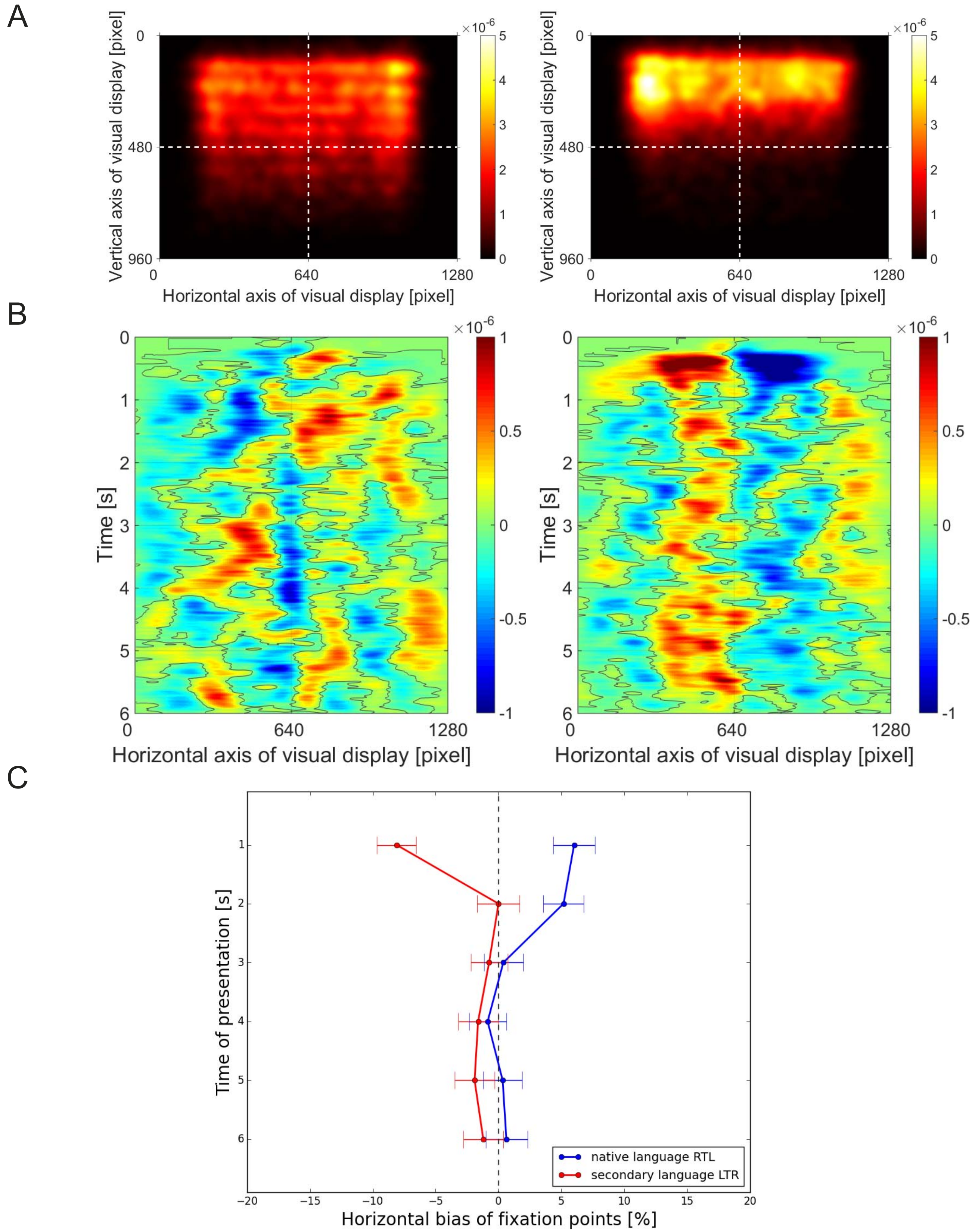

Figure 2. Results of Experiment 1a. (A) Fixation density maps during reading the text prime in the RTL condition (native language, left panel) and the LTR condition (second language, right panel). (B) Time course diagrams for the horizontal position of fixation points during free exploration of all test images presented after RTL text primes (left panel) and LTR text primes (right panel). (C) The horizontal spatial bias of fixations (mean $\pm$ *SEM*). Positive values represent a rightward spatial bias, and negative values represent a leftward spatial bias.

Prime 1 × Prime 2	t	df	Significance (two-tailed)
Time 1 × Time 1	−6.320	175	0.000*
Time 2 × Time 2	−2.241	175	0.026
Time 3 × Time 3	−0.549	175	0.584
Time 4 × Time 4	−0.361	175	0.718
Time 5 × Time 5	−0.957	175	0.340
Time 6 × Time 6	−0.804	175	0.423

Table 2. Paired-samples test (2 × 6) for Experiment 1 for all participants. *Notes*: $*p < 0.05$, statistically significant effect.

observed a statistically significant interaction of prime and time, $F(5, 875) = 5.5$, $p < 0.001$.

To see which time bin contributes to the significant effect, we performed paired t tests for different data subsets. We found a statistically significant effect between LTR text prime and RTL text prime only during the first second after onset of the stimuli, $t(175) = -6.320$, $p < 0.001$ (Table 2). This result demonstrates that reading a text modulates the direction and degree of spatial bias during early exploration of subsequent test images.

Experiment 1b complements this investigation by studying the effect of reading direction habit among bilinguals with an LTR language as a primary language and an RTL language as a secondary language. Participants in Experiment 1b were native LTR speakers who learned to read and write an RTL language later in life. Upon presentation of the text primes in their native language (LTR), participants read almost the entirety of the texts in the LTR primes (Figure 3A, left). In contrast, when reading texts in their second language (RTL), they showed marked difficulty in reading the texts and fixated mainly on the first two lines of the texts (Figure 3A, right). This difference demonstrates the increased effort of these participants when reading the second language. Upon exploration of the test images, participants fixated on the left part of the stimuli more often after LTR primes as well as after RTL primes (Figure 3B, C). For the trials, after LTR texts and in the first second after the trial started, there was approximately a 20% bias toward the left side of the images. Then, the bias turned to the middle of the screen, then to the right, and then it returned to the middle of the screen. After reading RTL texts, in the first second after stimulus presentation the bias started at about 10% on the left side of the images and then shifted back and forth to the right of the images and toward the middle.

