Modulating the Spatial Attention during Free Viewing Tasks: Eye-Tracking Studies

Dissertation

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Presented by

M.Sc. Zaeinab Afsari

1st Supervisor: Prof. Dr. Peter König

University of Osnabrück, Osnabrück, Germany

2nd Supervisor: Dr. Josè P. Ossandòn

University of Hamburg, Hamburg, Germany

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Mini CV (Curriculum Vitae)

Name: Zaeinab Afsari

Email: zafsari@uos.de

Academic Degrees

1. I received Bachelor of Science (B.Sc) degree in Diagnostic Radiology from Kuwait University, Faculty of Allied Health Sciences, July 2002.
2. I received Masters of Science (M.Sc) degree in Human Anatomy from Kuwait University, Faculty of Medicine, May 2006.
3. I joined Osnabrück University, Neurobiopsychology Department in winter semester (2011) for PhD studies and supervised by Prof. Peter König.

Teaching Courses

I participateed in teaching the course (Introductory Approach on Neuropsychiatry), SS 2014.

Conferences:

1. I participated in OCCAM (Osnabrück Computational Cognition Alliance Meeting) 2012 conference, Osnabrück.
2. I participated in ZiF 2013 workshop (Competition and Priority Control in Mind and Brain: New Perspectives from Task-driven Vision), Bielefeld.
3. I participated in the 10^{th} Göttingen of the Gereman Neuroscience Society, 2013, Göttingen.
4. I participated in KogWis 2014 conference, the 12 biannual meeting of the German Cognitive Science Society, Tübingen.

Publications during my master studies:

1. Afsari Z, Renno W, Abd-El-Basset E. Alteration of Glial Fibrillary Acidic Proteins Immunoreactivity in Astrocytes of the Spinal Cord Diabetic Rats. Anat. Rec. (Hoboken). 2008 Apr; 291 (4): 390-9.
2. Renno W, Alkhalaf M, Afsari Z, Abd-El-Basset E, Mousa A. Consumption of Green Tea Alters Glial Fibrillary Acidic Protein Immunoreactivity in the Spinal Cord Astrocytes of STZ-Diabetic Rats. Nutr. Neurosci. 2008 Feb; 11(1): 32-40.

Publications during my doctorate studies:

1. Afsari Z, Ossandón J, Koenig P. The dynamic effect of reading direction habit on spatial asymmetry of image perception. Journal of Vision. 2016 Sept; 16(11):8, 1-21
2. Afsari Z, Keshava A, Ossandón J, Koenig P. Inter-individual Differences among Native Right-to-Left Readers and Native Left-to-Right Readers during Free Viewing Task. (in review)**.**

Abstract

In everyday life our eyes are exposed to massive amounts of visual stimuli. However, even though the stimuli's features grab our attention, we have a natural tendency to focus on the centre of the scenes. This central spatial bias is not steady; in fact, while freely viewing a scene, the eyes shift towards the left for two seconds and then return to the centre (Ossandón, Onat, & König, 2014). The leftward spatial bias has also been reported in other behavioural studies, suggesting the role of the lateralization of the attention network. The attention network is activated dominantly on the right hemisphere when detecting new/novel stimuli, causing stronger effects on the contralateral (left) hemispatial side. Hence, in this thesis a series of behavioral studies were conducted using an eye-tracking technique to modulate the leftward spatial bias using different types of primes. Five different eye-tracking experiments were performed in the Neurobiopsychology (NBP) Department at Osnabrück University to investigate the interplay between the horizontal spatial bias and multiple different primes displayed prior to the presentation of images in free viewing tasks. The goal of Experiment 1 was to investigate if different reading directions can alter the leftward spatial bias. The results showed that native right-to-left (RTL) readers showed RTL spatial bias after reading RTL texts and left-to-right (LTR) spatial bias after reading LTR texts. This result suggests the dynamic role that the reading direction has on modifying the horizontal spatial bias. On the other hand, native LTR readers who learned RTL languages later in life showed a leftward spatial bias after reading both LTR and RTL texts. While these results suggest the crucial role of mastering RTL languages in modulating the spatial bias, a larger sample size is required to confirm these findings. The aim of Experiment 2 was to investigate if the reader's second language has a different effect than his/her native language on the leftward spatial bias. Compared to native language LTR texts, LTR/LTR bilinguals demonstrated a slight increase in the leftward spatial bias after reading second language LTR texts. This finding demonstrates the effect that the second language has on enhancing and reinforcing the leftward spatial bias. The goal of Experiment 3 was to study the difference between habitual reading and non-habitual reading (mirrored reading) on the leftward spatial bias. LTR bilinguals read LTR and mirrored LTR (mLTR) texts prior to image exploration and showed a strong leftward bias after reading both texts. The outcome of this experiment suggests that there is an influence of habitual (normal LTR) reading and not of non-habitual (mLTR) reading on the horizontal spatial bias, even though the same language was used in the primes. Experiment 4 investigated if the oculomotor control of the eye movement, without reading,

can modulate the leftward spatial bias as in habitual reading. Thus, LTR and RTL moving-dot primes without reading were presented prior to image exploration, mimicking the readers' eye movement. Native LTR readers showed a leftward bias after primed with LTR and RTL moving-dots. However, in a pilot study within this experiment, native RTL bilinguals demonstrated rightward bias after RTL moving-dots and a weak leftward bias after LTR moving-dots. These findings strengthen the effect of the habitual reading direction and exclude the role of language in reshaping the leftward horizontal bias. Following this, Experiment 5 studied the effect of different factors, including age, gender, first language, second language, second language proficiency, and age of second language acquisition, on the magnitude of the horizontal spatial bias. This Experiment is considered an extension of Experiment 1 in order to study the interindividual differences among native RTL readers after reading RTL texts in a free viewing task. Compared to the native LTR/LTR readers of Experiment 2, the rightward spatial bias among individuals of native RTL readers was strong and profound, but with a large variance of the measurements, suggesting inter-individual differences. This study found no correlation between the magnitude of the RTL spatial bias and the age, gender, first language, second language, second language proficiency, and age of second language acquisition of the participants. Thus, these findings strengthen the profound role that the habitual reading direction has on the RTL spatial bias, regardless of the biological and cultural variables mentioned above. Overall, the thesis proves that the RTL habitual reading direction has a flexible role in modulating the leftward spatial bias (Experiment 1). In addition, the LTR habitual scanning direction can reinforce the leftward bias among native LTR readers to a certain degree (Experiment 2). Yet, non-habitual reading process (Experiment 3) and oculomotor control without language involvement (Experiment 4) showed no influence on the horizontal spatial bias. Moreover, there was no evidence to suggest whether or not age, gender, first language, second language, second language proficiency, and age of second language acquisition influence the magnitude of the rightward horizontal spatial bias (Experiment 5). This leads to the conclusion that forming a habit of scanning direction is a strong factor in changing the natural spatial bias. Furthermore, even though no correlation was found between several biological/cultural factors and the magnitude of the RTL spatial bias, certain speculations can be proposed. First, the strength of the LTR and RTL scanning habits among RTL individuals could lead to an antagonizing effect and yield to interindividual differences. Second, the interindividual differences at the structural and functional cortical level among healthy individuals could cause interindividual differences in the horizontal spatial bias. Third, the narrow group sample of the LTR readers could lead to a small variance in comparison to the diversity of the RTL group sample. Overall, these five experiments have shed light on the dynamic effect of reading direction on the natural spatial bias and opened the door for potential cross-cultural studies regarding visuospatial attention.

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Chapter 1. Introduction

Vision is a sensory modality that seems to be simple because of how effortless the act of seeing is. However, it is a complex process that instantly unravels colours, motions, and locations under certain lighting conditions. In fact, to understand the complexity of visual processing, it is necessary to separate the act into smaller sections. In this process, looking at the eye movement's behavioural mechanisms leads to a better understanding of the visual processing.

Scientists are now able to explore this part of visual processing using eye-trackers, which demonstrate that under natural conditions human eyes tend to fixate the gaze around the centre of the scenes. However, this natural spatial bias is not always towards the centre; it initially deviates towards the left for several fixation points and then is reoriented towards the right/centre of the scene (Ossandón et al., 2014). This initial leftward bias could be due to the cerebral lateralization of spatial attention (Corbetta & Shulman, 2002).

In addition to the attention lateralization theory, another theory suggests that the language and reading direction habits influence the horizontal asymmetry of visual attention (Han & Northoff, 2008b). Based on this theory, it could be assumed that reading direction has an influence on the direction of the spatial bias, as most of the empirical experiments related to this notion were conducted in Western countries. However, the reading habit engages the eye movement in a consistent pattern of movement, either left-to-right (LTR) or right-to-left (RTL).

Therefore, this thesis tests the influence of the reading direction habit and language on the leftward spatial bias. The thesis consists of multiple behavioural experiments that were conducted using eye-trackers to display the temporal and spatial characteristics of the natural spatial bias under different circumstances. Hence, the thesis will answer the following questions:

1. *Does the reading direction habit modulate the horizontal spatial bias?*

To answer this question, the spatial bias was tested for two groups: native RTL readers who have mastered a second LTR language, and native LTR readers who learned a RTL language later in life. These two groups freely explored different categories of images after primed with texts written in the two different directions.

2. *Does the second language affect the spatial bias differently than the first language?*

The horizontal spatial bias for LTR/LTR bilinguals was tested after reading texts in native and second LTR languages. This group was also considered a control group for the previous experiment.

3. *Does non-habitual reading have the same effect as habitual reading on the spatial bias?*

Whether the effects of reading direction are due to a habitual nature of reading or not was investigated. LTR readers were asked to read normal LTR texts (habitual reading) and mirrored LTR texts (non-habitual reading) prior to the image viewing task.

4. *Is it the scanning habit, the language, or even the oculomotor behaviour of the eye that reshapes the spatial bias?*

The scanning habit was separated from language by introducing different trajectories of moving-dots as primes to resemble the eye movements while reading but without actually reading. Following this, the leftward spatial bias of two groups, LTR/LTR bilinguals and RTL/LTR bilinguals (pilot study), was measured.

5. *Are there inter-individual differences among native RTL readers that cause the large shift of the spatial bias?*

The broad interindividual variance for the horizontal spatial bias among the RTL/LTR group in comparison to the native LTR/LTR group after primed with native and second language texts was focused on. Specifically, the effect of different cultural and biological factors on the horizontal spatial bias was investigated, including age, gender, first language, second language, second language proficiency, and age of second language acquisition.

This thesis will first present a literature review regarding previous studies in the field. The methodology will then be explain in detail, as well as the data-acquisition and analysis processes. It must be noted that certain parts of the methods and results sections were used for publication purposes.

Chapter 2. Literature Review

2.1. How Do We Reorient Our Attention?

Vision is considered to be the main input that projects the outer environment into the brain. Anatomically, the retina contains the central fovea, which is responsible for acute vision (Tortora, 2013). Hence, it is one of the functions of the eye to guide the gaze to the highest resolution spot, a process that takes place with the help of attention. However, attention is not necessarily related to eye movement. In other words, attention can be detached from eye movement (covert attention) or linked to it (overt attention) (Posner, 1980).

With the use of eye-trackers many studies are focusing on the overt attention on complex scenes, trying to segregate the factors controlling the shifting of attention to certain locations while ignoring others (selective attention) (Kaspar, 2013). This process of 'filtering' is reported as a phenomenon of change blindness, which occurs when the observers fail to notice a change in a scene as their attention is focused on something else in that same scene (Levin & Simons, 1997; O'Regan, Rensink, & Clark, 1999; Simons & Ambinder, 2005). When one looks at a scene, the brain performs a series of organized processes to orient attention. In the early 'preattentive' visual stage, the whole image is processed in 'parallel.' Afterwards, selective processes are initiated by moving the eyes towards specific features while ignoring others (the attentive stage) (Itti & Koch, 2000; Kastner & Ungerleider, 2000; Theeuwes, 2010). Hence, selective attention takes place in the second stage of visual processing.

The question thus arises of how attention is controlled and oriented. Suppose that you are looking at a painting in a gallery, what will grasp your attention first? The colours? The objects? The sad/happy faces? While it seems to be a difficult question, based on years of research scientists have solved part of the puzzle. Generally, the answer to this question will be: it depends. It depends on a combination of many factors that come together at the moment of seeing the painting. These factors have been classified as: stimulus-driven factors, goal-driven tasks, and the natural spatial bias (Kollmorgen, Nortmann, Schröder, & König, 2010). In the following sections, I will briefly explain each of these factors, which affect attention-orientation.

2.1.1. Stimulus-Driven Factors

A stimulus' low-level features, such as its colour, intensity, orientation, shape, and motion, can involuntary shift attention (Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991). In this process, stimulus-driven cortical areas receive sensory inputs from V1 through the dorsal and ventral visual streams to orient attention. This 'bottom-up pathway' of transferring the sensory inputs is called the 'stimulus-driven pathway' or the 'exogenous attentional control' (Einhäuser & König, 2003; Itti & Koch, 2001; Parkhurst, Law, & Niebur, 2002).

The eye movement recordings have shown that the strategy for detecting low-level features is, to a certain level, different between humans and other mammals. In a recent free viewing task, while humans made consistent fixation location patterns, rhesus monkeys did not. Hence, different selection strategies exist between species. However, there were certain similarities in the selection processes of the low-level features in both species (Wilming et al., 2017).

Nowadays, neuroimaging experiments have made it possible to identify the cortical areas that are activated while performing stimulus-dependent tasks. To be more specific, the main cortical regions identified are: the right intera-parietal sulcus (IPs), the right frontal eye field (FEF), the right temporo-parietal junction (TPJ), and the right ventral frontal cortex (VFC), which includes the inferior and middle frontal gyri (IFG and MFG) (for meta-analysis please check; Corbetta & Shulman, 2002; Downar, Crawley, Mikulis, & Davis, 2000). These 'ventral frontoparietal' cortical areas are also activated while shifting attention towards unexpected spatial locations. For instance, subjects are presented with a pointed cue in the centre of a screen prior to the target's presentation. When the target appears in a direction opposite to the location pointed to by the cue, the subjects shift their attention unexpectedly to detect the target. This shift of attention causes strong and predominant activation in the ventral frontoparietal network (Corbetta & Shulman, 2002).

To summarize, the bottom-up attention system is responsible for recognizing the changes in the visual stimuli by receiving signals from visual scenes and then transferring these to higher cortical areas. Most importantly, this network is under the dominant control of the right cerebral hemisphere.

2.1.2. Goal-Driven Tasks

The signals to orient attention are processed both via a bottom-up network and a top-down network, which has been proved to be responsible for generating and maintaining commands to orient attention. Initiated from specific frontal areas, the signals are sent to the visual motor areas to adjust the eye-movement behaviour based on endogenous goals and anticipations. Therefore, this pathway is called 'goal-driven attention,' 'endogenous attention,' or 'task-dependent network' (Corbetta, Patel, & Shulman, 2008). This network can be activated at the same time as the bottom-up network (Buschman & Miller, 2007; Corbetta & Shulman, 2002; Itti & Koch, 2001; Theeuwes, 2010).

One of the major influencers of goal-driven attention is the individual's personality. Each of the five different personality traits (neuroticism, extraversion, openness, agreeableness, and conscientiousness) has its own influence on certain visual behaviours: number of fixations, mean fixation duration, and dwelling time. Even so, it has been suggested that motivation is the main factor marking the difference between the personality traits and eye movement behaviour (Kaspar & König, 2012; Rauthmann, Seubert, Sachse, & Furtner, 2012).

Another important factor impacting goal-driven attention is the individual's endogenous emotions. While studying emotions, two different types of emotions are involved: the emotional features of the stimuli and the participant's emotional state. When attention is affected by the emotional features of the stimuli, it is considered an exogenous-driven factor. However, when the participant's emotional state affects attention, it is considered an endogenous-driven factor (Kaspar et al., 2013; Kaspar & König, 2012). Eye movement is also affected by the participant's emotional state. Positive and negative emotional states have also been studied and compared to neutral emotional states. Through these studies, it has been demonstrated that eye movement behaviour is linked to a positive mood, with more peripheral fixations and more frequent saccades (Wadlinger & Isaacowitz, 2006). Thus, the participant's emotional state is a substantial variable in attention and eye movement tasks.

Neuroimaging techniques have helped to reveal the cortical areas related to goal-driven tasks. Unlike the stimulus-driven network, the goal-driven network is dominated by both left and right hemispheres and has been linked to control attention location and attention-to-motion direction (Corbetta & Shulman, 2002; Hahn, Ross, & Stein, 2006;

Hopfinger, Buonocore, & Mangun, 2000; Kastner & Ungerleider, 2000; Thompson, Biscoe, & Sato, 2005). This ‘dorsal frontoparietal network’ consists mainly of bilateral interaparietal sulci (IPs) and frontal eye fields (FEF).

A great part of this neuroimaging evidence has been obtained from individuals’ fMRI scans while they performed some kind of cued attention task. Most typically, the task requires subjects to respond to a peripherally-presented target. Prior to the appearance of the target, a central arrow (cue) points to the direction of the expected target appearance. In this cueing period, cortical areas in the parietal and frontal cortex (IPs and FEF) showed a strong and continuous response, compared to those in non-cued control trials (Corbetta, Kincade, & Shulman, 2002; Kastner & Ungerleider, 2000). Moreover, the dorsal frontoparietal network is activated during moving stimuli. For instance, when subjects were presented with a moving directional cue, fMRI images demonstrated sustained signals in the frontal FEF and parietal areas (Corbetta & Shulman, 2002; Shulman et al., 1999).

In brief, the top-down network controls spatial attention through motivations, goals, expectations, and internal emotions. It is bilaterally activated in the dorsal frontoparietal regions overlapping with specific areas of the bottom-up network.

2.1.2.1. How the Stimulus-Driven Factors and the Goal-Driven Tasks Intertwined to Reorient Attention?

In the literature on this topic there are three different models that explain the interplay between the stimulus-driven factors and the goal-driven tasks in reorienting attention. The first is the anatomical model, created by Corbetta and Shulman. As this model demonstrates, attention is first engaged in an ongoing specific task influenced by the goal-driven network, which responds voluntarily by shifting attention towards a specific location/stimulus. When a novel stimulus is detected unexpectedly, the sensory signals are transferred to the stimulus-driven network to reorient attention. At this point, the stimulus-driven pathway interrupts the loop of the information process that is running by the goal-driven network, causing an overlap of the two networks (Asplund, Todd, Snyder, & Marois, 2010; Corbetta et al., 2008; Corbetta & Shulman, 2002). Hence, both systems are integrated and precisely overlapping during novel and unexpected moments.

The second model suggests that the stimulus-driven network is the default selective attention network that sends the sensory inputs feed forward towards higher cortical areas, where the goal-driven network is the recurrent feedback process. As explained by Theeuwes, in the pre-attentive stage of a visual search task, the attention is shifted towards the highest salient object (a bottom-up input). If the salient object is not the target, that location will be inhibited (a top-down input) and the attention shifted towards the next salient object in line. However, if the salient object is the target, then the attention is 'engaged' with that location (a top-down input) (Theeuwes, 2010).

In addition to the previously-mentioned models, Awh and his team (Awh, Belopolsky, & Theeuwes, 2012) suggested another model to include the issues that were not resolved in the other models. As the authors suggested, there are two large categories that are not included in the models mentioned above. The first category is selection history, where the history of attention selection due to inter-trial priming causes a faster reaction time. The second category is reward history, where there is an impact of the reward expected to be received after achieving the task goals. As a result, Awh and his team suggested a modified priority map that integrates the above-mentioned systems in addition to the other factors. The modified priority map is constructed from three distinctive categories, which can work in cooperation or in opposition based on the observer's priority factor: the current goals, which are the voluntary part of the selection process and resembles the top-down motivations, the physical salience of the external stimuli, and the selection history, which includes the selection and reward histories.

Corbetta and Shulman's theory is based mainly on neuroimaging studies, while Theeuwes's theory is based mainly on behavioural studies. On the other hand, Awh's notion suggests a broader framework that covers different aspects influencing attention reorientation.

2.1.3. The Central Spatial Bias

The visual spatial attention is not only under the influence of stimulus-driven factors and goal-driven tasks, but also the "central (natural) spatial bias." According to this, under natural conditions the eyes tend to fixate around the centre of the scenes rather than the edges, regardless of the task and features in the scene (Kollmorgen et al., 2010; Ossandón et al., 2014; Tatler, 2007; Tseng, Carmi, Cameron, Munoz, & Itti, 2009).