Testing the difference in the laterality of the fixation points, a two-way repeated-measures ANOVA showed no significant effect of prime, $F(1, 70) = 0.100$, $p = 0.753$, but did show a main effect of time, $F(5, 350) = 4.153$, $p = 0.001$. Furthermore, no significant interaction between prime and time, $F(5, 350) = 1.198$, $p = 0.310$, was observed. Thus, contrary to our expectations, based on Experiment 1a, we did not observe a significant modulation of spatial bias by the reading direction of the text prime.

Discussion

After reading an RTL or LTR text prime, native RTL readers showed a significant rightward or leftward bias in subsequent visual exploration. This result is congruent with the modulation by direction of reading in other tasks (line bisection, inhibition of return, grayscale gradient bar, SNARC effect, and perceptual span tests). Furthermore, it demonstrates that the spatial bias can be dynamically modulated by text primes of appropriate reading direction.

It is believed that reading direction affects encoding information spatially, which can be noticed in different cognitive tasks (Göbel, Shaki, & Fischer, 2011). However, other behaviors that do not require visuospatial attention also are affected by the reading direction. For instance, finger counting, which is a universal act that starts early in development (around 3 years old), varies across cultures, and it is assumed that reading direction is an important factor (Göbel et al., 2011). However, other authors emphasize the role of culture and discuss multiple encoding schemas (Lindemann, Alipour, & Fischer, 2011). In an online survey across Persians and Western participants, the majority of the Western group stated that they start finger counting with their left hand, and nearly all of them referred to their thumb as number one. In contrast, most of the Persians stated that they start finger counting with their right hand and referred to their little finger as number one (Lindemann et al., 2011). In the spatial direction counting process, the effect of pure RTL language (in which numbers and words are written RTL) and a mixed RTL language (in which words are written RTL but numbers are written LTR) has been observed. In a study among preschoolers and scholars (native English speakers, native Hebrew speakers, and native Arabic speakers), they were instructed to count coins presented to them in a landscape format loudly while touching them. The British preschoolers preferred to start counting LTR, and the preference increased among the British scholars. The opposite effect was noticed with the Arabic preschoolers because they preferred counting RTL, and the effect increased among scholars. The Hebrew preschoolers mainly counted RTL, but the effect decreased among scholars, which could be due to the mixed Hebrew language (Shaki, Fischer, & Göbel, 2010). These experiments show that the acquisition of a first reading direction habit is not only an affective factor on the visuospatial attention system as is the case

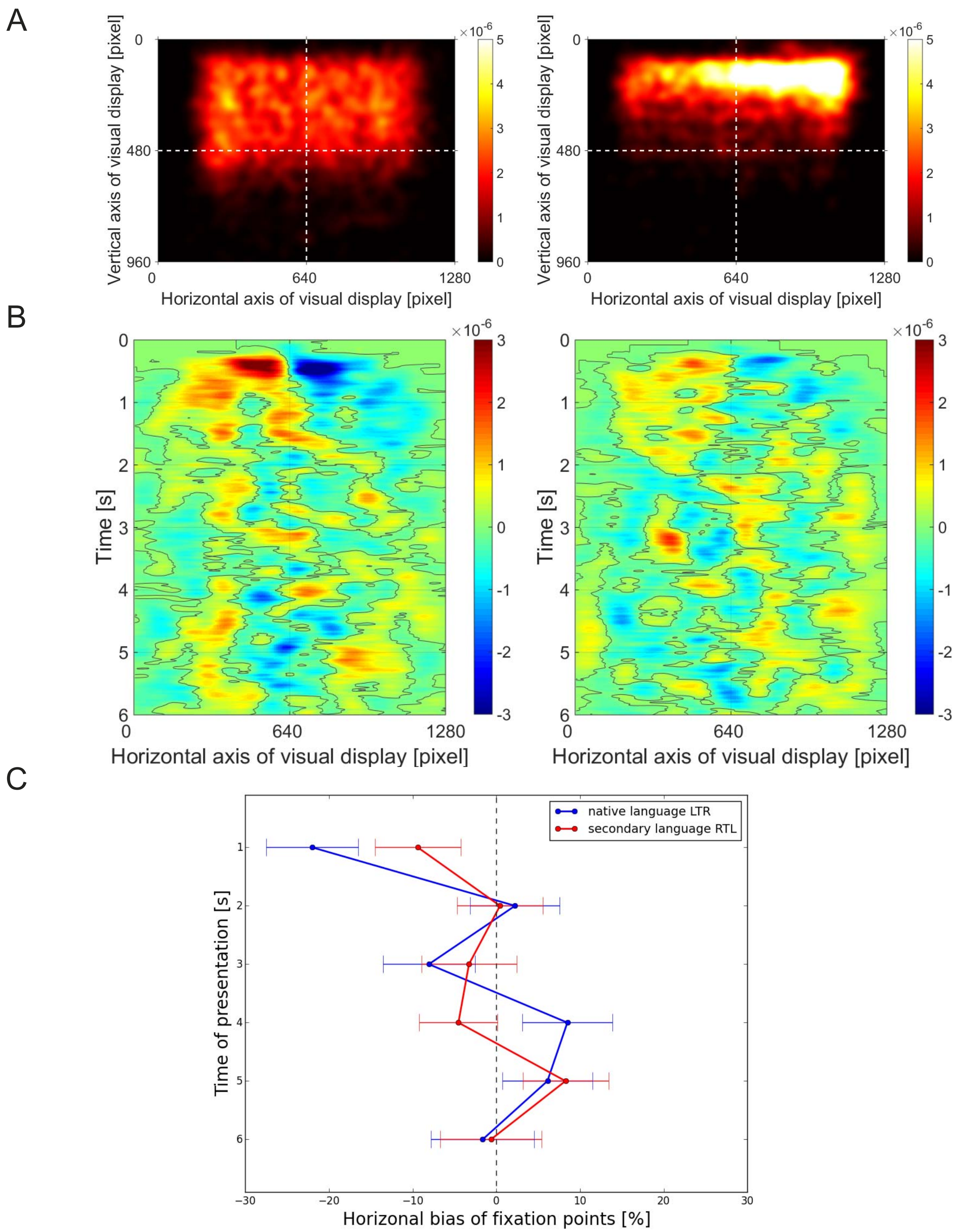

Figure 3. Results of Experiment 1b. (A) Fixation density maps during reading the text prime in the LTR condition (native language, left panel) and the RTL condition (second language, right panel). (B) Time course diagrams for the horizontal position of fixation points during free exploration of all test images presented after LTR text primes (left panel) and RTL text primes (right panel). (C) The horizontal spatial bias of fixations (mean ± *SEM*). The positive values represent the rightward bias, and the negative values represent the leftward bias.

of our experiment, but also on mental representation of numbers (Göbel et al., 2011).

However, we observed that native LTR readers who learned RTL languages showed a leftward bias toward the images after reading LTR primes and a reduced leftward bias after reading RTL text primes. The difference between these two biases, however, did not reach significance. How can we understand the difference in results of these two experiments? For that purpose, we analyzed the questionnaires and focused on the second-language proficiency as stated by the participants' self-report. The participants rated their second language on a scale ranging from poor to excellent. Interestingly, six out of 11 subjects stated that they are poor (the lowest possible rating) in their ability to read RTL texts. Furthermore, this is in line with their focus on the very first lines when reading the text primes. Because poor reading skills are due to insufficient practice, slow automaticity, and speed of word recognition (Cunningham & Stanovich, 1997), we speculate that the poorly skilled RTL readers of Experiment 1b had not established a habit of RTL reading due to less practicing compared to most of the highly skilled RTL readers in Experiment 1a and b. Presently, the limited group size and difficulties in recruiting local native LTR readers with high proficiency in reading an RTL language prohibit a test of this speculation.

Experiment 2: Primary versus secondary language effect on the horizontal spatial bias

Introduction

One of the pillars of neurolinguistics is the localization of language processing areas in the Broca's area and Wernicke's area of the left hemisphere (Friederici, 2011; Graves, 1997). This neural network dedicated to linguistic processing has been shown to be universal across cultures. For example, while performing a semantic task and measuring the blood oxygen level-dependent signal, Chinese individuals and Europeans expressed nearly identical cortical activation patterns (Nakamura et al., 2012). Yet investigating processing of native and second languages by fMRI scans reveals minor differences. For instance, the patterns of activity in Broca's area differ between processing the native language or a second language learned in adulthood. In contrast, in cases in which the second language was learned in childhood, the patterns of activation were identical (Kim, Relkin, Lee, & Hirsch, 1997). These differences in cortical processing raise the question of whether the spatial bias in visual exploration after reading an RTL or LTR text reported above is influenced by the language being native or learned later in life, respectively. For this purpose, in Experiment 2, we investigated native LTR readers who have mastered a second language that is equally read in the LTR direction.

Methods

Participants

The participants for Experiment 2 were bilinguals who speak at least two LTR languages. All of them mastered German and English. Twenty-three participants were recruited (13 males and 10 females, age range 18–27 years).

Stimuli

In contrast to Experiment 1, here the text primes were presented in two languages, German and English, both in the LTR reading direction. The visual stimuli shown after the text primes were identical to Experiment 1. The experimental setup and the data analysis were also identical to Experiment 1.

Results

During reading in their native language, participants covered nearly the whole text (Figure 4A, left panel). While reading the secondary language text prime, fixations were more restricted to the beginning of the lines and the upper part of the text (Figure 4A, right panel). We interpret this as a consequence of a reduced reading rate and a slightly increased effort.

In exploring the test images, participants initially fixated more toward the left after LTR text primes in both their native language and their second language (Figure 4B). After a few seconds, this effect was reversed, and a small bias to the right emerged (Figure 4C).

The statistical evaluation revealed that sphericity was violated for the factor of time, $\chi^2(14) = 40.200$, $p < 0.001$, and for the interaction between prime and time, $\chi^2(14) = 43.568$, $p < 0.001$; therefore, we corrected degrees of freedom using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.915$ and 0.913, respectively).

Two-way repeated-measures ANOVA revealed the main effect of prime, $F(1, 165) = 4.953$, $p = 0.027$. Further, Cohen's effect size value ($d = 0.097$) suggested a weak practical significance. Moreover, there was a statistically significant main effect of time, $F(4.575, 754) = 100.875$, $p < 0.001$, that can be explained by the dramatic shift in gaze direction after the first second in comparison with the remaining trial duration. The