While different studies have made an effort to reveal the cause of the central spatial bias, no clear empirical evidence has been found to explain it. One theory on the cause of the central spatial bias is the artefact due to the restrictions in the lab for studying the eye movement on a computer screen. In Bindemann *et al.*'s study the centre of the screen was detached from the centre of the scene by positioning the centre of the scene either to the left or to the right of the screen. Moreover, the fixation point prior to image presentation was positioned off-centre. In the first experiment, the task was to detect the presence of a person while detaching the centre of the scene from the centre of the screen. The results demonstrated a central spatial bias directly after the stimulus onset. Moreover, it was shown that when the scenes were positioned in the left of the screen and the central spatial bias was also shifted to the left of the screen, and vice versa. However, this shift of saccades was insufficient in magnitude, suggesting that the centre of the screen also affects the initial fixation position. These results showed the dual effect of the screen and the scene on the central spatial bias. In the second experiment, the luminance of the screen frame was changed while performing a free viewing task with the images without the person's detection. In this case, the same dual effect of scene/screen was noticed on the central spatial bias with no low-level salience effect regarding the luminance of the screen frame. Therefore, although this bias naturally exists, it is partially influenced by the computer's screen's position (Bindemann, 2010).

In addition to the experiments performed in laboratories, the central spatial bias was also detected in natural environments using video recorders (Schumann et al., 2008; Tseng et al., 2009). The detection of the central spatial bias in the natural environment with free head movement and without using a headset led to the understanding that this bias is not caused by lab-screen restrictions but that it is the natural behaviour of visual perception (Schumann et al., 2008; Tatler, 2007).

However, what can be the cause of this bias if not the lab screen limitations? One notion suggests the role of the photographer's bias, where the photographer prefers to focus on the salient objects by setting them in the centre of the photo shoot. Tattler and his team tested this theory by choosing images with different feature distributions (central/right peripheral/left peripheral) and asked the participants to perform two different tasks: free viewing and searching for the luminance spot. The researchers noticed central fixations in the free viewing task regardless of the location of the image's features, which was not found in the searching task (Tatler, 2007). In another experiment, Ossandón cancelled the photographic bias by exposing two different versions of the images (original and mirrored) in a free viewing task, where each participant saw only one of the images, either the original or the mirrored version. In the data analysis process the map of the spatial distribution of the fixation points for the mirrored images were flipped and subtracted from the original images. The result of the subtraction process demonstrated a consistent pattern of spatial bias (Ossandón et al., 2014). On the other hand, Tseng and his team noticed a positive correlation between the photographer bias and the central spatial bias (Tseng et al., 2009). However, since the correlational findings are not considered as causation, and there is a difference in the methodology performed by Tseng, therefore, the photographer bias is not considered a cause of the central spatial bias.

Another suggested cause of the spatial bias is the motor bias, where the eyes prefer to make short rather than long saccades (Tatler, 2007; Tseng et al., 2009). Tatler and his team designed an experiment to change the position of the pre-trial fixation point randomly and noticed a strong central preference in fixations, regardless of the location of the pre-trial fixation points, in both the free viewing task and in searching for a luminance target. Hence, the effect of the oculomotor behaviour on the spatial bias was eliminated (Tatler, 2007). Tseng and his colleagues tested the motor bias by simulating the saccade sequence using a random walk model. In this model, each step mimics the human saccade and amplitude, ending with a uniform distribution of the simulated points over a heat map, suggesting that the motor bias does not have a role on the central spatial bias (Tseng et al., 2009).

Other suggested causes of the spatial bias include the viewing strategy and the orbital reserve. The viewing strategy theory suggests that the viewer prefers to look at the centre of the image as a better spot to collect information from the image peripheries; however, this effect exists only for a short period of time. The orbital reserve theory suggests that the anatomical orbital position influences the action of looking straight to the centre of the screen. However, testing this theory has also showed that there is no effect on the spatial bias (Tseng et al., 2009).

The spatial and temporal properties of the natural spatial bias have also been analysed from a different perspective. In this study, right-handed subjects explored scenes under natural conditions and their eye movements were recorded by an eye-tracker. The distribution of the first two fixation points were located in the left side of the monitor regardless of the image content or category. However, during the rest of the trial duration (4 seconds), the fixation points were distributed to the right/centre (Ossandón et al., 2014). Interestingly, this leftward bias was not noticed among left-handers and was explained to be a result of the asymmetrical attention system. In other words, it is suggested that the hemispheric lateralization for detecting salient stimuli has a role in the initial preference for the leftward spatial bias. In addition, the role of the reading direction habit was speculated also as having an effect on this.

In brief, the spatial bias is a characteristic feature of the human visual perception that can be detected in a lab environment using eye-trackers. While there is no clear evidence for the causation of the bias yet, many studies support that this bias is innate. In addition, the time course analysis has shown an initial bias towards the left, followed by a shift towards the right claiming to be under the influence of cerebral lateralization.

2.2. Brain-Behaviour Correlation and Attention Lateralization

Clinical cases of brain damage have started to shed the light on the correlation between visual perception and attention lateralization. For instance, clinical studies on patients with epilepsy who had split-brain surgery showed that they have a distinctive lateralization of the visual perception (Gazzaniga, 1995). Moreover, brain lesions in some cortical and subcortical areas can cause hemispatial neglect, a condition where a deficit of attention occurs, affecting the spatial visual field contralateral to the lesion site without any damage to the sensory or motor pathways. Behaviourally, the left hemispheric neglect patients who performed line bisection tasks demonstrated a rightward bias to the midline, which proved that the visual information processing became biased (Ishiai, Furukawa, & Tsukagoshi, 1989).

Two different neural models explain the correlation between visual perception and attention lateralization and, correspondingly, the neglect syndrome. The first model claims that the neglect syndrome is caused by the impairment of the right hemisphere attention system, which controls attention orientation to both the right and left hemispace. On the other hand, the model argues that the left hemisphere attention system only controls the right hemispace (Mesulam, 1999). The other model suggests that both hemispheres control the contralateral hemifields but that the strength of the connectivity varies for the right compared to the left, leading to a stronger effect of neglect when the damage occurs to the right hemisphere (Kinsbourne, 1970). Even though these models differ in their explanations for the mechanism of the hemispatial neglect, they both refer to the superiority role of the right hemisphere in reorienting spatial attention.

The horizontal deviation during the line bisection task is not a unique characteristic of hemispatial neglect patients. In fact, healthy adults also demonstrate a slightly leftward deviation while performing a line bisection task, referred to as 'pseudoneglect' (Bowers & Heilman, 1980). In the line bisection task, it was noticed that the age of the subject, length of the line, and reading/scanning direction affect the outcome of the task (Chokron, Bartolomeo, Perenin, Helft, & Imbert, 1998; Chokron & Imbert, 1993; Fujii, Fukatsu, Yamadori, & Kimura, 1995; Jewell & McCourt, 2000). Moreover, the link between the line bisection task and the attention lateralization network has been confirmed by fMRI scans, where the leftward bias in a line bisection judgment task triggers the right hemispheric lateralization (Zago et al., 2017). However, the pseudoneglect phenomenon does not develop from birth. In fact, it manifests gradually over a person's development, starting at the age of five and becoming stable at the age of eight. The latter finding strengthens the suggestion of the incomplete biological development of perceptual, attention, and motoric components at an early age (Girelli, Marinelli, Grossi, & Arduino, 2017).

Pseudoneglect has also been detected in other visual tasks, including: the grey scale task (Friedrich, Hunter, & Elias, 2016), the visual search task (Nicholls, Hobson, Petty, Churches, & Thomas, 2017), the nonvisual task (touch-driven tactile rod bisection and mental number line) (Brooks, Darling, Malvaso, & Della Sala, 2016), and the draw-a-person test (Heller, 1991). Hence, attentional bias towards the left is considered a normal biological behaviour that develops at an early age in life.

Recent anatomical-neuroimaging findings suggest a link between the volume of the superior longitudinal fasciculus and the spatial attention bias. Using the Diffusion Imaging Tractography technique, the volume of the second component of the superior longitudinal fasciculus (SLF II) has been measured. Following this, the structural asymmetry in the size of the left and right fascicles was reported. Indeed, SLF II has been found to be lateralized to the right. At a behavioural level, positive correlation was reported between the volume of the SLF II and 1) the magnitude of the leftward bias in line bisection task, and 2) the speed of the detection time in left hemifield (de Schotten et al., 2011). In addition, patients with right hemisphere strokes performed the lateralized spatial orienting task while being MRI scanned. Their results showed a correlation between the integrity of the white matter tracks in the frontoparietal area and visuospatial attention (Carter et al., 2017).

2.3. The Organization of Attention-Language Networks

The language cortical network is a network that is known to be lateralized to the left hemisphere and consists mainly of the Broca's and Wernicke's areas. Broca's area is located precisely in the inferior frontal gyrus and represented in Broadman's area 44 and 45. Wernicke's area, instead, is specifically located in the posterior section of the superior temporal gyrus and represented in Broadman's area 22. In addition, a connective structural network was identified connecting the areas with each other: the superior longitudinal fascicle, the Uncinate fascicle, and an extreme fibre capsule system (Friederici, 2011; Price, 2000).

Interestingly, different researchers have studied the laterality of language and spatial attention domains in healthy individuals (Cai, Haegen, & Brysbaert, 2013; Flöel et al., 2001; Flöel, Buyx, Breitenstein, Lohmann, & Knecht, 2005). These studies showed that the majority of the right-handers with a left hemisphere dominance of language had a right hemisphere dominance of spatial attention. Similarly, the majority of the left-handers who had the spatial attention on the left hemisphere had the language system localized on their right hemisphere. It is believed that this functional specialization and lateralization has evolutionary origins (Cai et al., 2013). In line with this understanding, the pattern of lateralization of the two domains has been further studied among healthy subjects. For instance, in one study in which functional lateralization was measured indirectly via Functional Transcranial Doppler Ultrasonography, participants were requested to perform visuospatial and tactile attentional tasks, as well as one language task. The outcome of the study was that healthy individuals can be categorized into three different categories: the normal group (R attention/L language), the crossed group (L attention/R language), and the atypical group (language and attention localized within the same hemisphere). In addition, handedness was also related to attention/language lateralization for most of the subjects (Flöel et al., 2005). Therefore, although the attention network is right lateralized and the language network is left lateralized, different patterns of lateralization of these two networks do exist among healthy population.

2.4. The Influence of the Reading Direction Habit

The previous paragraphs discussed the natural spatial bias of attention and its time course change, which shows a leftward bias during the first few fixation points. In this section, the focus is on identifying several factors that can influence the direction of the horizontal spatial bias. While the main speculation for the cause of this bias is the influence of the hemispheric attention lateralization network, the effect of other factors must not be excluded (Ossandón et al., 2014). One suggested factor is the reading direction habit or, as some would call it, the "scanning habit". Since most of the spatial bias experiments were performed in Western countries, where the reading direction is LTR, it could be that the reading direction has also an impact on the leftward spatial bias. In fact, recording the eye movements in groups of people who learned languages with different reading directions (LTR, RTL, and top-down), while freely viewing a symmetrical pattern of black dots, showed a difference in the direction of saccades reflecting the reading direction habit for each group (Abed, 1991).

A habit is defined as the gradual intensifying of the bond between a stimulus and a response. At a cortical level, the acquisition process requires consecutive repetitions triggered by either external cues or internal goals, leading to forming a habit without the involvement of consciousness. At a neural level, each repetition process triggers small alterations in the brain. Rodents, monkeys, and humans showed that there is a link between the neural networks related to habitual behaviours and the cortical/basal ganglia circuit. In other words, the dopamine system dominates the midbrain as the system responsible for habit-consolidation processes (Wood & Rünger, 2016).

For humans, the time required to form a habit differs between individuals (18-254 days) (Lally, van Jaarsveld, Potts, & Wardle, 2010). While a habit is developed, a gradual shift from goal-directed action to habitual control is made. At first, the goal-directed network links the action with a reward/motivation. Then, with constant repetition of the action, the reward/motivation is ignored and the action continues to occur, becoming a habit. Thus, a habit is considered a cognitive adjustment to reduce control on routine procedures and shift one's attention towards unfamiliar tasks (Gasbarri, Pompili, Packard, & Tomaz, 2014). The following sections discuss different behavioural tasks that were linked to the reading direction habit.

2.4.1. The Visual Line Bisection Task

The visual line bisection task is a simple behavioural task used to evaluate the attention lateralization among healthy adults, a condition called 'pseudoneglect' (Jewell & McCourt, 2000). In this task, healthy right-handed adults drew a vertical line to intersect a horizontal line at its midpoint, showing a leftward bias tendency (Bradshaw, Nettleton, Nathan, & Wilson, 1985; Hausmann, Waldie, & Corballis, 2003; Zafirova, Giagtzidou, Vassileva, & Andonova, n.d.). Interestingly, when healthy RTL monolinguals performed this task, they showed a reversed bias: a tendency to bisect the lines towards the right (Chokron & Imbert, 1993; Rashidi-Ranjbar, Goudarzvand, Jahangiri, Brugger, & Loetscher, 2014).

The shift of spatial attention towards the left starts in puberty. In their early years, right handed children demonstrated a rightward bias in the line bisection task (Zafirova et al., n.d.). On the other hand, 13-15 year-old children begin to show a bias towards the left (Hausmann et al., 2003; Zafirova et al., n.d.). In the same sequence, pre-school children from RTL and LTR cultural backgrounds both showed preference to bisect the line in a direction that reflects their cultural reading direction (Chokron & De Agostini, 1995). While this test is linked directly to attention lateralization, which was suggested to cause the leftward line bisection, the leftward bias can be altered by opposite reading direction habits.

2.4.2. The Grey Scale Task

The influence of the reading direction has also been tested with the gray scale task. In this task, two gray scale bars are presented simultaneously, one on top of the other. These bars are a luminance gradient bar (the darkest side at one end and the brightest side at the other end) and its mirrored version. The participant is asked to judge which bar is darker. Although LTR readers demonstrated a leftward preference for the darker side, the RTL readers showed reduced/no bias towards one luminance gradient over another (Friedrich & Elias, 2014; Nicholls & Roberts, 2002). However, some minor factors were shown to contribute to the change in the preference side, such as monolingualism vs. bilingualism and being right-handed vs. left-handed (Nicholls & Roberts, 2002).

In a slightly modified task, images with a source of light that is located either on the left or right upper corner replace the gray scale bars. In this task the choice of the preferred image is based on no criteria regarding brightness. Still, LTR readers showed a bias towards the left and RTL readers showed no preference bias (Smith & Elias, 2013). The neurological mechanism underneath the luminance preference bias is mainly linked to the biased spatial attention towards the salient features in the left hemispace (Friedrich & Elias, 2016). Still the reading direction habit can modulate luminance preference.

2.4.3. The Cancellation Task

The cancellation task consists of a white board filled with targets and distractors distributed randomly, where the subjects are requested to cancel out all the targets as quickly and accurately as possible. The horizontal bias is calculated by the movement within each axis and between the marks. In this particular task, LTR monolinguals and RTL monolinguals showed a bias in cancelling according to their reading direction. Interestingly, RTL/LTR bilinguals showed no significant bias (Rinaldi, Di Luca, Henik, & Girelli, 2014).

2.4.4. The Asymmetric Chimeric Faces Test

Horizontal asymmetry in face perception is detected at behavioural and neural levels. A general leftward bias starts to be noticed among 6-month-old infants and adults when presented with images of humans' neutral expressions. Furthermore, animals such as rhesus monkeys and domestic dogs showed leftward asymmetry when viewing human faces. Such studies have suggested the right hemispheric specialization for face processing among humans and different animal species (Guo, Meints, Hall, Hall, & Mills, 2009).

The human brain area that is specialized for face perception is located on the lateral side of the mid-fusiform gyrus (fusiform face area (FFA)) (Kanwisher & Yovel, 2006). Since the FFA is dominant in the right hemisphere, it influences the left visual field superiority in face recognition. This notion is reported in the result of fMRI studies that measured the magnitude of the asymmetrical responses to faces. For more confirmation, the asymmetric chimeric faces test followed the fMRI test and showed a positive correlation between the leftward asymmetry and the FFA activation in the right hemisphere (Yovel, Tambini, & Brandman, 2008).

The asymmetric chimeric faces test combines half of a face with a neutral expression with another half with a smiling expression. Then, a mirrored version of the chimeric face is made and presented with the original version on the same page. The task requires the person to make a subjective judgment for in which image the face looks happier. The side of the smile of the image chosen demonstrates if the preference is towards the left or the right. Performing this test on children and adults (Levine & Levy, 1986) and right-handed and left-handed people (Levy, Heller, Banich, & Burton, 1983) has demonstrated a leftward bias. Interestingly, native RTL readers who performed the asymmetric chimeric face test showed mixed results. In one study, native RTL readers showed no preference towards the left (Eviatar, 1997). In a more detailed study, different groups participated in the asymmetric chimeric face test: LTR, RTL, LTR/RTL bilinguals, and illiterate people, with a combination of different handedness. Right-handed LTR subjects showed the greatest mean of a leftward scoring of the image, while the RTL subjects showed the greatest mean of the rightward scoring. Interestingly, illiterate subjects showed a leftward bias (Heath, Rouhana, & Ghanem, 2005; Vaid & Singh, 1989).

2.4.5. The Face Matching Task

The face matching task is another face-involving task that was performed by LTR and RTL readers. In this task, two faces are presented in an upper line and another 10 faces in a lower line. The participants must match one of the faces in the upper line with one of the faces in the lower line. Both LTR and RTL readers matched the faces that appeared on the left more accurately than the faces that appeared on the right. In addition, the magnitude of the left side matching was weaker for RTL readers than LTR readers, supporting the notion of the dominant role of the right cerebral hemisphere in face recognition and the modification role of reading direction (Megreya & Havard, 2011).

2.4.6. The Aesthetic Preference Test

The effect of the scanning habit is also observed in the judgment of aesthetic images. In this task image pairs are presented (original and mirrored), containing objects with a leftward/rightward directionality. The person must select the image of the pair that is more aesthetically pleasing to look at. Monolingual right-handed LTR and RTL, as well as children and adults, were tested and showed different results based on their scanning directionality. LTR readers preferred images with a rightward directionality and RTL readers preferred the opposite (Chokron & De Agostini, 2000). The same results were found when the experiment was tested among RTL and LTR readers who have the same cultural background and live in the same geographical area (Friedrich & Elias, 2016). These results are explained by the right hemisphere dominance for aesthetic preference, and reading direction.

2.4.7. The Gaze-Contingent Window Test

The perceptual span and reading rate can be measured in the gaze-contingent window test. In this test part of the script is exposed in a window while surrounded by blurred scripts. The window moves in synchronicity with the eyes while, at the same time, the eye recorder records eye movement. The window is modified to either be symmetrical or off-centre to the right/left. Testing bilingual RTL readers reading both RTL and LTR scripts showed that those reading LTR scored the highest when the window was off-centre to the right. On the other hand, those reading RTL scripts scored the highest when the window was off-centre to the left (Jordan et al., 2013; Paterson et al., 2014; Pollatsek, Bolozky, Well, & Rayner, 1981).

Therefore, the difference in the perceptual span was related to the directionality of the window, which reflects the scanning habit of the language used.

2.4.8. The Mental Representation of Numbers and the Finger Counting Habit

In typical Spatial-Numeric Association of Response Codes (SNARC), small number magnitudes are associated with the left side of the space and large number magnitudes with the right side of the space (Göbel, Shaki, & Fischer, 2011). To test the SNARC effect in the lab, the parity judgment test was designed. In this test, random numbers from one to eight are presented on a screen and the subjects classify them as odd or even by pressing a button (one key for an even digit, another for an odd digit). Based on this, the speed and accuracy of the responses are measured. The SNARC effect is assessed by calculating the average difference (RT of the right minus RT of the left). LTR monolinguals show a strong SNARC effect while RTL monolinguals show a reverse SNARC effect. Interestingly, for a mixed language system group, in which the number system is written LTR but the word system RTL, no SNARC effect was found (Shaki, Fischer, & Petrusic, 2009). Furthermore, RTL readers showed a reduced SNARC effect, which was linked to the number of years they spent in a Western country (Dehaene, Bossini, & Giraux, 1993). In a more explicit study, the parity test was primed with (1) reading texts (LTR/RTL) and (2) listening texts. Bilingual LTR/RTL subjects showed a SNARC effect after reading LTR texts but a reduced effect after reading RTL texts. Interestingly, no change was found in the SNARC effect during the auditory test for the RTL/LTR group, supporting the role of visual stimuli and the reading direction on the SNARC effect (Shaki & Fischer, 2008).

Additionally, the SNARC effect is associated with the finger counting habit. It must be noted that the finger counting habit is not linked to handedness; most right-handers start counting fingers from the left hand (left starters). In these studies, when the subjects performed the finger counting test and the parity judgment test, the SNARC effect was stronger among left starters but a reversed SNARC effect was recorded among right starters (Fischer, 2008). In a cross-cultural study for finger counting, LTR readers started counting with the left thumb, while most RTL readers started counting with the right little finger (Lindemann, Alipour, & Fischer, 2011). In another form of the counting direction test, four identical coins are arranged in a linear array and the participants count the coins loudly while pointing at them. In this test, the reading direction has shown an influence on the counting direction for both RTL and LTR readers. In addition, illiterate and mixed language subjects show no preference for counting direction. Among school children, LTR school children showed a LTR counting direction that is positively correlated with age. A similar finding was noticed among RTL school children. However, mixed language school children had a RTL counting preference that was negatively correlated with age. The most interesting findings are the results of the studies with preschool children (3-5 years old) who have adapted counting direction from their cultures. This was explained through observational learning, such as reading bedtime stories with their parents (Göbel, McCrink, Fischer, & Shaki, 2018; McCrink, Caldera, & Shaki, n.d.; Shaki, Fischer, & Göbel, 2012). Therefore, even though several studies reinforce the hypothesis that the finger counting habit is mainly a cultural behaviour, genetic, biological, and developmental factors cannot be excluded (Previtali, Rinaldi, & Girelli, 2011).

Another test that uses cross-cultural numerals is the oral SNARC test or the oral version of same-different judgment task. In this test two numerals appear on a screen, one to the right and one to the left. Hence, there is LTR and RTL presentation directionality. The subjects judge the numerical similarities or differences by saying ‘yes’ or ‘no’ into a microphone. Then, the numerals disappear and the speed and accuracy of the responses are recorded and assessed. In a study that included five groups of subjects (monolingual RTL, bilingual RTL/LTR, illiterate, bilingual RTL/LTR children, monolingual LTR), the monolingual RTL subjects showed a reverse oral SNARC effect, while the bilingual RTL/LTR and monolingual LTR subjects showed no significant oral SNARC effect. Furthermore, illiterate subjects showed no oral SNARC effect, while bilingual children showed a strong reverse oral SNARC effect, suggesting the importance of the native language in the early school years (Zebian, 2005).

This section presented the different cognitive behavioural tasks that have been linked to reading direction habit. The following explains this thesis’ methodology.

Chapter 3. Methodology

3.1. Data Acquisition

3.1.1. Participants

All the subjects in this study were either RTL/LTR or LTR/LTR bilinguals. Table 3.1 summarizes the number of participants for each experiment with native and second language information for each. Given that previous studies reported a significant influence of handedness on the central spatial bias (Ossandón et al., 2014), this study only recruited right-handed participants. The subjects also had normal or corrected-to-normal vision and participated either for money (5-15€) or study credits. The subjects performed the handedness test (Edinburgh Test) (Oldfield, 1971), vision accuracy test, and dominant eye test (Miles Test) (Miles, 1929). Each experiment had certain criteria for recruiting participants based on the experimental goal, which will be explained further on.

Table 3.1: Number of Participants in each Experiment and their First and Second Language.

	Experiment							
	1		2	3	4		5	
	(a)	(b)			(a)	(b)	(a)	(b)
No. of participants	39	11	23	19	48	7	56	23
1st language	A/U/P	G/E	G	G/E	G/E	A/U/P	A/U/P	G/E
2nd language	G/E	A/U/P	E	G/E	G/E	G/E	G/E	A/U/P

Note. A= Arabic, U= Urdu, P= Persian, G= German, E= English. Arabic/Urdu and Persian languages are RTL languages while German and English are LTR languages.

3.1.1.1. Ethical Concerns

In regards to ethical guidelines, informed consent was obtained from all participants and the experimental procedures conformed to the Declaration of Helsinki and national guidelines that were approved by the University of Osnabrück Internal Review Board.

3.1.2. Stimuli

3.1.2.1. Images

The images used in the experiments were selected from different categories, including urban and natural scenes and artificial fractal images. The urban category included 60 high-resolution photos of public spaces around Zürich representing man-made environments (taken with a high resolution Nikon D2Z, Japan Camera) (Onat, Açık, Schumann, & König, 2014). The natural category included 60 scenes from the Calibrated Colour Image Database (Olmos & Kingdom, 2004) depicting outdoor natural environment scenes. The artificial fractal category included 60 computer-generated images with shapes of second-order statistics to represent unfamiliar and unnatural stimuli. These were chosen from three different web databases: the 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.net/fegal). The images were presented either in original or mirrored conditions to each subject to eliminate a bias secondary to image content distribution (Ossandón et al., 2014). Figure 3.1 presents samples of the image categories (urban, natural, and fractals) in different conditions (original and mirrored).

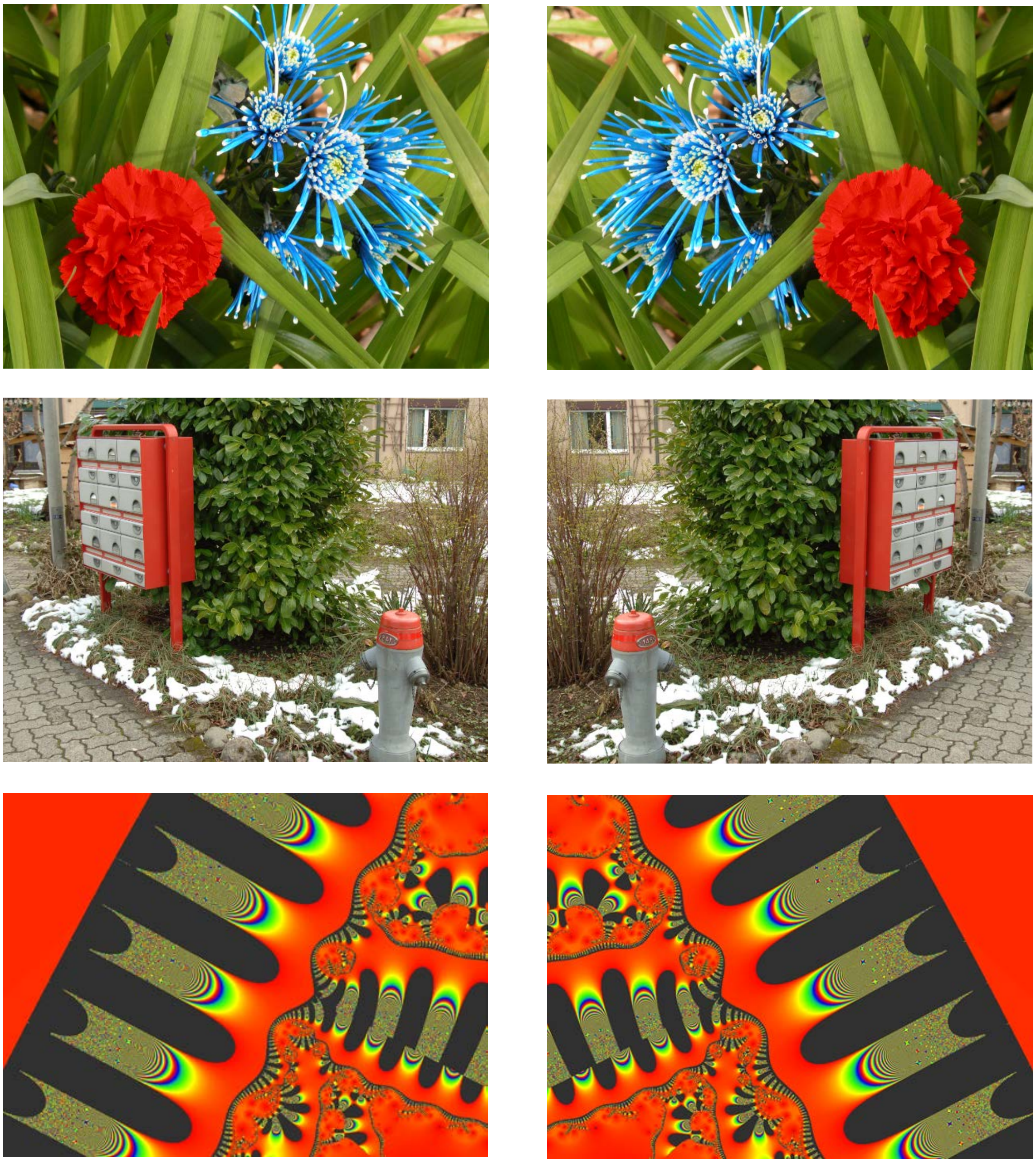


Figure 3.1: Examples of the images used in the experiments.
Images from a natural scene (upper row) and urban scene (middle row) and fractal images (lower row) are presented in the original and mirrored conditions.

3.1.2.2. Primes

The primes differed based on the goal of each experiment. In general, written texts were chosen from neutral excerpts of Wikipedia the Free Encyclopaedia, the British Broadcasting Corporation (BBC), and the German newspapers *Die Zeit* and *Süddeutsche Zeitung*. All the texts used in the experiments were centred to ensure an almost equal number of words distributed on each half of the screen. In addition, the length of the lines was relatively long so that the reader could make a shift of gaze either to the right or to the left when starting the reading process. The images and the primes' white background occupied the whole screen, leaving a small gap between the screen borders and letters. As the leftward spatial bias during visual exploration leads to a few saccades near the boundary of the images, no effect on the fixation behaviour of these gaps was expected. Overall, the size of the primes and subsequent images were comparable. Finally, both the images and primes were viewed on a 21" CRT monitor (Samsung SyncMaster 1100 DF, Samsung Electronics, Suwon, South Korea) at a refresh rate of 85 Hz and a resolution of 1280x960 pixels.

3.1.3. Experimental Setup

A fixation point in the middle of a grey screen (often called drift control) preceded each stimulus presentation. It allowed for the subject to return the gaze to the centre of the screen before starting a new trial and for a continuous calibration of the eye tracker. Except for Experiment 4, an experimental block consists of a text stimulus as a prime, followed by a total of nine images that were presented either in original or mirrored conditions. In a complete experimental design, five blocks with first language primes were presented, followed by five blocks with second language primes. After an optional five-minute break, another five blocks of second language primes were presented, followed by another five blocks of first language primes. A total of 20 primes with 180 test images were presented in 20 blocks. The sequence was balanced with respect to the first and second language across participants. The diagram in Figure 3.2 shows this experimental setup.

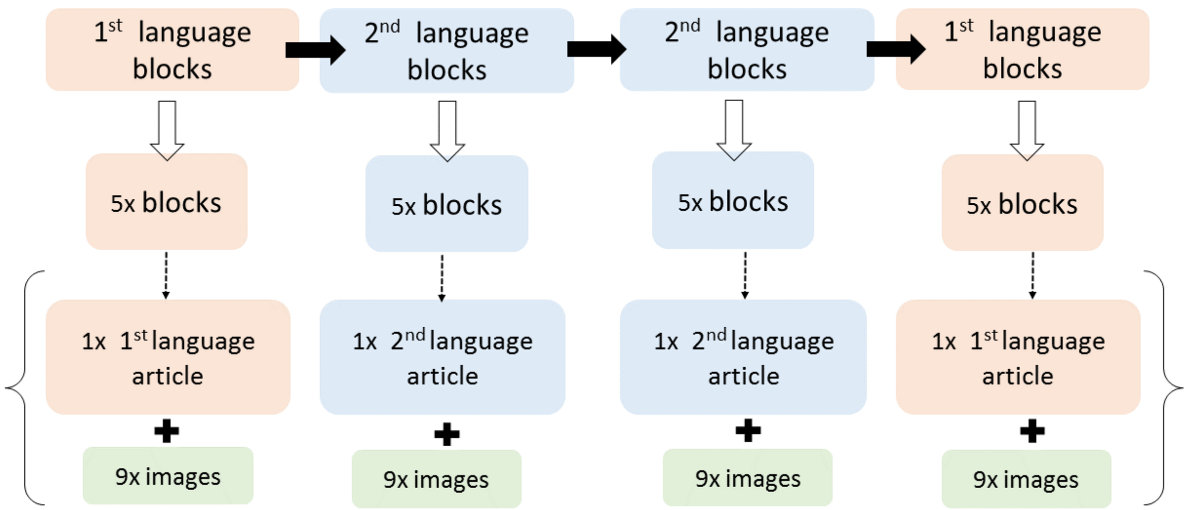


Figure 3.2: The experimental setup for all experiments, except Experiment 4.

3.1.3.1. The Hardware

The hardware used for the experiments mainly included two computers and an eye-tracking device. The experimental code was operated on a 21” Samsung SyncMaster 1100 DF 2004 CRT monitor (Samsung Electronics) with a resolution of 1280x960 pixels and a refresh rate of 85Hz. This monitor is connected to an Apple Powermac G4 800 MHz computer (Apple Inc.). The EyeLink® software (SR Research Ltd) was installed on a Dell Pentium 4 PC (Dell Inc.) and connected remotely to the Powermac to send commands to control the experiment.

3.1.3.2. Eye Tracking Device

The NBP lab in Osnabrück University uses a head-mounted video-based eye tracker system of binocular pupil tracking at 500 Hz with 0.5º average accuracy (Eyelink II, SR Research Ltd, Mississauga, Canada). Eyelink II consists of three miniature cameras mounted on an adjustable headset (Figure 3.3). The infrared light is reflected from the pupils and detected by the video cameras, which are optically-sensitive. The two eye cameras are responsible for binocular tracking while the head camera is used for accurate head position tracking (http://www.sr-research.com/eyelinkII.html). The eye tracker was adjusted to a validation error below 0.3˚ for at least one eye.

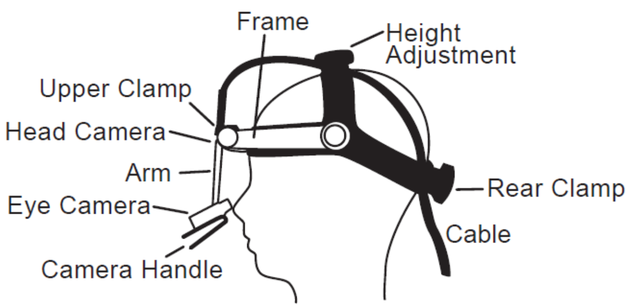


Figure 3.3: Illustrated diagram of the Eyelink II that is used in the NBP department, Osnabrück University.
(http://www.sr-research.com/pdf/ELII dia.pdf).

3.1.4. Experimental Code

A randomization code was prepared to randomize primes, images, and image conditions across subjects. For image conditions, the randomization ensured that for every two participants, one would be presented with the original image and the other with the mirrored image. It also ensured that the experiment started and ended with the blocks containing first language primes and that the blocks in between contained second language primes. The randomization code was inserted into the main experimental code, which ran the experiment in the subsequent randomization after being linked to the subject index and the subject's first and second language. After terminating the experiment, the recorded data was saved as Eyetracker Data Files (EDF).

3.1.5. Experimental Procedure

As the first step all the participants had to read and sign the consent form (Appendix A). After collecting the signed consent, they performed a visual acuity test and dominant eye test (Miles Test) (Miles, 1929). Then, they filled out a questionnaire and handedness test (Edinburgh Test) (Oldfield, 1971). Next, the different parts of the eye-tracker were explained to them in detail, including how it works. The participants received instructions to read the texts silently, avoid moving the head, read in their normal reading speed, and continue reading until the texts disappeared or they finished reading. The participants were aware that there were no follow-up questions about the texts. Once the participants were set 80 cm away from the monitor, had the eye tracker fixed, the lights were switched off, and the calibration step was passed, the experiment started. There was an optional five-minute break after finishing half of the experiment, but it required another calibration afterwards. When the experiment was finished, the eye tracker was quickly removed, the lights switched on, and the subjects received the reward money or student credit promised.

3.2. Data Analysis

3.2.1. Analysis of EDF Files

The EDF files gathered were transferred to the lab computers for further analysis, where the EDFread Matlab extension converted the EDF files into fixmat data files. The fixmat data files contained the following fields: onset of the fixation points (start), offset the fixation points (end), horizontal fixation points (x), vertical fixation points (y), trials index (trial), images index (image), image conditions index (condition), subject index, text prime index (article), image category (category), and language of the primes (language). The data regarding the calibration process and the pre-trial fixations were then deleted and the data was categorized into image data and prime data. The image data was further categorized based on the type of primes presented prior to the images (first type prime/second type prime).

3.2.2. Creating Fixation Density Maps (Heat Maps)

Fixation-density maps were created to generally visualize the spatial effect of the reading direction across the subjects. These maps were created for different primes and images presented after different primes. Therefore, the fixation points were separated into fixation points over the primes and fixation points over the images. The horizontal and vertical spatial distributions of the fixation points over the stimuli were transformed to a probability distribution and displayed graphically into 2D tables. To avoid binning artefacts, the distribution was smoothed using a convolution with a circular 2D Gaussian kernel of 0.5˚ full width at half maximum. On these graphs, the lighter colours (from yellow to white) represent the areas that were fixated on more frequently. On the other hand, the darker colours (from red to black) represent the areas that were less fixated on or not fixated on at all. Therefore, fixation density maps highlight the overall fixations that were made on a given set of stimuli without showing the changes over the time course.

3.2.3. Creating Time Course Diagrams

To investigate how the fixations changed position over time, time course diagrams were created. For each text, prime condition (2 levels) and time interval (1s width, equally spaced from 0s to 6s) were considered and, after pooling across all subjects, the time course of the horizontal fixation points was visualized. First, the temporal and the horizontal spatial coordinates of fixation points were extracted from original and mirrored images, separately. Next, to reduce the amount of high frequency noise on the images, these data were convoluted with spatial (Gaussian kernel of full width at half maximum = 2˚) and temporal (Gaussian kernel of full width at half maximum = 20 ms) filters. After this, the horizontally flipped mirrored image matrices were subtracted from the original image matrices. Positive values indicated more fixations at this position compared to the corresponding position in the mirrored image. Correspondingly, negative values indicate fewer fixations at this position compared to the corresponding position in the mirrored image. Therefore, the positive values are represented in yellow to red colours while negative values are displayed in blue tones. The green colour represents the areas that received no fixations.

3.2.4. The Difference between the Left and Right Horizontal Coordinates of the Fixation Points

For each prime condition (LTR or RTL) and time interval (1s width, equally spaced from 0s to 6s) the horizontal spatial bias was calculated, after pooling across all the subjects. For all original images the summed horizontal position of the fixations left-of-the-centre was subtracted from the summed horizontal position of the fixations right-of-the-centre. This calculation was repeated for the mirrored images and subtracted from the result of the original images. Finally, the result was normalized by the total number of fixation points, expressing the average horizontal spatial bias.