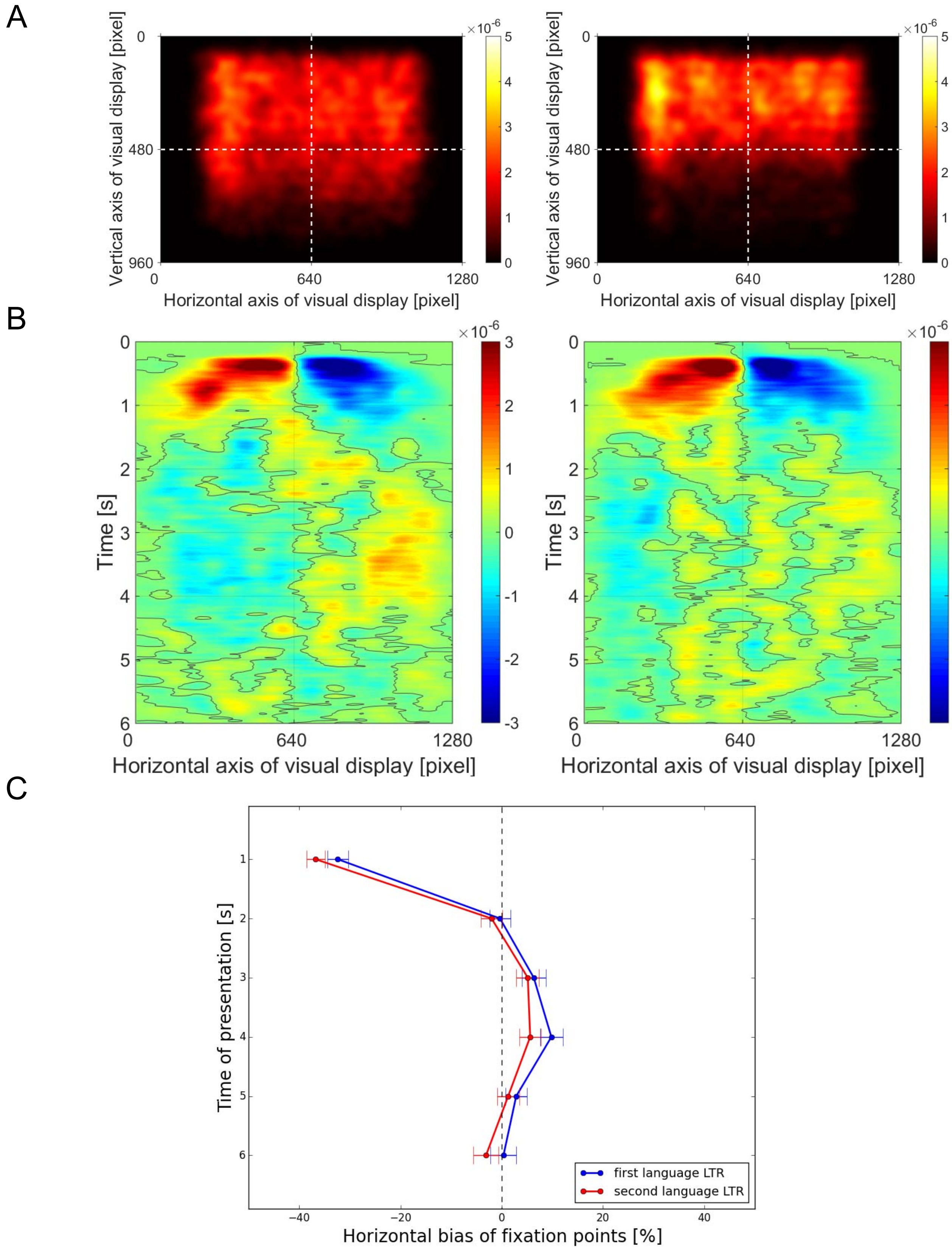

Figure 4. Results of Experiment 2. (A) Fixation density maps of text stimuli in native language (LTR, left panel) and secondary language (LTR, right panel). (B) Time course diagrams for the horizontal position of fixation points during free exploration of all test images presented after native language primes (left panel) and secondary language primes (right panel). (C) The horizontal spatial bias of fixations (mean ± *SEM*). The positive values represent the rightward bias, and the negative values represent the leftward bias.

interaction of prime and time was not significant, $F(4.564, 753) = 0.199$, $p = 0.954$.

Discussion

We designed Experiment 2 to compare two LTR languages and control the effect of native versus secondary language. It revealed a small but significant effect: The spatial bias is larger after a second language prime as compared to the native language. Subjects in Experiment 1a displayed a small reversed spatial bias in their native RTL language and a large left bias in their second LTR language. The systematic effect of native versus second language might have contributed to this big difference. Experiment 1b, in contrast, displayed a notable leftward spatial bias after reading text primes in their native LTR language and only a slightly (nonsignificantly) smaller spatial bias after reading text primes in their second RTL language. Thus, the contribution of being a second language to the leftward bias in this case likely worked against the effect of an RTL text prime and, thus, reduces the differences between the two experimental conditions in Experiment 1b. Therefore, taking into account the small but systematic effect of primes in native and second languages observed in Experiment 2, we can further understand the differences observed between the two groups tested in Experiment 1.

Experiment 3: The role of nonhabitual reading direction on horizontal spatial bias

Introduction

Above, we emphasized the dynamic modulation of reading direction as a factor in the spatial bias. This raises the question of whether the spatial bias is influenced by the actual reading direction of a text prime or by the habitual reading direction determined by the language of the text prime. Thus, in Experiment 3, we study the effect of *habitual* reading and *nonhabitual* reading on image perception. By using normal and mirrored LTR text primes, we disentangle the actual and habitual reading directions and can compare the spatial bias between the two conditions.

Methods

Participants

Nineteen new participants were recruited (seven males and 12 females, age range 18–35 years), and the same criteria and tests from the previous experiments were applied.

Stimuli

In contrast to the previous experiments, we presented the text primes only in native language (LTR, English or German). However, half of them were displayed in the habitual reading direction and half in a mirrored condition (mLTR). The test images were identical to those of Experiments 1 and 2. The experimental setup, the procedure, and the data analysis were identical to the previous experiments.

Results

In Experiment 3, we investigated the relative influence of habitual and nonhabitual reading processes on the spatial bias. When the participants read texts in their native language (Figure 5A, left), they easily and evenly covered the whole extent. In contrast, when they were reading mirrored texts in their native language (Figure 5A, right), they explored only the first line and the beginning of the second line. This demonstrates the large difference in effort necessary for reading mirrored text versus text in original script.

Exploring test images in the first 2 s, participants fixated much more on the left side of the images after either prime (Figure 5B, C). Mauchly's test of sphericity for the factor of time and for the interaction effect between prime and time were violated, $\chi^2(14) = 33.383$, $p = 0.003$ and $\chi^2(14) = 34.907$, $p = 0.002$, respectively. Degrees of freedom were corrected by Greenhouse-Geisser test ($\varepsilon = 0.926$ and $\varepsilon = 0.913$, respectively).