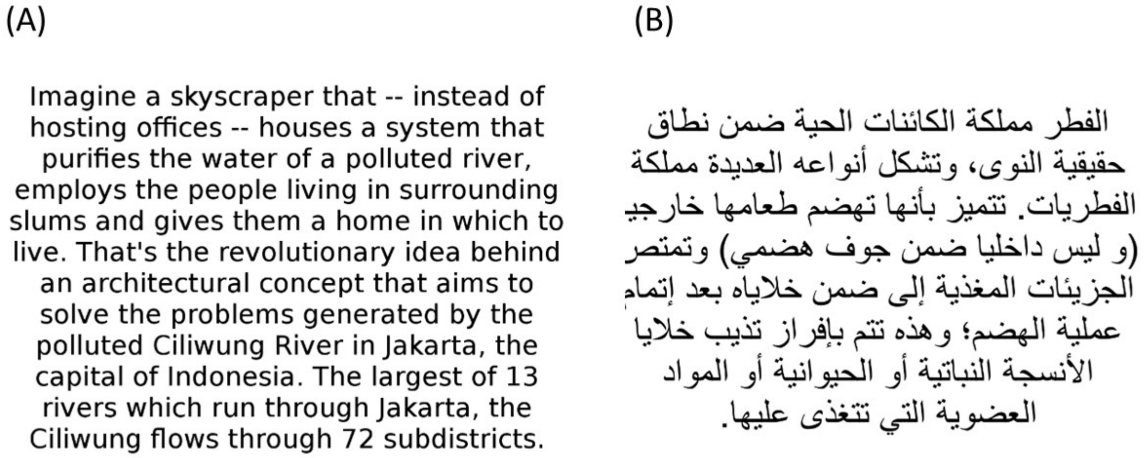
3.2.5. Statistical Analysis

The statistical analysis was based on the average horizontal spatial bias. These data were distributed in 12 groups based on two independent variables: text primes (2 levels) and time (6 levels). The effects of the text primes, time, and their interactions were analysed by two-way repeated measures ANOVA. All the groups' normality was checked with the D'Agostino-Pearson Test. When it was violated, these were corrected through outlier removal by using the outlier labelling rule (Tukey, 1977). The homogeneity of the variance was also checked for using Mauchly's Test.

Chapter 4. The Effect of Reading Direction on the Horizontal Spatial Bias

This chapter answers the question of whether or not the reading direction habit has a dynamic effect on the horizontal spatial bias. For this purpose, two groups of participants were recruited. Experiment 1(a) included 39 bilinguals (8 females; 21-60 years) that were native in a RTL language (Arabic, Urdu, or Persian) and had a good level in a LTR language (German and/or English). Experiment 1(b) included 10 Germans and 1 Pakistani (4 females; 14-30 years) that were native in a LTR language and who learned to read and write a RTL language later in life; either in school or from one of their parents.

In Experiment 1 texts written in languages with RTL and LTR reading directions (Arabic/Urdu/Persian and German/English respectively) served as primes before each set of images. On average, the RTL texts included 10 lines, while the LTR texts had 12 lines. This small difference is due to the character's size and the length of the sentences. Figure 4.1 shows examples of RTL and LTR text primes.


(A)

Imagine a skyscraper that -- instead of hosting offices -- houses a system that purifies the water of a polluted river, employs the people living in surrounding slums and gives them a home in which to live. That's the revolutionary idea behind an architectural concept that aims to solve the problems generated by the polluted Ciliwung River in Jakarta, the capital of Indonesia. The largest of 13 rivers which run through Jakarta, the Ciliwung flows through 72 subdistricts.

(B)

الفطر مملكة الكائنات الحية ضمن نطاق
حقيقية النوى، وتشكل أنواعه العديدة مملكة
الفطريات. تتميز بأنها تهضم طعامها خارجيا
(و ليس داخليا ضمن جوف هضمي) وتمتص
الجزيئات المغذية إلى ضمن خلاياه بعد إتمام
عملية الهضم؛ وهذه تتم بإفراز تذيب خلايا
الأنسجة النباتية أو الحيوانية أو المواد
العضوية التي تتغذى عليها.

Figure 4.1: (A) LTR text prime and (B) RTL text prime examples.

4.1. Results of Experiment 1(a)

The overall viewing behaviour of the RTL/LTR group after reading the RTL and LTR text primes are demonstrated in Figure 4.2 using fixation density maps. In this case, native RTL readers fixated more at the beginning of each line and could read most of the texts written in their native language (Figure 4.2 A, left panel). On the other hand, for the texts in the second language, participants fixated mostly in the upper half of the texts (Figure 4.2 A, right panel). This effect is presumably due to the higher fluency of their native language compared to that of the secondary language (Pollatsek et al., 1981). The fixation density maps for the images after the primes showed an almost similar effect in the overall fixations. The fixations over the images after reading RTL primes and LTR primes were concentrated mainly in the middle of the screen (Figure 4.2 B), which suggests a similar overall viewing behaviour after reading texts with different reading directions.

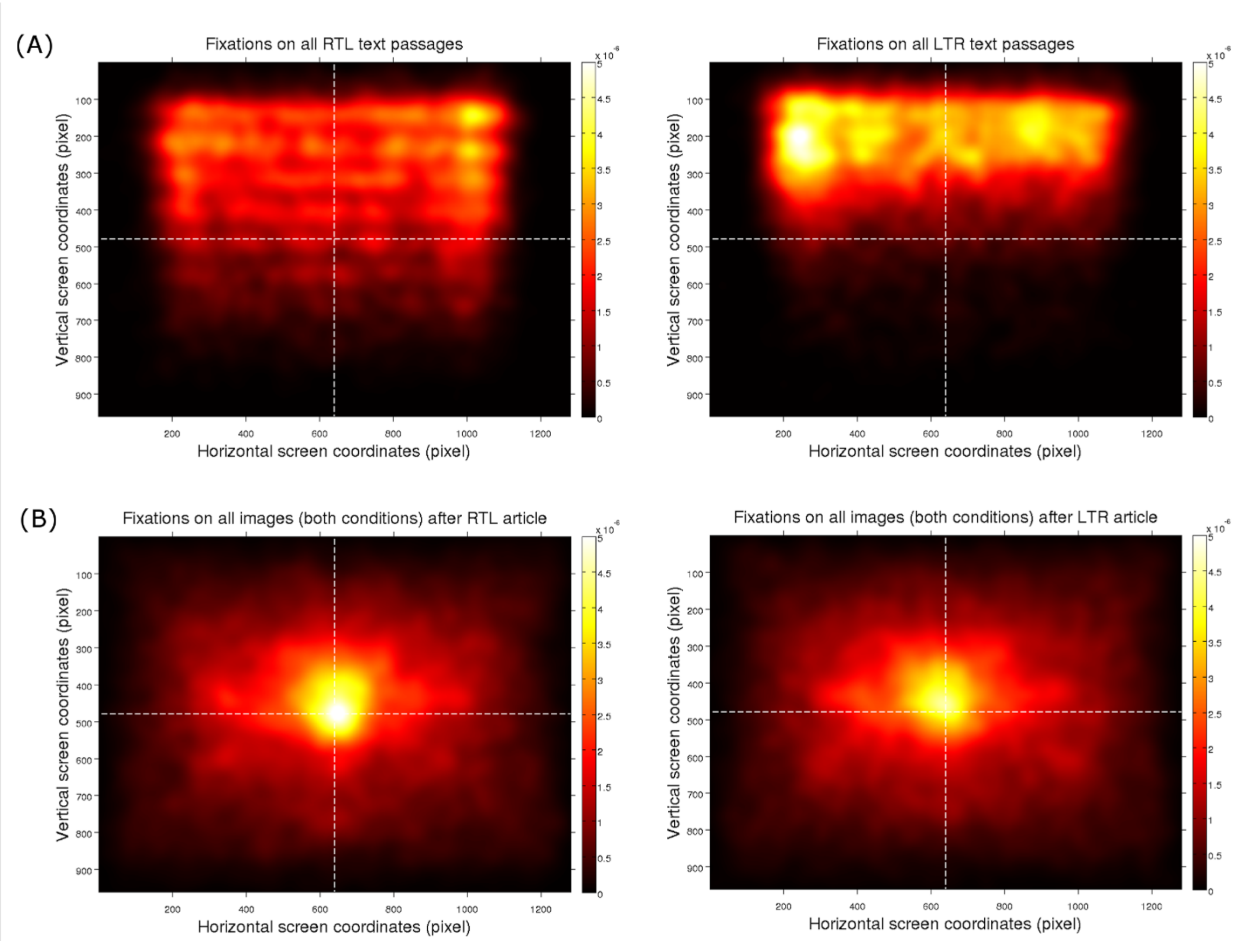


Figure 4.2: Experiment 1(a): Fixation density maps for (A) RTL and LTR text primes and (B) all the images presented after the primes.
The lighter colours represent the areas that were fixated on more frequently, while the darker colours represent the areas that were less fixated on.

In the subsequent exploration of complex scenes, the time course diagrams showed an early rightward bias after reading RTL text primes (Figure 4.3, left panel, and Figure 4.4). In contrast, an early leftward bias after reading LTR texts was observed (Figure 4.3, right panel, and Figure 4.4).

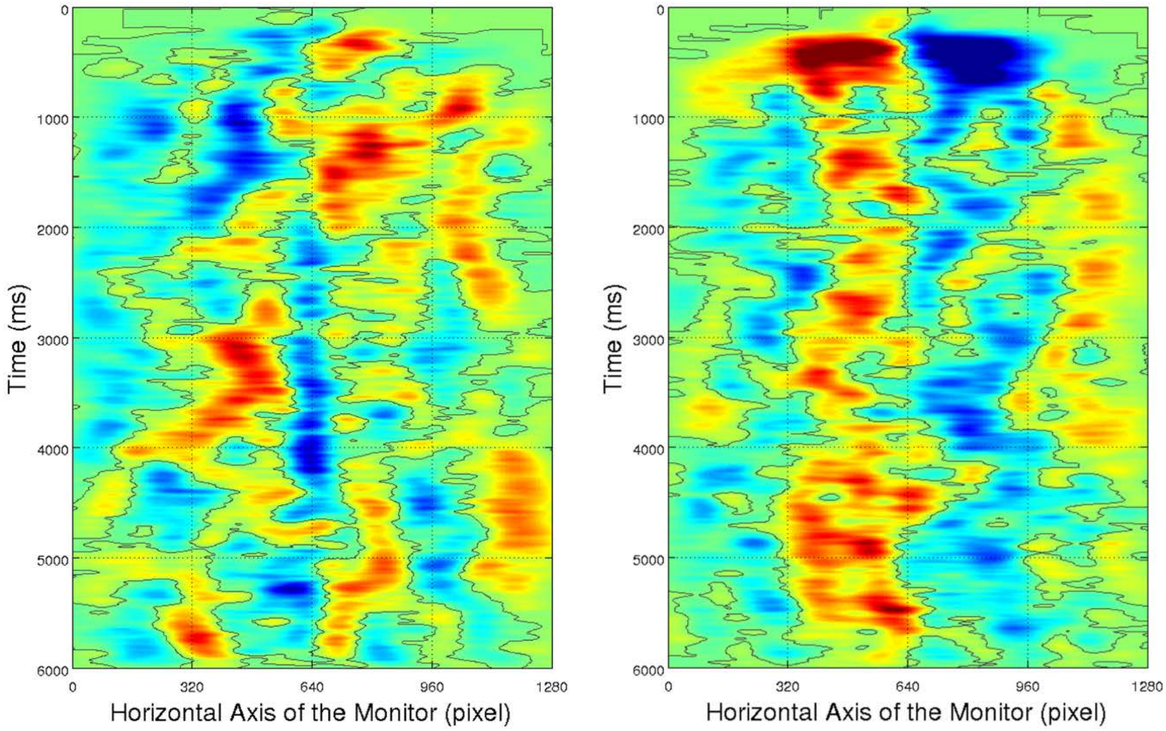


Figure 4.3: Experiment 1(a): Time course diagrams for the fixations on all images following RTL text primes (left) and LTR text primes (right).
The red-yellow tones represent the fixations on the original images while the blue tones represent the fixations on the mirrored images. The green areas are the areas with no fixation points.

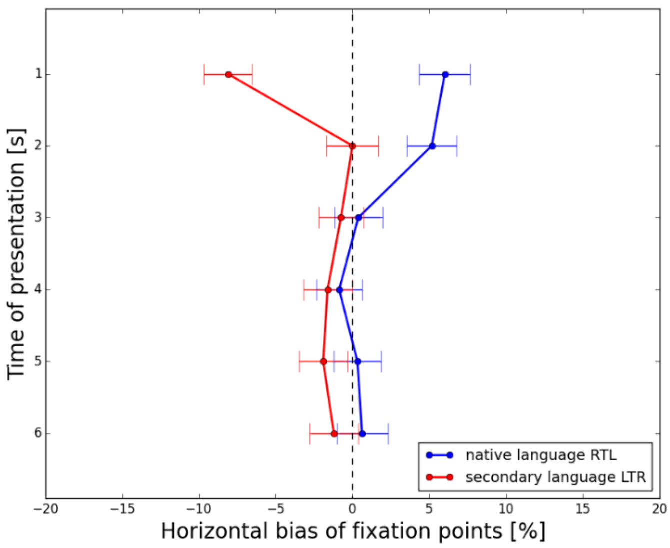


Figure 4.4: Experiment 1(a): The horizontal spatial bias of the fixation points (mean ± SE.M).
The positive values represent a rightward spatial bias and the negative values represent a leftward spatial bias when compared to the center of the screen (zero value).

Statistically, the two-way repeated measures ANOVA within subjects revealed a significant main effect of the prime *($F(1,175)=17.4$, p*<0.001) and also that the time factor was not significant *($F(5,875)=1.6$, $p\sim0.15$)*. However, a statistically-significant interaction of prime and time *($F(5,875)=5.5$, $p<0.001$)* can be observed.

To see which intervals contributed to the effect, the paired t-test was performed. A statistically-significant effect between RTL and LTR text primes was detected only during the first second after the onset of the stimuli *($t(175)=-6.320$, $p<0.001$,* Table 4.1*)*. This demonstrates that reading a text dynamically modulates the direction and degree of spatial bias during the exploration of subsequent test images, but that this modulation occurs for a short period of time, specifically during the first two seconds of image viewing.

Table 4.1: Experiment 1(a): Paired sample t-test (2x6).
*p<0.05, statistically-significant effect.

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

4.2. Results of Experiment 1(b)

Experiment 1(b) complements this investigation by studying the effect of the reading direction habit among native LTR language speakers who learned a RTL language later in life. Upon presentation of the text primes in their native language, participants read almost the entirety of the texts in the LTR primes (Figure 4.5 A, left panel). In contrast, when reading texts in their second language, they showed a marked difficulty in reading the texts and fixated mainly on the first two lines of the texts (Figure 4.5 A, right panel). This difference demonstrates the participants' increased effort while reading in their second language. The fixation density maps also show that the fixations on the images after reading the LTR texts were slightly biased to the left (Figure 4.5 B, left panel), while the fixations on the images after reading the RTL texts were concentrated on the centre of the images (Figure 4.5 B, right panel).

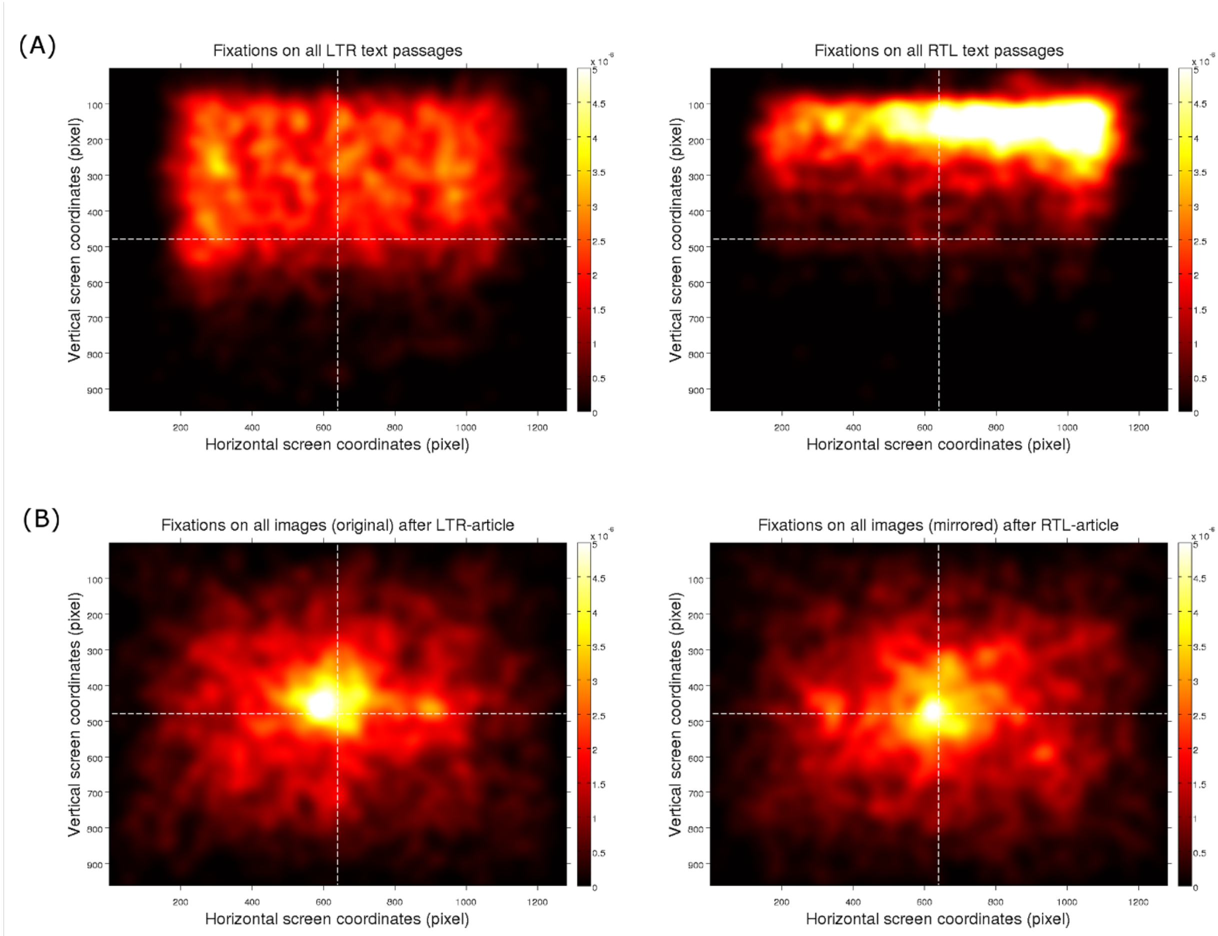


Figure 4.5: Experiment 1(b): Fixation density maps for (A) LTR and RTL text primes and (B) all the images presented after the primes.

The time course diagrams show that participants fixated on the left part of the images more often both after LTR and RTL primes (Figure 4.6). The results also showed that, after reading LTR texts and in the first second of stimulus onset, there was approximately a 20% bias towards the left side of the images. Afterwards, the bias varied around the centre. After reading RTL texts, in the first second after the stimulus presentation, the bias started at about 10% on the left side of the images and then shifted back and forth (Figure 4.7).

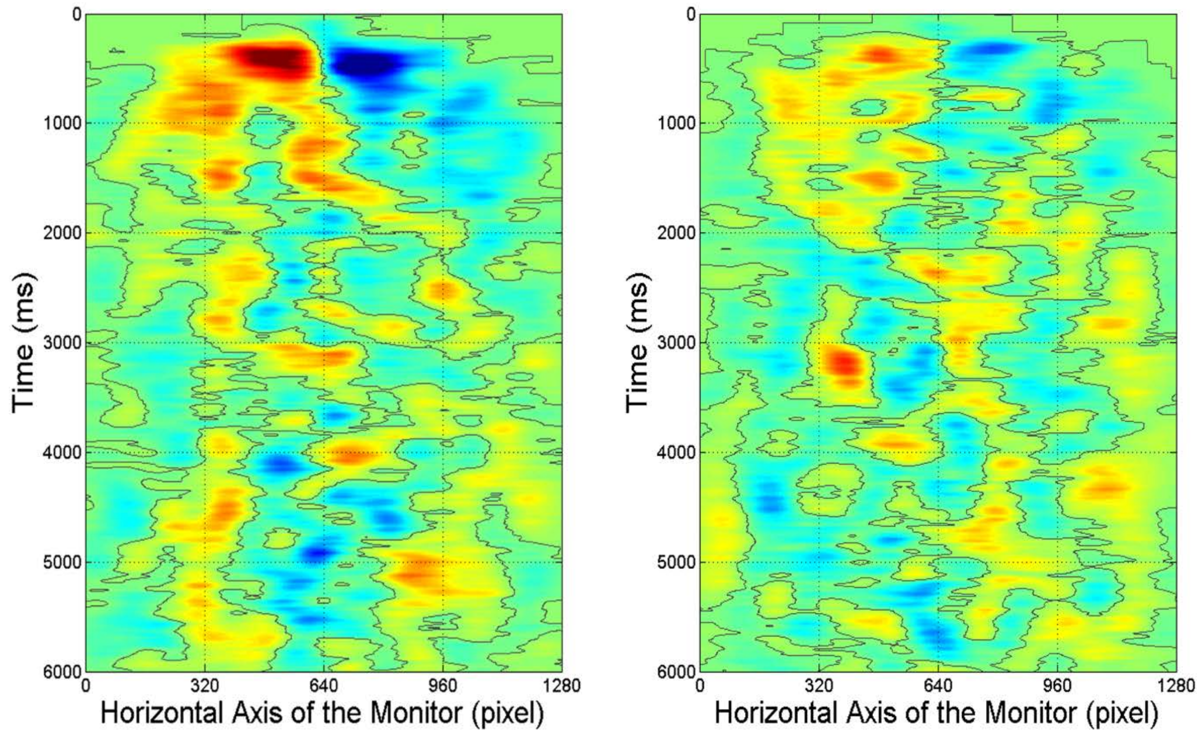


Figure 4.6: Experiment 1(b): Time course diagrams for the fixations on all images that followed LTR text primes (left) and RTL text primes (right).