The two-way repeated-measures ANOVA revealed a significant main effect of prime, $F(1, 151) = 11.330$, $p = 0.001$, and a significant main effect of time, $F(4.631, 699) = 38.117$, $p < 0.001$. However, the difference in effect size of LTR and mLTR primes was small and more leftward directed for the mLTR stimuli (Figure 5B, C). Furthermore, the interaction between prime and time, $F(4.563, 688) = 0.833$, $p = 0.518$, was not significant.

Discussion

We recorded the eye movement while reading original and mirrored texts written in the participant's native languages. Participants had, as expected, difficulty finishing mirrored texts. The difficulty of reading the text is congruent with the processing model for eye-movement behavior during reading. This model declares that complexities of the linguistics lead to longer

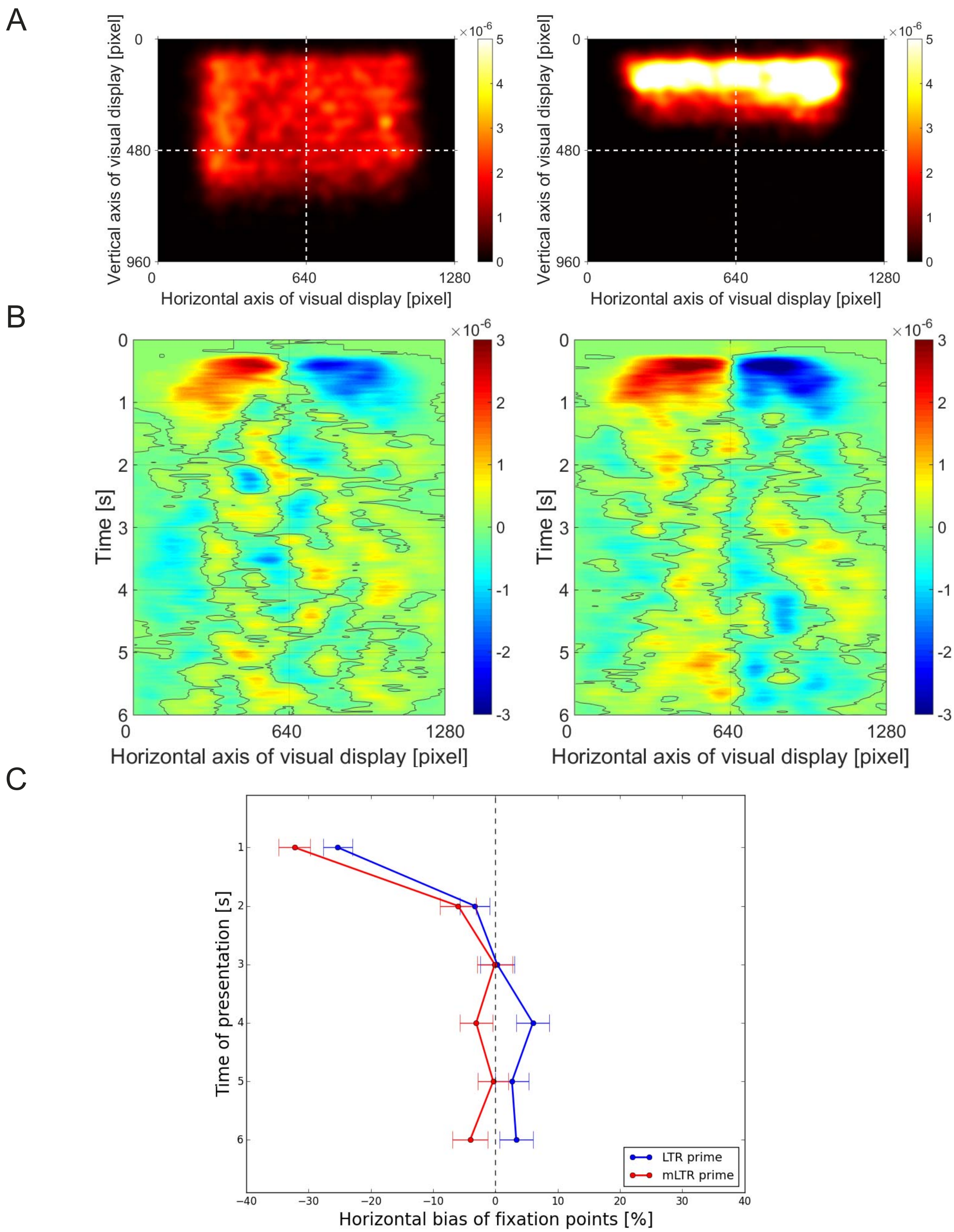

Figure 5. Results of Experiment 3. (A) Fixation density maps of text stimuli in native language (LTR, left panel) and mirrored native language (mLTR, right panel). (B) Time course diagrams for the horizontal position of fixation points during free exploration of all test images presented after normal text primes (left panel) and mirrored text primes (right panel). (C) The horizontal spatial bias of fixations (mean ± *SEM*). The positive values represent the rightward bias, and the negative values represent the leftward bias.

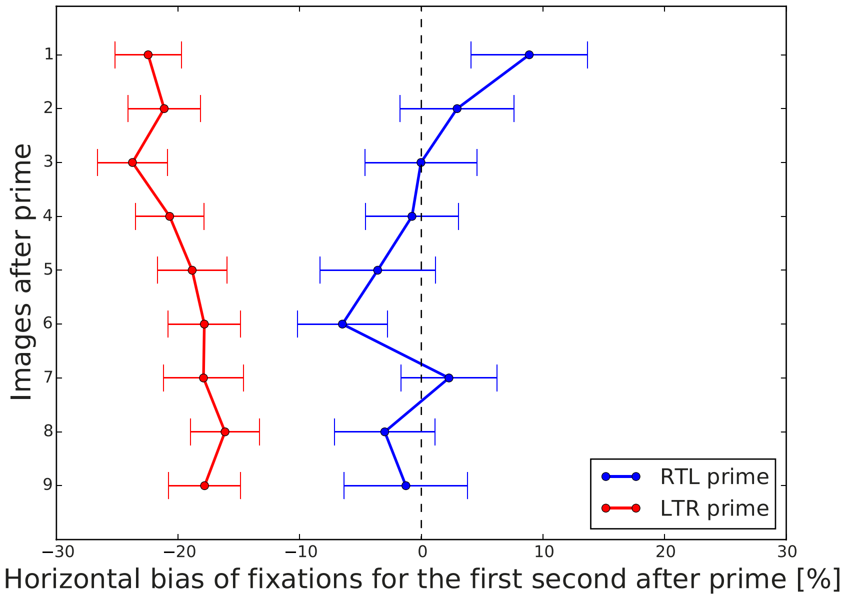

Figure 6. The spatial bias of horizontal fixation position (mean ± *SEM*) time resolved across the presentation of sets of nine test images after presentation of each text prime. The spatial bias was calculated for the first second after exploring the images and pooled across all participants. The positive values represent the rightward bias, and the negative values represent the leftward bias.

fixation times on the words (Henderson & Ferreira, 1990; Morrison, 1984).

We observe that the leftward spatial bias in the mirrored condition is even slightly larger than in the normal conditions. This increased leftward spatial bias after the increased effort of reading mirror script is in line with the observations of Experiment 2. Importantly, the strong and significant leftward bias in either condition demonstrates that not the actual reading direction, but the habitual reading direction is relevant.

Joint analysis of the duration of the effect on the spatial bias

We studied the decay of the spatial bias across the sequence of test images after reading a text prime by pooling all the subjects of the preceding experiments in whom we observed a leftward bias. We pooled all the LTR priming images together (Experiment 1a, second prime; Experiment 1b, first prime; Experiment 2, first and second primes; and Experiment 3, first prime) and pooled all the RTL priming images together (Experiment 1a, first prime and Experiment 1b, second prime). Figure 6 displays the spatial bias during the first second after reading LTR primes or RTL primes as a function of position of test image in the sequence. The LTR prime shifts the spatial bias to the left throughout the sequence of test images.

Please note that, from the analysis above, we know that when viewing a single image after the first second, the spatial bias declines and partly reverses. Yet these data demonstrate that upon the presentation of another image (e.g., the second), the leftward spatial bias is reestablished. Indeed, during the first second of visual exploration of the ninth test image, the spatial bias is nearly 80% of the strength observed during the first test image. In contrast to the reliable effect after LTR text primes, the RTL prime shifts the spatial bias slightly to the right when exploring the first two images, and later the bias was shifted more to the left.

Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated for the effect of images and for the interaction effect of prime and images, respectively, $\chi^2(35) = 41.773$, $p = 0.203$; $\chi^2(35) = 41.462$, $p = 0.212$. Subsequently, a two-way repeated-measures ANOVA was performed to study the interaction between primes and images (2×9). It showed that there is no significant main effect of the position of images in the sequence, $F(8, 368) = 0.688$, $p = 0.702$, but there is a significant main effect of prime, $F(1, 46) = 23.610$, $p < 0.001$. Furthermore, there is no significant effect for the interaction of images and primes, $F(8, 368) = 1.405$, $p = 0.193$.

These data demonstrate that the leftward spatial bias can be quickly modulated by LTR text primes and that this effect is reinstantiated upon each new image presentation for at least one minute.

Experiment 4: The role of priming on shifting the attention in free-viewing behavior

Introduction

The experiments described above give evidence that text primes can modulate the spatial bias. Yet presently we cannot exclude the option that eye movements performed during fluent reading by themselves can exert such an effect (the reading of mirrored text is not fluent). That is, can the leftward bias be strengthened by eye movements matching reading movements without involving linguistic material?

In the following experiment, we introduce primes to mimic the eye movements while reading when no reading tasks are involved and test if the prime effect by itself has an impact on shifting the leftward bias of the viewing behavior.

Methods

Participants

For Experiment 4, we recruited 48 new participants (31 female and 17 male, age range 18–36 years). All the participants were right-handed and spoke LTR languages only. The same criteria and tests from the previous experiments were applied to this group.

Stimuli

For the purpose of this experiment, we replaced the text primes with moving-dot primes. Here, participants fixated their gaze on a white circle with a black dot in the middle that moved on a gray background. The circle (or the moving dot) was positioned during the whole time of trial presentation along a (virtual) horizontal line at half the height of the monitor. It moved from one end of the monitor toward the other end then disappeared and reappeared at the beginning of the line again for 60 s, which was 12 repetitions. In two of the four trials, the moving dot moved LTR. In the other two trials, it moved RTL for the same time duration. The test image stimuli were kept identical to the previous experiments.

Experimental setup

Before the start of each trial, a point appeared in the middle of the gray background for drift correction. An experimental block consisted of a moving dot as a prime, pursued by a total of 45 test images chosen randomly from three image categories, either in original or mirrored condition. Four experimental blocks were presented for each participant. For half of the participants, the first and the last block of the experiment were the RTL blocks and the second and third blocks were the LTR blocks. For the other half of the participants, they were presented with the opposite order. A total of four primes with 180 test images were presented in four blocks. The data analysis of Experiment 4 was similar to the previous experiments.

Results

In close analogy to the preceding experiments, we investigate the horizontal bias during exploration of test images. First, we investigate the viewing bias time resolved across the visual exploration of test images, averaged over the whole sequence of 45 test images (Figure 7A). The spatial bias is visualized separately for RTL and LTR moving-dot primes. The participants started the image exploration with about 20% of spatial bias toward the left side of the images. Afterward, they sharply shifted their gaze toward the right side of the images and continued with a small bias on that side for the rest of the trial duration. The spatial bias after RTL moving-dot primes, in comparison with the LTR moving-dot primes, is slightly smaller and shifted toward the right.

To test the significance difference between the RTL and the LTR moving-dot primes, two-way repeated-measures ANOVA within subjects was performed. It revealed no significant main effect of prime, $F(1, 46) = 0.081$, $p = 0.777$, but a significant effect of the factor time, $F(2.354, 108) = 31$, $p \leq 0.001$. Importantly, we observed no statistically significant interaction of prime and time, $F(5, 230) = 1.782$, $p = 0.117$.