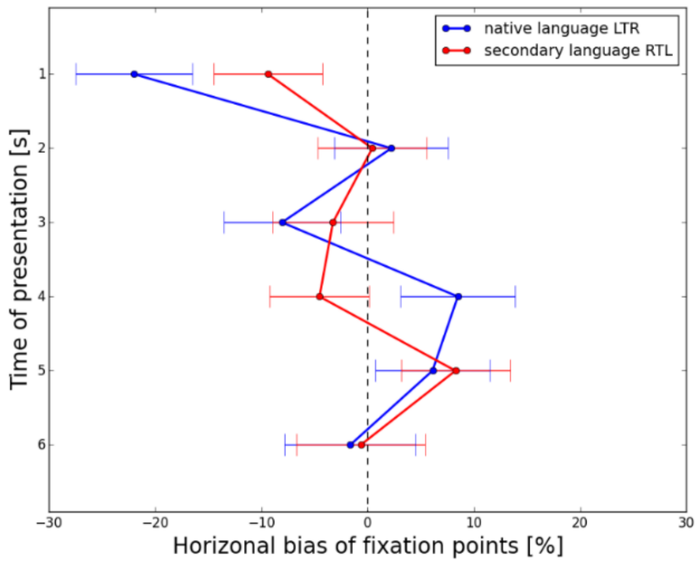


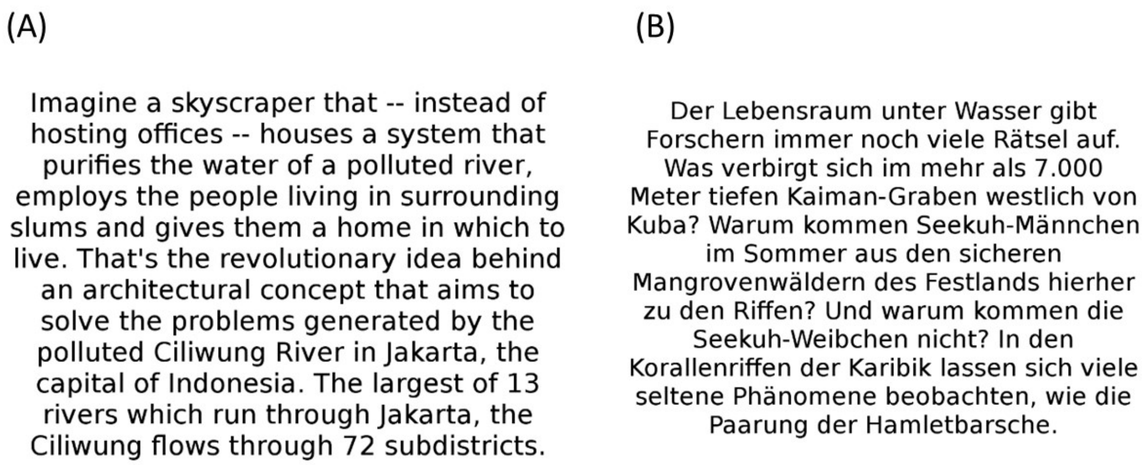
Figure 4.7: Experiment 1(b): The horizontal spatial bias of the fixation points (mean ± SE.M).

The large SEM in the graph is due to this group's small sample size.

Testing the difference in the laterality of the fixation points, a two-way repeated-measures ANOVA showed no significant effect of the 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 the prime and time *(F(5,350)=1.198, p=0.310)* was observed. Thus, in spite of the fact that there was a reduction in the leftward spatial bias after reading RTL text primes, the effect was not significant. This could either be due to the group's small sample size (only 11 subjects) or their low proficiency in reading RTL language texts.

Chapter 5. The Effect of Native and Second LTR Languages on the Horizontal Spatial Bias

This experiment was aimed at understanding the difference in the horizontal spatial bias after reading two different languages written in the same direction. For this purpose, the text primes were presented in German and English, both in the LTR reading direction (Figure 5.1). The participants of Experiment 2 were bilinguals who spoke at least two LTR languages. The group consisted of 23 participants who mastered German and English (10 females, 18-27 years). This experiment was also a control group for Experiment 1.



(A)

Imagine a skyscraper that -- instead of hosting offices -- houses a system that purifies the water of a polluted river, employs the people living in surrounding slums and gives them a home in which to live. That's the revolutionary idea behind an architectural concept that aims to solve the problems generated by the polluted Ciliwung River in Jakarta, the capital of Indonesia. The largest of 13 rivers which run through Jakarta, the Ciliwung flows through 72 subdistricts.

(B)

Der Lebensraum unter Wasser gibt Forschern immer noch viele Rätsel auf. Was verbirgt sich im mehr als 7.000 Meter tiefen Kaiman-Graben westlich von Kuba? Warum kommen Seekuh-Männchen im Sommer aus den sicheren Mangrovenwäldern des Festlands hierher zu den Riffen? Und warum kommen die Seekuh-Weibchen nicht? In den Korallenriffen der Karibik lassen sich viele seltene Phänomene beobachten, wie die Paarung der Hamletbarsche.

Figure 5.1: (A) English text prime and (B) German text prime examples.

5.1. Results of Experiment 2

During the reading of native LTR texts, participants read nearly the whole texts (Figure 5.2 A, left panel). While reading the second language texts, fixations were more restricted to the beginning of the lines and to the upper half of the texts (Figure 5.2 A, right panel). Similar to in Experiment 1, this can be interpreted as the consequence of a lower proficiency in the second language, with a reduced reading rate and a slightly increased effort. The fixation density maps for the images showed a central spatial bias after reading both the text in the native and in the second language (Figure 5.2 B).

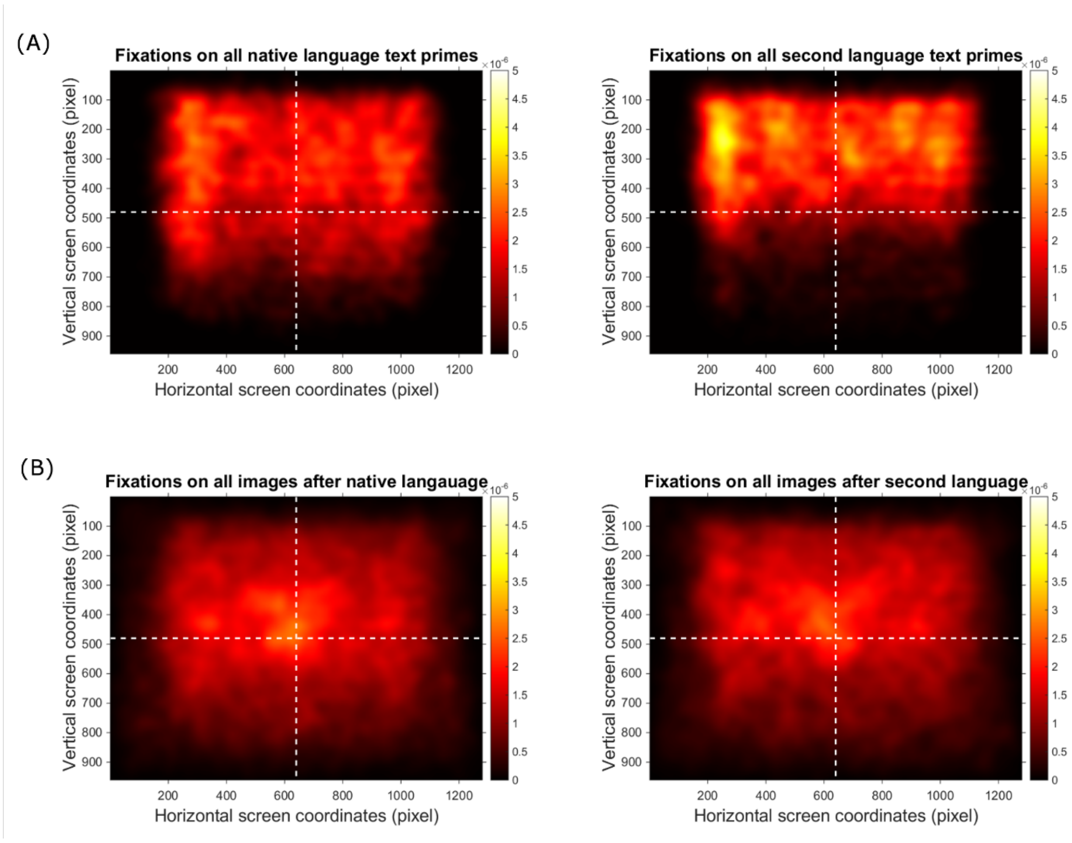


Figure 5.2: Experiment 2: Fixation density maps for (A) native and second language primes and (B) all the images presented after primes.

Time course diagrams showed that participants initially fixated more towards the left after LTR text primes in their native and second language (Figure 5.3, and Figure 5.4). After a few seconds, this effect was reversed and a small bias to the right emerged (Figure 5.4).

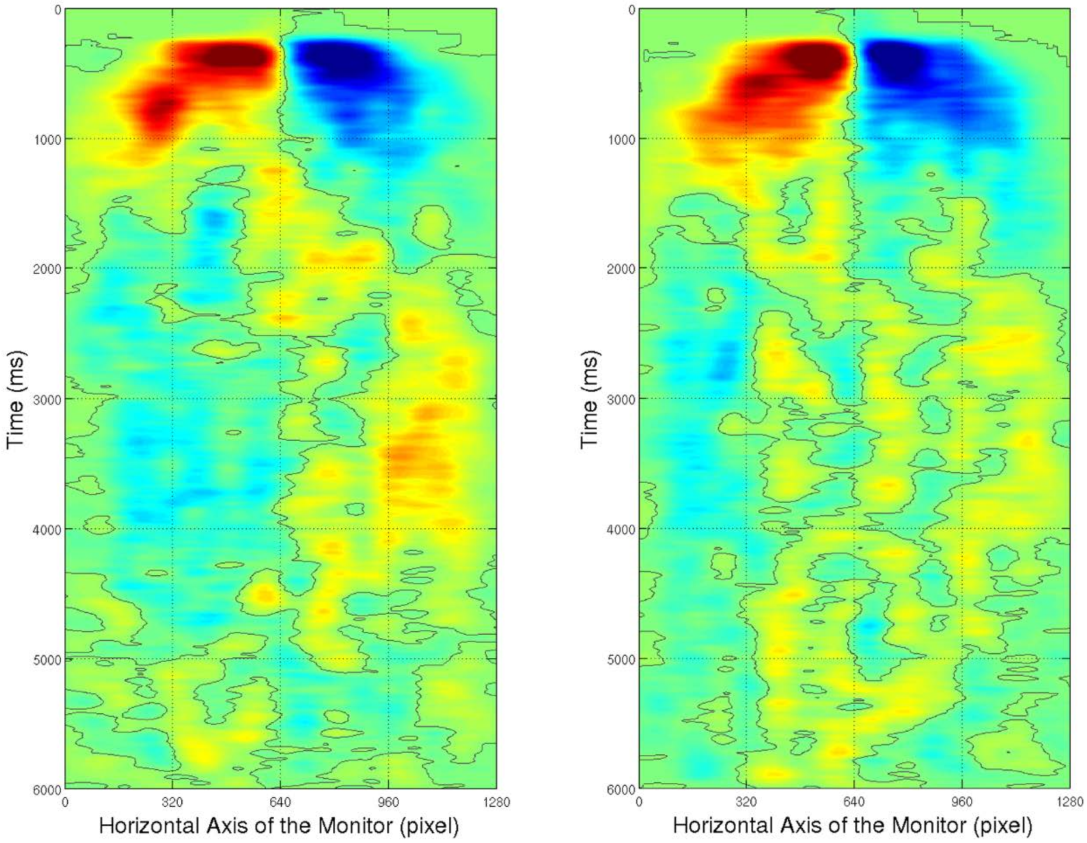


Figure 5.3: Experiment 2: Time course diagrams for the fixations on all images that followed native language primes (left) and second language primes (right).

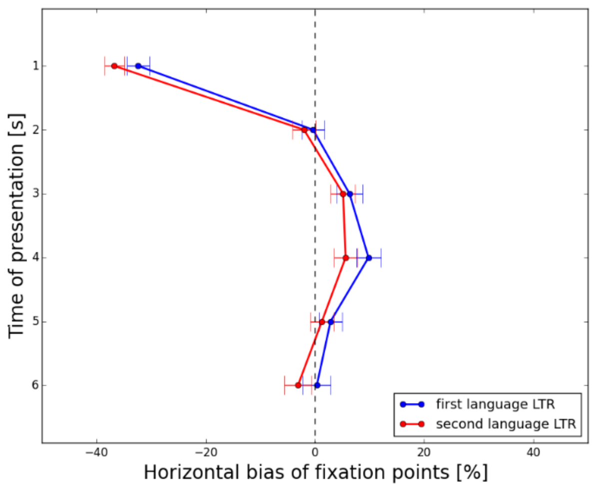


Figure 5.4: Experiment 2: The horizontal spatial bias of the fixation points (mean ± SE.M).

The statistical evaluation revealed that sphericity was violated for the factor of time *(X2 (14)=40.200,* $p<0.001$*)* and for the interaction between prime and time *(X2 (14)=43.568,* *p<0.001)*. Therefore, the degrees of freedom were corrected using Greenhause-Geisser estimates of sphericity *(ε=0.915 and 0.913, respectively)*.

A two-way repeated measures ANOVA revealed a main effect of the prime *(F(1,165)=4.953,* p*=0.027)*. Furthermore, 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 interaction of prime and time was not significant *(F(4.564,753)=0.199, p=0.954)*.

Chapter 6. The Effect of Habitual and Non-Habitual Reading Direction on the Horizontal Spatial Bias

This chapter presents the result of the examination of the relative influence of habitual and non-habitual reading processes on the horizontal spatial bias. For this purpose, subjects were presented with text primes only in their native language (LTR; English or German). However, half of these were displayed in the habitual reading direction and the other half in a mirrored condition (mLTR) (Figure 6.1). The group included 19 new participants (12 females, 18–35 years) who spoke and read only LTR languages.

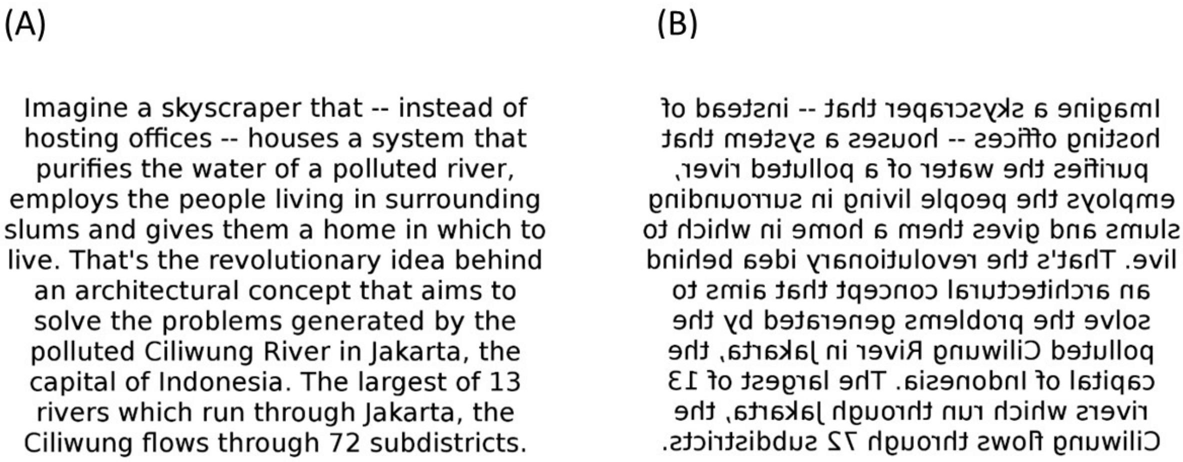


Figure 6.1: (A) LTR text and (B) mirrored LTR text examples.

6.1. Results of Experiment 3

When the participants read texts in their native language (Figure 6.2 A, left panel), they easily and evenly covered the whole texts. In contrast, when they were reading mirrored texts in their native language (Figure 6.2 A, right panel), they explored only the first line and the beginning of the second line. This demonstrates the large difference in the effort necessary for reading mirrored texts versus texts in the original script. The fixation density maps for the images presented after the primes showed a preference to fixate slightly to the left of the images after reading the normal LTR texts and to the centre of the images after reading the mLTR texts (Figure 6.2 B).

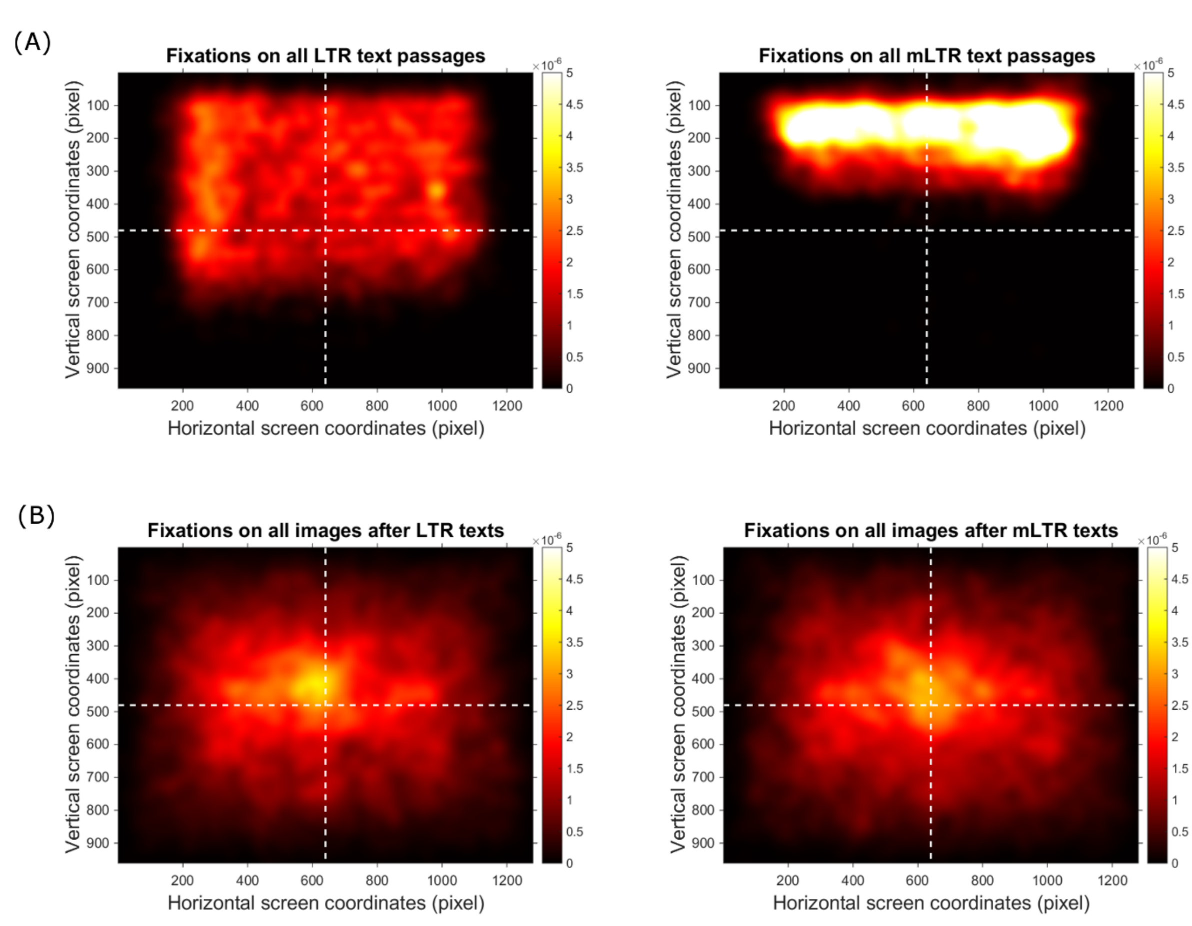


Figure 6.2: Experiment3: Fixation density maps for (A) LTR and mLTR texts and (B) all images following the text primes.