As we did not find a significant effect of prime averaged over the whole sequence of images, we tested for potential short-lasting effects. We selected the set of the first 10 images after moving-dot primes for the analysis. In this subgroup of images, there was also no difference between the LTR and RTL moving-dot primes. Two-way repeated-measures ANOVA demonstrated no significant main effect of prime, $F(1, 47) = 0.157$, $p = 0.693$. On the other hand, a significant effect of the time was reported, $F(3.778, 177) = 18.911$, $p \leq 0.001$. There was also no statistically significant interaction of prime and time, $F(4.101, 192) = 1.800$, $p = 0.129$).

In the last part of the data analysis, we tested for a fleeting effect of the moving-dot primes and studied the effect of prime on the first images presented immediately after the prime. After following the LTR moving-dot primes, participants shifted their gaze toward the left side of the images in the first 3 s of trial duration. Then, they shifted their gaze toward the right side of

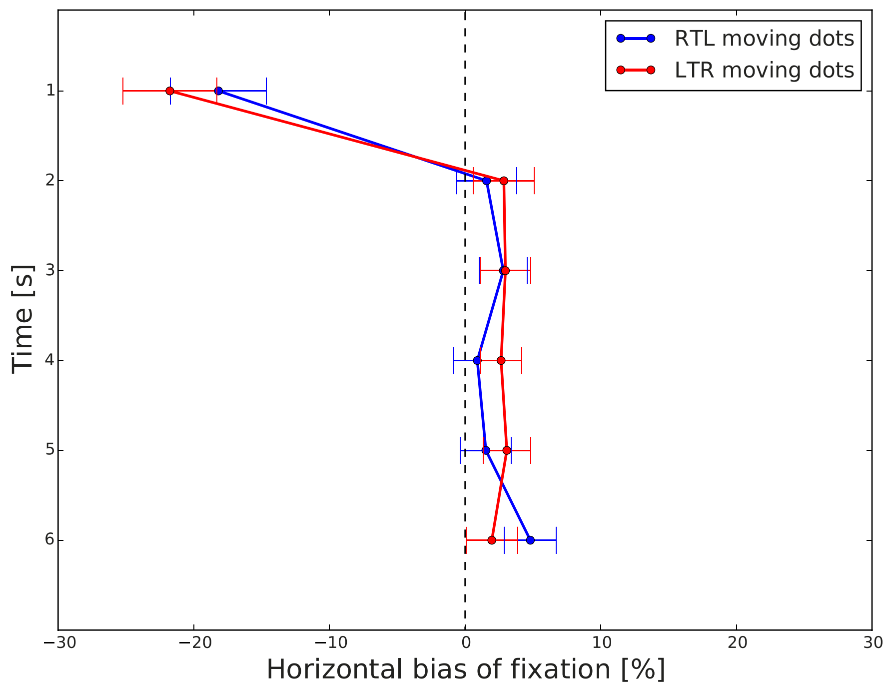

Figure 7. Results of Experiment 4. The horizontal spatial bias of fixations (mean ± *SEM*) after LTR and RTL moving-dot primes averaged over the whole sequence of 45 test images.

the images. After following the RTL moving-dot primes, the gaze remained on the left side of the images during the exploration of the first post-prime images. However, due to the dramatic reduction in the amount of data, the pattern is rather noisy. Indeed, the statistical analysis using two-way repeated-measures ANOVA showed no significant main effect of prime, $F(1, 47) = 1.433$, $p = 0.237$. But the effect of time was statistically significant, $F(4.105, 192) = 3.330$, $p = 0.011$. Adding to this, we report no statistically significant interaction of prime and time, $F(4.051, 190) = 0.844$, $p = 0.500$. Thus, we do not have any indication of a differential effect of RTL and LTR moving-dot primes.

Discussion

Priming is a form of memory with which the pretrial presentation of a stimulus accelerates the identification process in the subsequent trial when perceptual cues are given (Dobbins, Schnyer, Verfaellie, & Schacter, 2004; D. L. Schacter, Chiu, & Ochsner, 1993; Tulving & Schacter, 1990). Thus, priming has been categorized as a type of implicit memory in which the nonconscious recall of the previous experiments can produce an impact on the performance of the following trials (D. L. Schacter et al., 1993; Tulving & Schacter, 1990).

In Experiment 4, we tested whether motor priming can modulate the leftward spatial bias in image exploration even without linguistic content. After priming with either a RTL or LTR moving dot, the initial bias, i.e., during the first second after onset of a test image, was always to the left. Compared to an LTR prime, the spatial bias induced by the RTL moving dot showed only a minor nonsignificant reduction. However, even in reduced subsets early after different prime, similar to the length of the observed effect of Experiments 1, 2, and 3, there was no difference between primes. Thus, we do not have any indication that repetitive eye movements in the absence of text stimuli induce a modulation of the spatial bias as has been observed in the preceding experiments described above.

A potential reason that we did not observe an impact of the primes on modifying the exploratory bias could be an insufficient intensity of priming. It is known that priming effects increase with the number of repetitions (Wiggs & Martin, 1998). However, we chose the duration of the priming to be comparable to the text prime duration of the other experiments. Furthermore, subjectively, following the moving dot is a rather intense experience, and it is not obvious that an increase in length of the priming procedure would pass a critical threshold. Thus, we assume that priming by actual reading text and performing guided eye movements simulating reading in the absence of text should be equally effective.

The investigation of priming by moving dot leads to the conclusion that the motoric pattern of eye movements by itself is not sufficient to modulate the spatial bias in visual exploration. Instead, processing of linguistic material with its associated habitual reading direction seems to be the essential ingredient to achieve a modulation of spatial bias.

General discussion

In this study, we demonstrated a dynamic and long-lasting modulation of a general leftward bias in visual exploration by the habitual reading direction of preceding text primes. Specifically, the spatial bias in native speakers of an RTL language is decreased (less leftward) in the case of RTL reading direction and is increased (more leftward) by text primes with LTR reading direction. Importantly, as shown by mirrored text and moving-dot primes, what is decisive is not the actual movement pattern of the eyes but the habitual reading direction of the respective language.

Many studies have shown the leftward bias in the initial exploration of complex scenes, but these studies did not control for image content asymmetry (Leonards & Scott-Samuel, 2005; Parkhurst, Law, & Niebur, 2002; Tatler, Baddeley, & Gilchrist, 2005). Only two recent studies confirmed this early leftward bias with controlled stimuli: one on constructive memory errors (Dickinson & Intraub, 2009) and the other on the relationship between viewing bias and the perceptual bias of pseudoneglect (Foulsham et al., 2013). In these two studies, the images were presented for half of the participants in the original condition and for the other half in the mirrored condition to avoid biases of the salient objects. We took this into consideration and included the two versions of the images in all our four experiments.

Notwithstanding the observation of a dynamic modulation of the spatial bias by text primes in multiple variations of experimental settings, differences between native speakers of RTL and LTR languages have to be discussed. In Experiment 1, we observed a strong differential modulation of spatial bias by RTL or LTR text primes in native speakers of an RTL language. In contrast, the differential effect of RTL or LTR text primes in native speakers of an LTR language was small and not significant. A potential reason for this discrepancy is the difference in age at the time of acquisition of the second language as well as differences in proficiency therein. The experiment was conducted at the University Osnabrück, and subjects were recruited locally. All the native speakers of an RTL language learned a second LTR language (English or French) at school in their native countries and German upon their arrival in Germany. Thus, they learned the language in courses tailored to this specific group as well as by being immersed in a society speaking that language. Native speakers of an LTR language learned the basics of RTL languages later in life and were not exposed to it or did not interact with it on a daily basis. Some of these participants have lived in a country where RTL is an official language but for only less than a year. At the time of the experiment, they lived in Germany and thus continued to be immersed in a society speaking their native LTR language. The consequences of these differences are hard to estimate and might have contributed to the observed differences on modulatory effect of text primes in native speakers of RTL and LTR languages. For example, Hull and Vaid's (2007) meta-analysis suggested the role of the potential length of the exposure of the second language as a factor on the right hemisphere dominance in bilinguals. A study on the effect of reading direction on SNARC effect that tested Persian subjects showed a reduced SNARC effect but not the reverse effect (Dehaene et al., 1993). They tested the interindividual differences and found a correlation between the years that the subjects spent in France, the familiarity of the second language, and the evolution of SNARC effect. Thus, to avoid such differences in subject groups, a well-controlled multicenter study would be necessary.

Experiment 2 supplies a fresh view on the differences of native RTL and LTR groups in Experiment 1. Experiment 1a displayed a small reversed (right) spatial bias in the subjects' native RTL language and a large left bias in their second LTR language. The systematic effect of native versus second language demonstrated by Experiment 2 might have contributed to this difference. Experiment 1b, in contrast, displayed a notable leftward spatial bias after reading text primes in their native LTR language and only a slightly (nonsignificantly) small spatial bias after reading text primes in their second RTL language. The contribution of being a second language to the leftward bias in this case works against the effect of an RTL text prime and, thus, reduces the differences between the two experimental conditions of Experiment 1b. Therefore, taking into account the small but systematic effect of primes in native and second languages, we can understand the differences observed between the two groups tested in Experiment 1.

The outcomes of Experiments 3 and 4 confirm that reading habit formation, rather than a simple oculomotor habit, is the process that can influence the free-viewing bias. These results are in agreement with a study by Nicholls and Roberts (2002), in which both static and dynamic effects of reading habits and oculomotor scanning priming, respectively, were tested in grayscale and line-bisection tasks. Both LTR and RTL native readers showed a leftward bias regardless of the direction of a motor priming procedure similar to the one used here in Experiment 4. Both studies thus indicate that, performing directionally, eye movement does not influence viewing behavior or perception afterward. The question that remains is why habitual RTL scanning habits can shift the bias toward the right when activated by previous image presentation? The answer can be illuminated by considering the possible association between the direction of a reading habit and spatial processing and the developmental effects of learning to read in more than one language. The association between reading habit and spatial processing has been demonstrated in tasks such as the SNARC test. For instance, Shaki et al. (2009) reported that the activation of preexisting reading habits drives this perceptual bias to be shifted. RTL bilingual readers showed a reverse SNARC in comparison with bilingual LTR readers, which led the authors to suggest that there exists a long-term association between the habits of reading direction and the spatial–numerical association. A similar result linking reading habits with spatial processing is supported by testing the effect of unilateral and bilateral presentation of different linguistic conditions among English monolinguals, balanced Arabic bilinguals, and unbalanced Hebrew bilinguals (Ibrahim, 2009). The results showed an advantage of balanced Arabic and unbalanced Hebrew bilinguals in bilateral presentation over unilateral presentation. This effect was attributed to an increased interhemispheric cooperation among RTL and LTR bilinguals, in which the fluent bilinguals switch effortlessly between the left and right hemispheres in response to the task requirements. As far as both language and reading process is lateralized in the brain to the left, both for LTR and RTL languages, static or dynamic effects of reading habits cannot be explained simply by associating the activation of a hemisphere with a contralateral bias. It is interesting however, that the results above about a benefit for RTL native readers suggesting increased interhemispheric communication is congruent with the results of studies of brain activation among bilinguals that have acquired a second language at different stages of their lives. Learning a second language in an early age (around 6 years old) activates the right hemisphere to play a role in the language network in contrast to learning a second language at later age, which keeps the language network mostly in the left hemisphere (Hull & Vaid, 2007). Thus, the effect in viewing bias seen for RTL natives in Experiment 1 might be associated to this extra activation of the right hemisphere, perhaps working in competition with the activation of the right-lateralized attentional network that biases attention to the left after the appearance of a new image.

Keywords: habitual reading direction, attention, fixation, spatial perception, eye movements

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