The time course diagrams for exploring the images showed a leftward bias during the first two seconds and then a bias around the centre of the images. The graphs demonstrated a similar pattern for the viewing behaviour after reading the normal and mirrored LTR texts (Figure 6.3 and Figure 6.4).

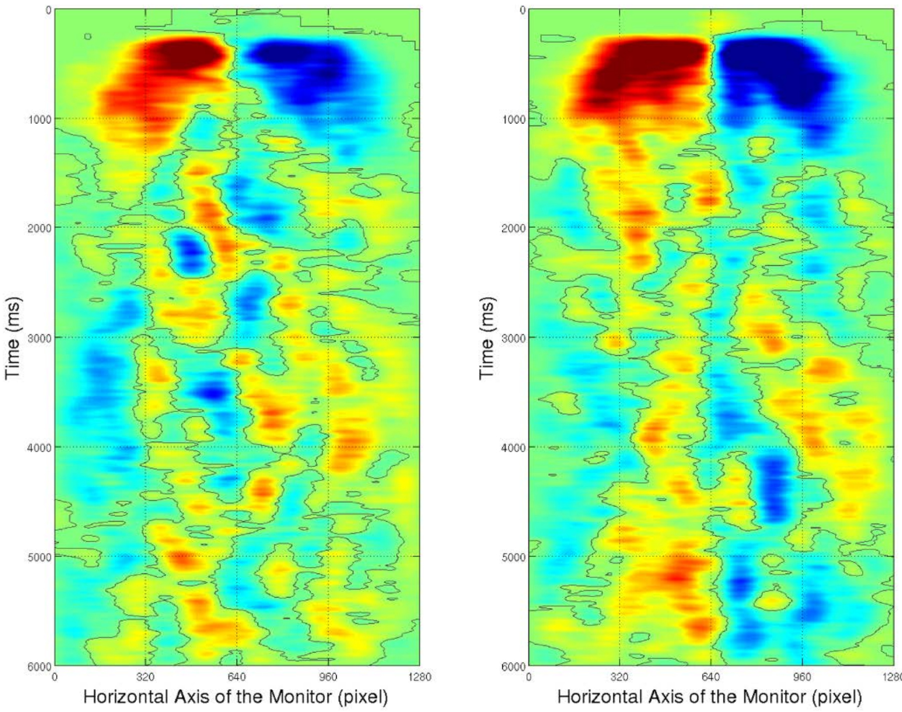


Figure 6.3: Experiment 3: Time course diagrams for the fixation points during the free exploration of all images presented after the normal text primes (left) and mirrored text primes (right).

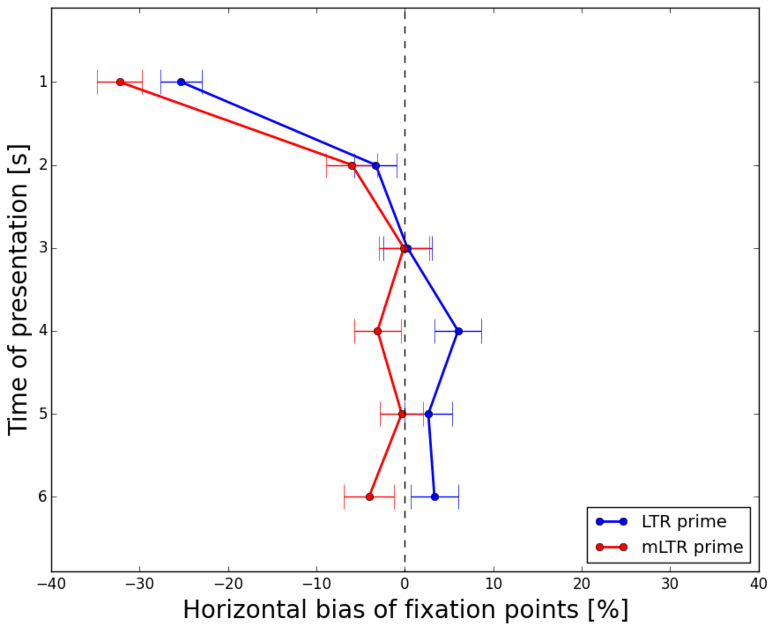


Figure 6.4: Experiment 3: The horizontal spatial bias of the fixation points (mean ± SE.M).

Statistically, Mauchly's Test of Sphericity for the factor of time and the interaction effect between prime and time was violated *(X2 (14)=33.383, p=0.003, X2 (14)=34.907,* *p=0.002, respectively*). The degrees of freedom were corrected with the Greenhause-Geisser test *(ε=0.926, ε=0.913, respectively)*.

The two-way repeated-measures ANOVA revealed a significant main effect of the 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 the effect size of LTR and mLTR primes was small and more leftward-directed for the mLTR stimuli. Furthermore, the interaction between the prime and time ($F(4.563,688)=0.833$, $p=0.518$) was not significant.

Chapter 7. Joint Analysis of the Duration Effect on the Spatial Bias

In the previous experiments a decline of the spatial bias across the sequence of images after reading the text primes could be observed. When pooling all the subjects in these three experiments, two categories can be created: images displayed after LTR texts and images displayed after RTL texts. To create these categories, Experiment 1(a), (first and second primes), Experiment 1(b) (first and second primes), Experiment 2 (first and second primes), and Experiment 3 (first prime) were pooled into RTL and LTR prime groups, as appropriate. Figure 7.1 displays the spatial bias after reading LTR primes and RTL primes during the first second of the visual exploration as a function of the position of the test image in the sequence. The LTR prime shifts the spatial bias to the left throughout the image sequences. Note that while 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 one), the leftward spatial bias is re-established. Indeed, during the first second of visual exploration of the ninth image, the spatial bias is nearly 80% of the strength observed during the first image. In contrast to the reliable effect after LTR text primes, the RTL prime shifts the spatial bias slightly to the right while exploring the first two images, and later the bias is shifted more to the left.

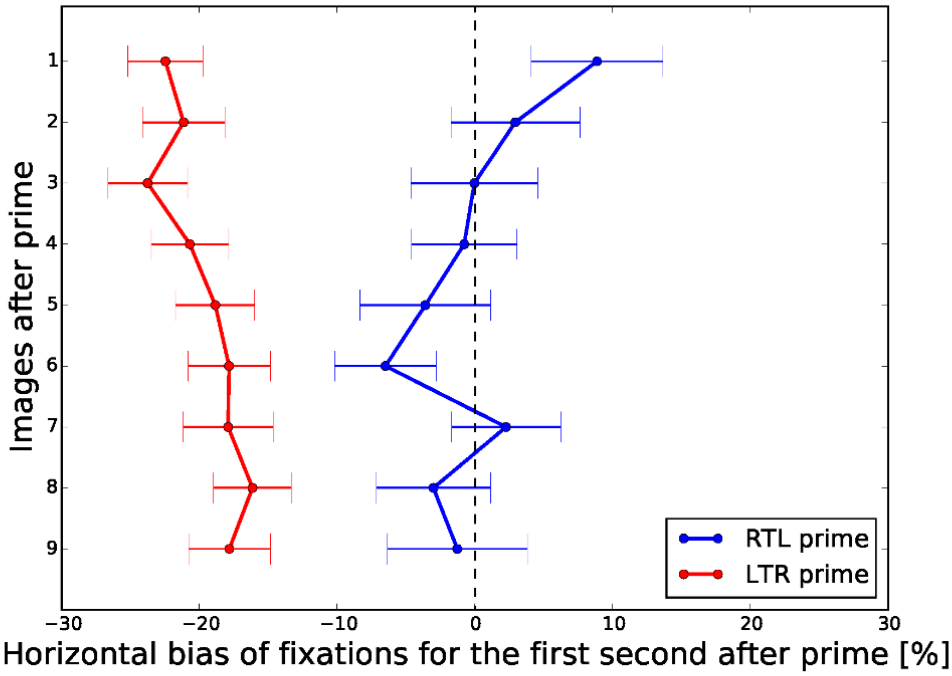


Figure 7.1: The spatial bias of the horizontal fixation position (mean ± SE.M) for Experiments 1-3.
Time resolved across the presentation of sets of nine test images after the presentation of each text prime. The spatial bias was calculated for the first second after exploring the images and pooled across all participants. The positive values represent the rightward bias, and the negative values represent the leftward bias.

Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated for the effect of the images and for the interaction effect of the primes and images, respectively ($X^2(35)=41.773, p=0.203, X^2(35)=41.462, p=0.212$). Subsequently, a two-way repeated-measures ANOVA was performed to study the interaction between primes and images (2 x 9). This showed that there was no significant main effect of the position of the images in the sequence ($F(8,368)=0.688, p=0.702$), but that there was a significant main effect of the prime ($F(1, 46)=23.610, p<0.001$). Furthermore, there was no significant effect found in 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 re-instantiated upon each new image presentation for at least one minute.

Chapter 8. The Effect of the Oculomotor Control on the Horizontal Spatial Bias

This chapter presents the results of Experiment 4, which tests the effect of the oculomotor control on the horizontal spatial bias without including linguistic contents in the trials. For this purpose, the reading text primes were replaced with moving-dot primes. Before the start of each trial, a point appeared in the middle of a grey background for drift correction. Participants fixated their gaze on a white circle with a black dot in the middle that moved on the grey background. The circle (called moving-dot) was positioned during the whole trial presentation along a virtual horizontal line at the monitor's half height. It moved from one end of the monitor towards the other end, then disappeared and reappeared at the beginning of the line again. It took 12 repetitions of the moving-dot row to use 60s (Figure 8.1).

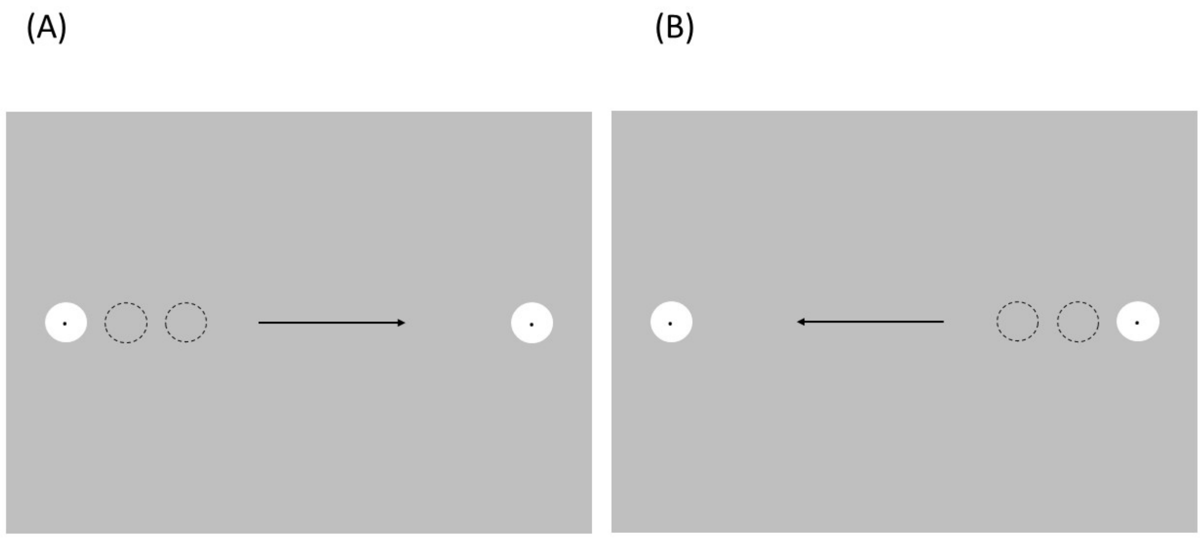


Figure 8.1: (A) LTR moving-dot, and (B) RTL moving-dot.

The experimental setup was as follows: A total of four primes with 180 test images were presented in four blocks. Each block consisted of a moving-dot as a prime, followed by a total of 45 test images chosen randomly from the three images categories; either in original or mirrored condition. In two of four prime trials, the moving-dots moved from left to right. In the other two prime trials, they moved from right to left for the same amount of time. The test-image stimuli were kept identical to the previous experiments. For half of the participants, the first and last block presented a RTL trajectory and the second and third block a LTR trajectory. For the other half of the participants, RTL and LTR trajectory blocks were interchanged (Figure 8.2). The data analysis for Experiment 4 is similar to that of Experiments 1-3.

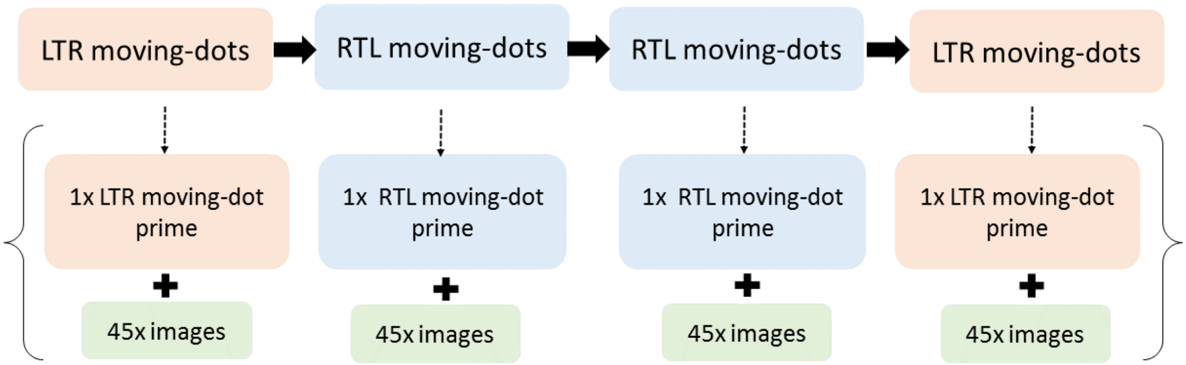


Figure 8.2: Experimental setup for Experiment 4.
In Experiment 4, two of four prime trials consisted of LTR moving-dots. The other two prime trials consisted of RTL moving-dots. 45 images were presented randomly after each moving-dots trial. Each moving-dots trial was presented for 60s while each image was presented for 6s.

In close analogy to the preceding experiments, the horizontal bias was investigated during the image exploration. Two groups of subjects were recruited for this experiment: 48 new participants (31 female, 18-36 years) who spoke LTR languages were recruited to be in group (a) and 7 native RTL readers who learned LTR languages were recruited for group (b) (pilot study).

8.1. Results of Experiment 4(a)

The fixation density maps for the moving-dot trials demonstrated that the participants did successfully follow the moving-dots in either direction without focusing somewhere else (Figure 8.3 A). Their overall fixations of the images following both the LTR and RTL moving-dots were focused around the centre (Figure 8.3 B).

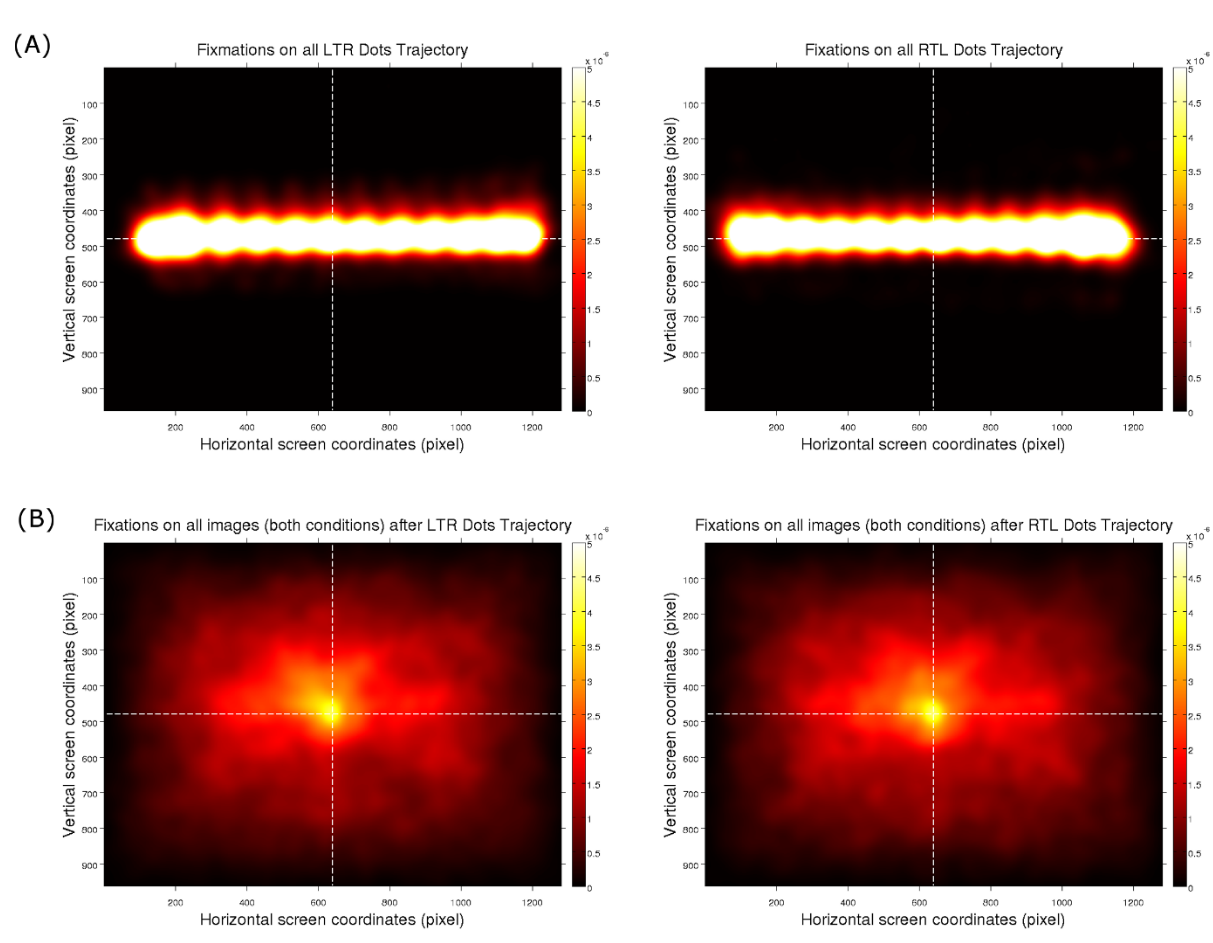


Figure 8.3: Experiment 4(a): Fixation density maps for (A) LTR and RTL moving-dots primes and (B) all images following the moving-dot primes.

The viewing bias time resolved across the visual exploration of images averaged over the whole sequence of 45 test images after each prime was also investigated. The results showed that the fixation points started biased to the left and then shifted towards the centre of the images (Figure 8.4). The participants started the image exploration with about 20% spatial bias towards the left side. Afterward, they sharply shifted their gaze towards 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-dots primes, in comparison with the LTR moving-dots primes, was slightly smaller and also shifted towards the right (Figure 8.5).

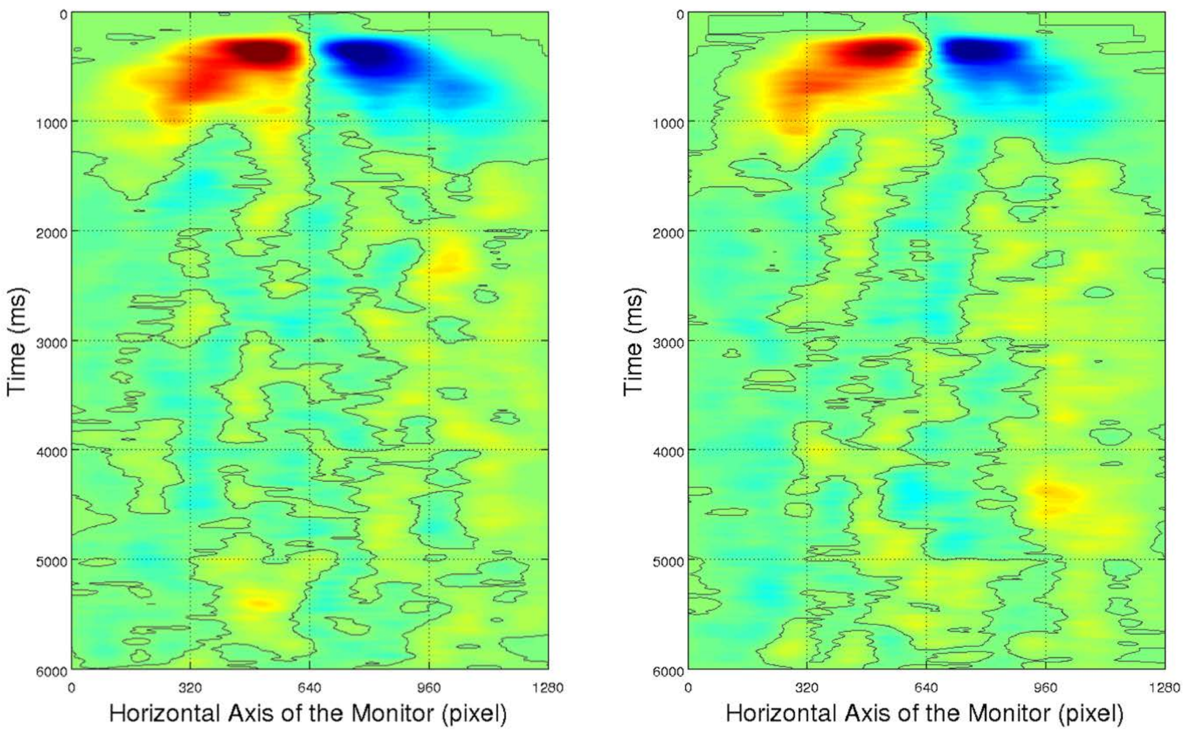


Figure 8.4: Time course diagrams for the fixation points during the free exploration of all images presented after LTR moving-dots (left) and RTL moving-dots (right).

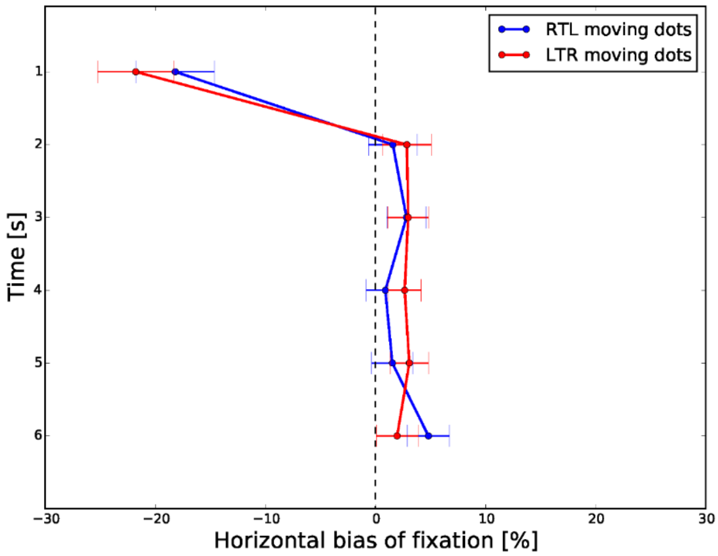


Figure 8.5: Experiment 4(a): The horizontal spatial bias of the fixation points (mean ± SE.M) after LTR and RTL moving-dots primes averaged over the whole sequence of images.

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

As there was no significant effect of the prime averaged over the whole sequence of images, potential short-lasting effects were tested. The first 10 images after the moving-dot primes were selected for this analysis. A two-way repeated-measures ANOVA demonstrated no significant main effect of the prime *(F(1,47)=0.157, p=0.693)*. On the other hand, a significant effect of the time factor was reported *(F(3.778,177)=18.911, p≤0.001)*. Furthermore, there was no statistically-significant interaction of the prime and time *(F(4.101,192)=1.800, p=0.129)*. Thus, even on a short time scale, no significant difference between the LTR and RTL moving-dot primes was reported.

In the final part of the analysis for the LTR group, a fleeting effect of the moving-dot primes was tested for and the effect of the prime on the very first images presented immediately after it was studied. After following the LTR moving-dots primes, participants shifted their gaze towards the left side of the images in the first three seconds of the trial. Then, they shifted their gaze towards the right side of the images. After following the RTL moving-dots 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 a two-way repeated-measures ANOVA showed no significant main effect of the prime *(F(1,47)=1.433, p=0.237)*. However, the effect of time was statistically-significant *(F(4.105,192)=3.330, p=0.011)*. Adding to this, no statistically-significant interaction of the prime and time was reported *(F(4.051,190)=0.844, p=0.500)*. Thus, there was no indication for a differential effect of the oculomotor control on the horizontal spatial bias.

8.2. Results of Experiment 4(b)

Seven native RTL readers were tested with identical circumstances, as for Experiment 4(a). The horizontal spatial bias timing was analysed across the visual exploration of images, averaged over the complete sequence of 45 test images (Figure 8.6, Table 8.1). The first observation is that there was a large mean standard of error due to the small number of participants recruited. The participants started the image exploration with a slight spatial bias towards the left side of the images after the LTR moving-dot primes. Afterwards, they shifted their gaze towards the right side of the images and continued with a small bias on that side for the rest of the trial. On the other hand, the spatial bias after the RTL moving-dot primes was shifted completely to the right side of the images for the whole trial duration. This observation is optimistic for future studies differentiating between LTR and RTL groups in the horizontal spatial bias when primed with moving-dots with different trajectories. A larger sample size would allow for a clear understanding of the effect of the scanning habit on the horizontal spatial bias when priming with different trajectories of moving-dots.

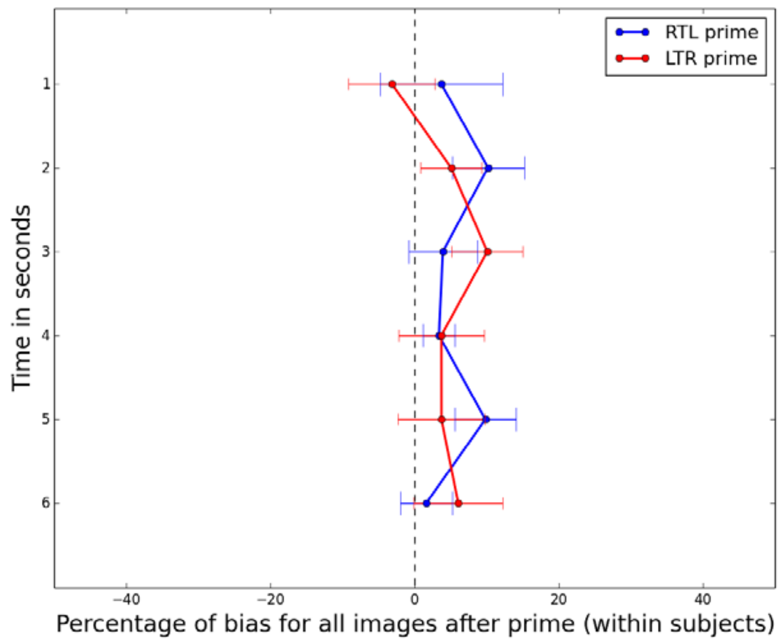


Figure 8.6: Experiment 4(b): The horizontal spatial bias of the fixations (mean ± SE.M) after LTR and RTL moving-dots primes averaged over the complete sequence of images.

Table 8.1: Descriptive statistics (mean and standard deviation (SD)) for the fraction of horizontal spatial bias after LTR and RTL moving-dot primes.
The positive values represent the fraction of the rightward bias and the negative values represent the fraction of the leftward bias.

Time in seconds	RTL prime		LTR prime	
	Mean	SD	Mean	SD
1	3.7143	22.46621	-3.1484	15.81562
2	10.2110	13.27384	5.0764	11.35066
3	3.9531	12.57266	10.1129	13.04472
4	3.4149	5.80399	3.7468	15.81698
5	9.8522	11.24837	3.7583	16.05633
6	1.6244	9.60794	6.0939	16.25298

Chapter 9. Interindividual Differences among RTL/LTR and LTR/LTR Readers during the Free Viewing Tasks

The outcome of Experiment 1 shows that the participants who had mastered two languages written in two different directions could modulate the horizontal spatial bias according to the direction of the language they used. This means that reading direction has an influence on the horizontal spatial bias. This dynamic nature of the spatial bias opens the door to investigate other factors that might have an impact on the magnitude of the bias. This section explores the RTL horizontal spatial bias magnitude, which does vary between subjects, by extending the work of Experiment 1 and considering the subjects as units of observation. Part of the data was already used in Experiment 1(a) and 2, which was enlarged by the addition of 17 new participants recruited specifically for this experiment. The primes of Experiment 5 were identical to those of Experiments 1 and 2. The inter-individual variations were examined by looking at different factors to see if there were correlations between certain factors (age, gender, first language, second language, second language proficiency, and the age of second language acquisition) and the magnitude of the horizontal spatial bias.

In general, age can affect human's natural viewing behaviour at a certain level. For instance, older adults (>72 years old) are less dependent on low-level features and more dependent on top-down mechanisms, in comparison to children and young adults, when performing the patch recognition task (Açık, Sarwary, Schultze-Kraft, Onat, & König, 2010). Another example can be found in Learmonth's study, where older adults (60-80 years) showed a reduction in the hemispheric lateralization for spatial attention in comparison to younger adults (18-25). This EEG study compared the results of a computerized line bisection task (landmark task) with the Event Related Potentials recordings (Learmonth, Benwell, Thut, & Harvey, 2017). Therefore, older adults rely on different strategies to explore scenes.

In addition, second language proficiency and the age of second language acquisition can make an impact in linguistic studies. For instance, late Spanish bilinguals (>17 years old) showed a negative correlation with accurate judgment of English sentences, while early Spanish bilinguals (≤16 years old) did not (Birdsong & Molis, 2001). In the same sequence, the meta-analysis research work done by Hull and Vaid reported that early bilinguals (< 6 years old) have a bilateral hemispheric interference in a dichotic listening test. On the other hand, late bilinguals who are also less proficient in their second language demonstrated a higher interference of left (Hull & Vaid, 2006, 2007). Hence, our focus will be on these factors.

9.1. Specific Data Analysis

For the purpose of Experiment 5, the subject was considered as the unit of observation. For each participant, the data was pooled across the images and the difference between the left and right horizontal coordinates during the first second of the trial was calculated. The fixation points and their horizontal positions for all the subjects were also separately extracted. The fixation points were then classified into two categories: fixation points after reading texts in native languages and fixation points after reading texts in second languages. The fixation points for the images were also separated from the fixation points for reading text primes. To calculate the amount of horizontal bias for each subject, the total amount of fixation points on the left side of the images was subtracted from the total amount of fixation points on the right side of the images. Then, the result was divided over the summation of the right and left fixation points. The results were multiplied by 100 to get the fraction amount of the horizontal bias, resulting in two measurements for each individual: The fraction of the bias after reading native language primes (RTL spatial bias) and the fraction of the bias after reading second language primes (LTR spatial bias). Ultimately, the data in this experiment represents the fraction of the horizontal bias on the images during the first second of the trial duration after reading the primes for each individual subject.

9.2. Results of Experiment 5

To assess the impact of native/second language primes on the leftward spatial bias, data analysis between the subjects was performed. The data was analysed for each of the 56 native RTL/LTR readers (row data from Experiment 1 and 17 new subjects) and 23 native LTR/LTR readers (row data from Experiment 2) after reading texts in their native and second languages, followed by a free-viewing task. For a general visualization of all of the data, a scatter graph was plotted to represent the fraction of biases after reading the first and second primes for the RTL/LTR and LTR/LTR groups. An ellipsoid around the mean score for each group was created by performing a principal component analysis (Figure 9.1). In this figure, there is a remarkable difference in the position of the two ellipsoids. In comparison to the screen midline, the centre of the LTR/LTR ellipsoid (the mean score) is totally located within the left side of the images (negative area) after reading both native and second languages. On the other hand, the centre of the RTL/LTR ellipsoid (the mean score) is rightward and upward shifted to be localized in the middle area of the images; a little to the right after reading native RTL texts and a little to the left after reading LTR texts. In numbers, the RTL/LTR group, reading RTL texts as primes shifted the mean score of the horizontal spatial bias to the right (1.19 ± 24.42) (the screen midline is zero) and while reading LTR texts as primes shifted the mean score of the horizontal bias to the left (-10.63 ± 22.78). On the other hand, the LTR/LTR group demonstrated a strong leftward shift for the horizontal spatial bias after reading native LTR and second LTR text primes, (-34.09 ± 19.23) and (-35.81 ± 17.65), respectively. The most important observation is the wide dispersion of the data points for the RTL/LTR group, which can be attributed to interindividual differences within the group.

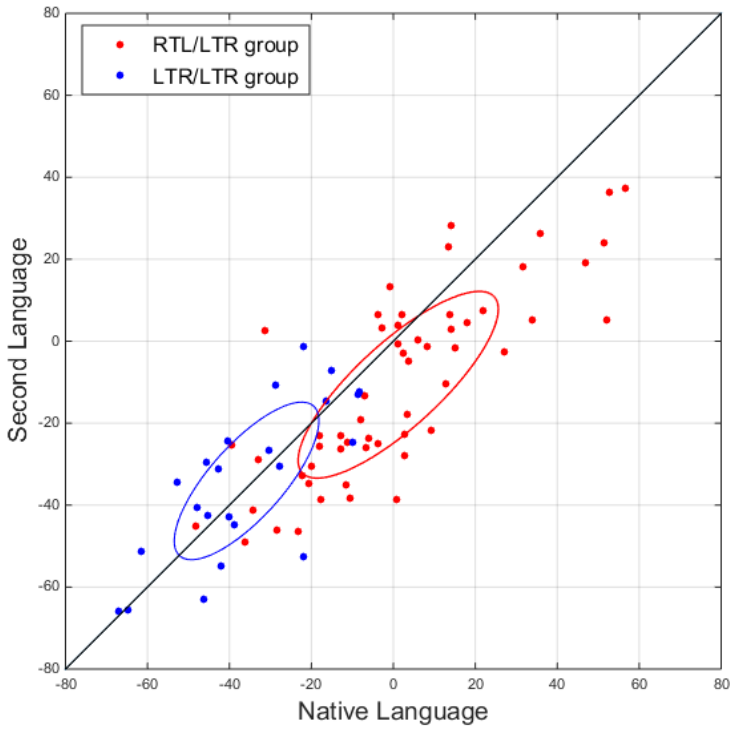


Figure 9.1: The relationship between the score of means for the horizontal spatial bias after reading native language texts and second language texts for RTL/LTR and LTR/LTR groups.
Each marker represents the average of the values across trials for each individual. The positive values in the abscissa represent the bias towards the right side of the images and the negative values represent the bias towards the left side of the images. The data represent the first second of trial onset.

To visualize the wide dispersion of the data points on one scale, Figure 9.2 shows a histogram for the two groups after the subjects were only exposed to native language primes. The distribution of the bias for the RTL/LTR group is clearly seen as broader and shifted towards the center of the screen (zero value), compared to the distribution of the LTR/LTR group, which is narrow and shifted to the left side of the screen. Statistically, an independent t-test reported that the mean of the RTL/LTR group (1.19 ± 24.42) is significantly-different from the mean of the LTR/LTR group (-34.09 ± 19.23) *(t (77) = 5.781, p< 0.01).*

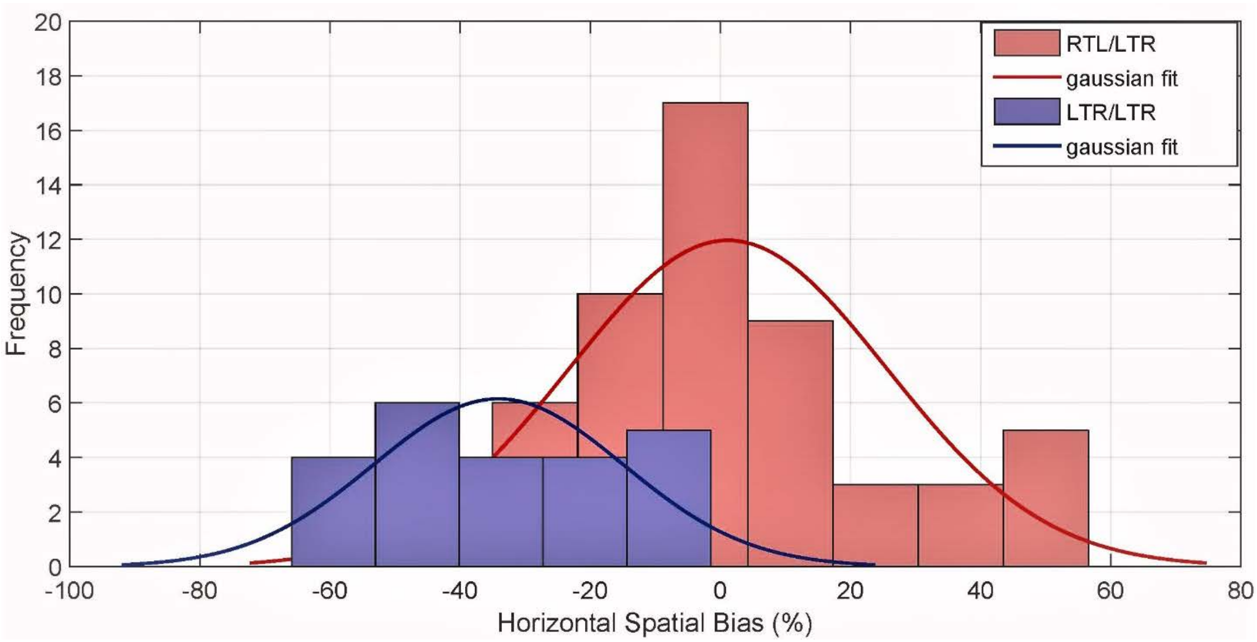


Figure 9.2: Histogram of the horizontal spatial bias for RTL/LTR and LTR/LTR groups after reading texts in their native languages.
The positive values on the abscissa represent the fraction of bias towards the right and the negative values represent the fraction of bias towards the left, from the viewer's perspective.

One possibility for this large interindividual variance could be the heterogeneity of the sampled group. In other words, could it be that some hidden variables lead to this large variance? Therefore, the focus of the next sections is to analyze multiple biological and cultural factors collected in the questionnaires (see Appendix B) for the RTL/LTR group in order to detect any interindividual impacts. Hence, the role of age, gender, native country, first language, second language, proficiency of the second language, age of second language acquisition, and number of years spent in Germany are evaluated based on the magnitude of the bias score for the RTL/LTR group after reading RTL texts.

9.2.1. The Effect of Age

The correlation between the age of the participants and the horizontal bias after reading the native language primes was investigated. For the RTL/LTR group, the age of the participants ranged between 21 and 60-years-old. It must be noted that, due to the limited geographical area, it was difficult to recruit native RTL/LTR who were over 45-years-old. The correlation coefficient was computed to evaluate the relationship between the RTL spatial bias and the participants' age. The analysis showed no significant correlation between the two variables *(r (56) = 0.110, p = 0.418)*. As for the LTR/LTR control group, the age of the participants ranged between 18 and 27-years-old. Again, no significant correlation was detected between the age and the magnitude of the bias after reading the texts in their native language *(r (23) = 0.172, p = 0.432)* (Figure 9.3). Therefore, based on these data, age was not a significant factor impacting the horizontal spatial bias after reading native text primes for this specific group of subjects.

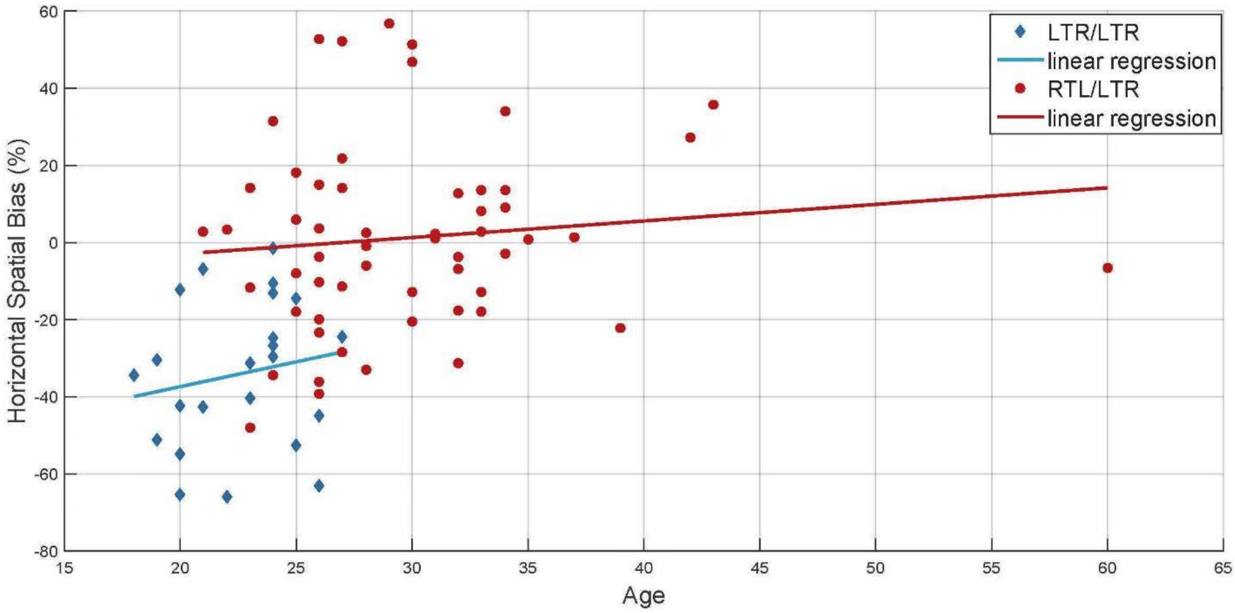


Figure 9.3: Scatter graph of the correlation between the age of the participants in both groups and the horizontal spatial bias after reading the native language text primes. For the y-axis, the percentage of the bias represents the first second of the image exploration. The positive values represent the bias towards the right and the negative values represent the bias towards the left.

9.2.2. The Effect of Gender

Likewise, the relationship between the participants' gender and the horizontal spatial bias was tested. For the RTL/LTR group, of 56 participants that performed the task 10 were female. An independent t-test showed that the mean score of the male group (2.41 ± 24.72) was not significantly-different than the mean of the female group (-4.40 ± 23.37) *(t (54) = 0.796, p= 0.737)*. For the LTR/LTR control group, 10 out of 23 participants were female and the results also showed no significant difference in the mean score of the bias between male (-35.79 ± 20.79) and female (-31.87 ± 17.82) participants after reading texts in their native language *(t (21) = -0.48, p=0.639)*. Thus, there was no evidence to imply an effect of gender on the manipulation of the horizontal spatial bias.

9.2.3. The Effect of the Native Country

One remark regarding the RTL/LTR group was the diversity of the participants based on their native country. In fact, the 56 participants were originally from 14 different countries. Figure 9.4 shows the geographical and cultural backgrounds of the sample. However, in order to study the effect of the native country on the horizontal bias, more subjects must be recruited from each country.

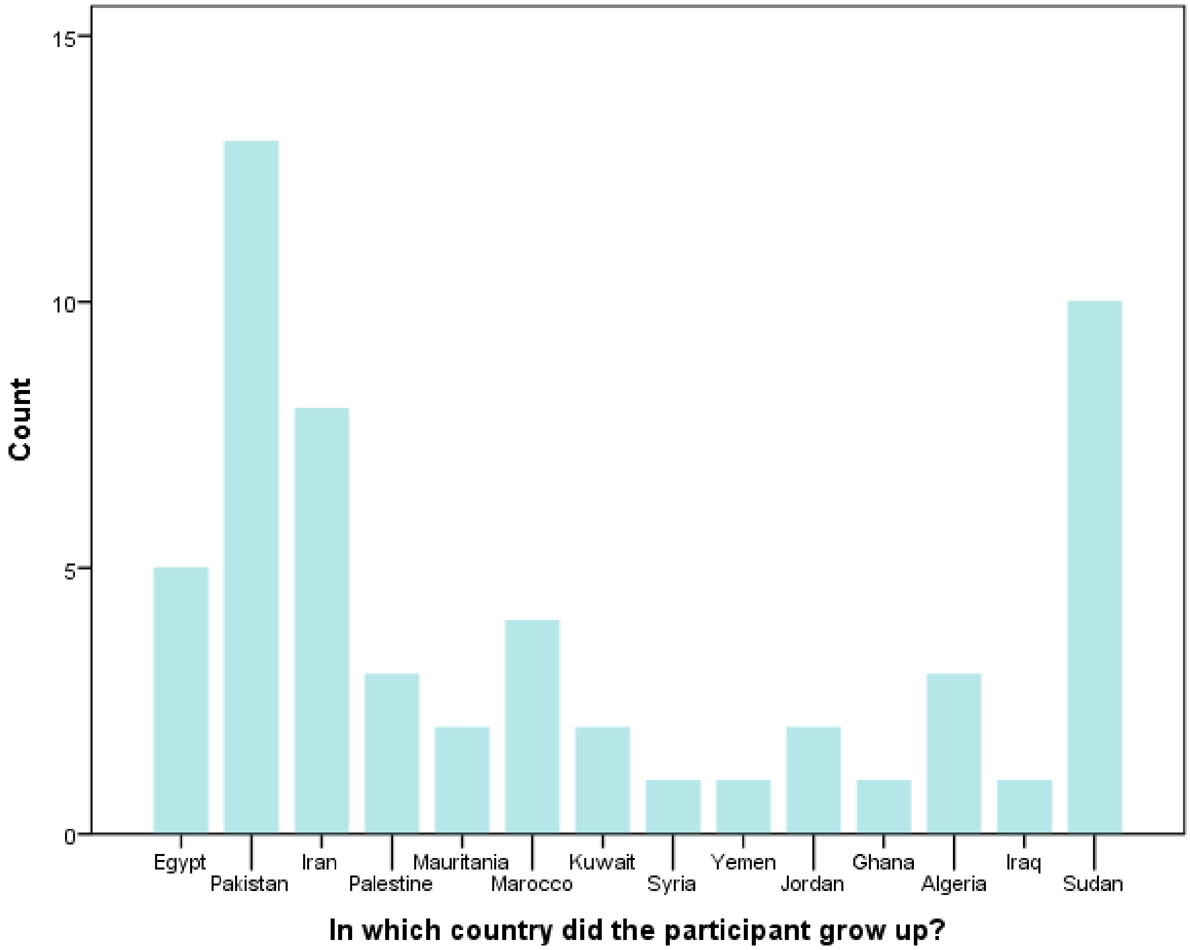


Figure 9.4: The number of participants native to each country.

9.2.4. The Effect of the First Language

The three different native languages used as the first text primes were Arabic, Urdu – the official Pakistani language –, and Persian –the official Iranian language. The Arabic language is the official language in 24 countries and is spoken in other areas in West Asia and North Africa. In this experiment 35 native Arabic speakers, 13 native Urdu speakers, and 8 Persian native speakers participated. A one-way ANOVA shows that there were no statistically-significant differences between the means of different native languages used as primes *($F(2, 53) = 0.576$, $p = 0.565$)*. Thus, there was no indication that the identity of the native language, given that it was a RTL language, influences the horizontal spatial bias.

9.2.5. The Effect of the Second Language

Many RTL/LTR participants were multilingual and came from different multilinguistic cultures. For the purpose of this study, they chose as the second language either English or German. Therefore, it was analysed whether the second language, English and German, influenced the spatial bias among the RTL/LTR group. An independent t-test showed that the mean of the spatial bias in the German-as-a-second-language group (6.71 ± 23.29) was not significantly-different from the mean of the English-as-a-second-language group (-1.21 ± 24.81) *($t(54) = 1.120$, $p = 0.267$)*. Hence, there was no sign that the identity of the second language influenced the magnitude of the horizontal spatial bias.

9.2.6. The Effect of the Second Language Proficiency

The following step was to investigate if there was an influence of the second language proficiency on the horizontal spatial bias. In the questionnaire, participants evaluated their second language proficiency by selecting the best choice from four options: excellent, very good, good, and poor. A one-way ANOVA for the RTL/LTR group shows that there is no statistically-significant difference between the means of the different levels of second language proficiency *($F(3, 52) = 0.263$, $p = 0.852$)*. For the LTR/LTR group, all participants evaluated themselves either as excellent or very good in their second language proficiency and the mean score for the horizontal spatial bias of the "excellent" group (-29.03 ± 16.71) was not significantly different from the mean score of the "very good" group (-41.95 ± 21.17) *($t(21) =1.631$, $p = 0.118$)*. Consequently, there is no evidence to suggest that the horizontal spatial bias can be modulated by the participants' proficiency of their second language.

9.2.6.1. Second Language Proficiency and Median Height

In order to be more precise regarding reading proficiency, the median height for the fixation points over the text primes was calculated assuming that the amount of reading represents the level of proficiency. Therefore, the more proficient the reader is, the more lines of the texts that are read and the greater the value of the median height. For each participant, the median score was calculated for the vertical fixation points extracted from the second language text primes. Figure 9.5 is an example of how the median height matches the reading level.

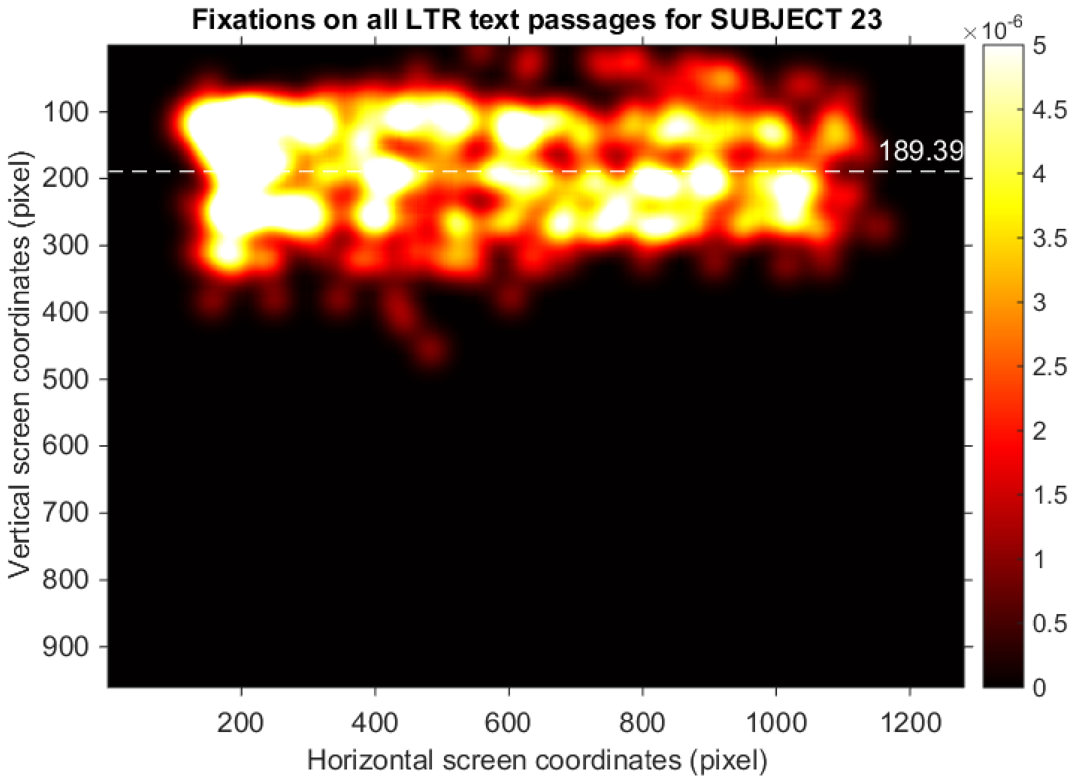


Figure 9.5: Fixation density map demonstrating the distribution density of the fixation points for an individual while reading the LTR text.
The horizontal white dotted line represents the position for the median height point, which is in this case 189.39 pixels starting from the top of the vertical screen height.

Statistically, there was no correlation between the median height for reading LTR texts and the RTL horizontal spatial bias *(r (56) = 0.198, p = 0.143)*. Consequently, these numbers are congruent with the subjective answers in the questionnaires regarding second language proficiency.

9.2.7. The Effect of Age of Second Language Acquisition

The correlation between the age of the participants when they acquired the second language and the magnitude of the horizontal spatial bias was also analysed. Of the 56 participants in the RTL/LTR group, 45 answered this question. The analysis demonstrated that there was no correlation between the age at which the subjects learned to read/write their second language and the RTL horizontal spatial bias *(r(46) = 0.043, p = 0.774)* (Figure 9.6).

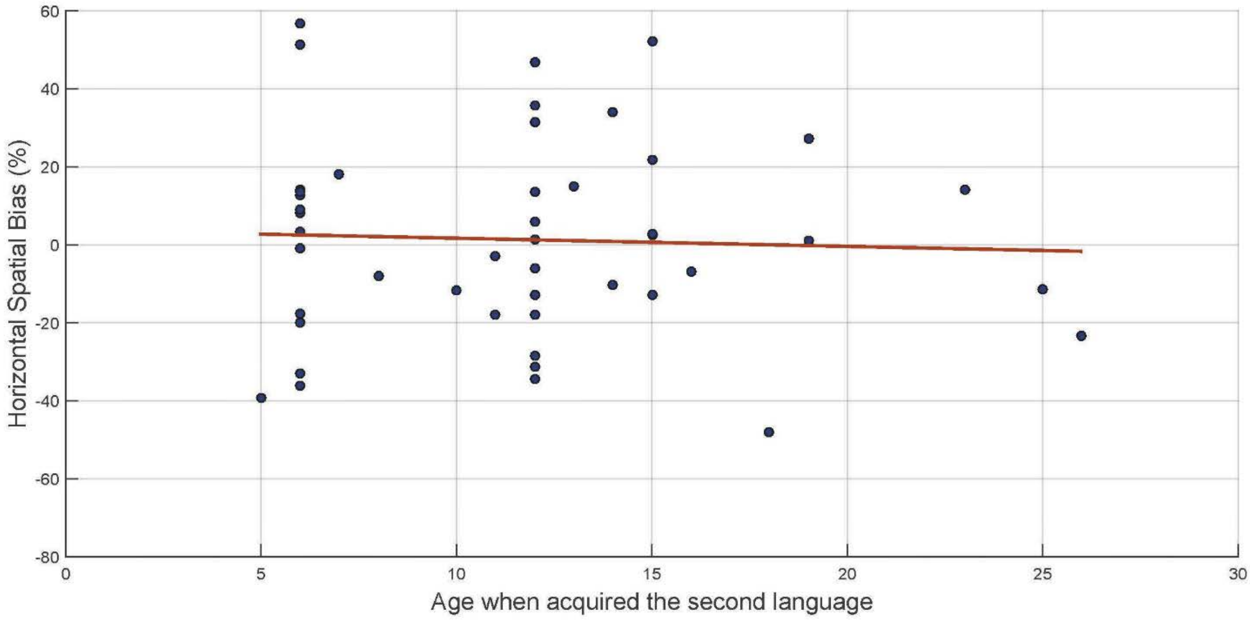


Figure 9.6: Scatter graph of the correlation and linear regression between the age of the participant's second language acquisition and the horizontal spatial bias after reading native text primes for the RTL/LTR group.
For the y-axis, the percentage of the bias represents the first second of the image exploration. The positive values represent the bias towards the right and the negative values represent the bias towards the left.

9.2.8. The Effect of the Time Spent in Germany

The last variable to be examined was the time that the participants had spent in Germany and how this could influence the magnitude and shift of the horizontal spatial bias. To answer this question, participants selected one of the following choices from the questionnaire: < 5 years, 5-10 years, 10-15 years, > 20 years, and > 30 years. However, the small number of participants in each subgroup made it difficult to perform a statistical comparison. Therefore, to improve this work in the future, a clear statement regarding the number of years spent in countries with official LTR language should be taken into consideration.

Chapter 10. Discussion

10.1. Summary of the Results

This thesis concentrated on studying visual spatial attention while freely exploring images. Precisely, the focus was on the leftward spatial bias at a behavioural level. Under natural conditions, the eyes tend to fixate around the centre of the scenes rather than the edges. It follows that the time analysis for the central bias showed an initial leftward spatial bias followed by a central shift, a behaviour that has been linked to the attention lateralization network (Ossandón et al., 2014). The aim of this thesis was to examine the characteristic features of the spatial bias by studying the flexibility of the direction of the bias through manipulating several factors. Hence, the thesis asked whether the leftward spatial bias is considered a steady behaviour or a changeable one.

Experiment 1 tested whether reading direction has an influence on the leftward spatial bias. To do so, native RTL readers and native LTR readers viewed images freely after reading texts written in RTL and LTR directions. The first two seconds of the trials' onset demonstrated different results for the two groups. Native RTL readers showed a RTL spatial bias after reading RTL texts and a LTR spatial bias after reading LTR texts. This finding shows the dynamic modulation of the horizontal spatial bias to reflect the scanning direction of the texts read prior to image exploration. However, this finding was not confirmed by the results of the native LTR readers, who showed a leftward spatial bias after reading both LTR and RTL text primes. The cause of this difference is not clear, as the sample size of the latter group is very small. In addition, it could be that their poor RTL skills did not have a strong impact on the spatial bias. Thus, Experiment 1 supports the notion that reading direction has a strong influence on the horizontal spatial bias for native RTL/LTR readers. To overcome the limitation of this study in prospective works and have better comparison results, bigger sample sizes of native LTR groups who have mastered a RTL language should be taken into consideration.

Experiment 2 focused on the difference between the native and second language on the leftward spatial bias when the two languages have the same reading direction. Here, the horizontal spatial bias among native LTR/LTR readers after reading LTR texts in native (German) and second (English) languages was biased towards the left. A slightly larger bias was reported after the second language primes in comparison to the first language primes.

Hence, the scanning direction habit can magnify and intensify the natural leftward spatial bias if the scanning direction is congruent with the natural spatial bias.

Experiment 3 studied the difference between habitual reading (LTR texts) and non-habitual reading (mirrored LTR texts) on the horizontal spatial bias. Native LTR readers freely viewed the images after reading LTR and mLTR texts without a training phase. The outcome clearly shows that mirrored reading, resembling a RTL reading direction, has no effect on the leftward horizontal bias. Therefore, it can be assumed that the non-habitual scanning direction does not impact the horizontal spatial bias, but that this is done by the habitual scanning direction, which is developed after much practice.

The goal of Experiment 4 was to modify the direction of the leftward spatial bias by controlling the oculomotor movement without the reading primes. Native LTR readers explored the images freely after being primed with RTL and LTR moving-dots resembling the direction of the reading process but without texts. Interestingly, LTR readers showed a leftward spatial bias after being primed with both RTL and LTR moving-dots during the first second of image exploration. However, in the pilot study, where seven native RTL readers performed the experiment, they showed a deviated horizontal spatial bias towards the right after being primed with RTL moving-dots and a slight leftward bias after being primed with LTR moving-dots. As a result, the role of the oculomotor control and language on the modulation of the spatial bias was excluded and the role of the habitual scanning direction maintained. In future studies, larger sample sizes of native RTL readers are needed to have clear results regarding the indifferent role of the oculomotor control.

Experiment 5 was considered an extension of Experiment 1, with more native RTL participants and a different data analysis process. By considering the subjects as the unit of observation, the RTL individuals showed a clear rightward spatial bias after reading RTL text primes in comparison to the native LTR individuals in Experiment 2. Moreover, the measurements of the RTL spatial bias among native RTL individuals have a large variance, suggesting inter-individual differences. Because of this, the relationship between several parameters (age, gender, first language, second language, second language proficiency, and age of second language acquisition) and the magnitude of the RTL spatial bias was tested and no strong correlations were detected. To improve this work in the future, measuring the proficiency of each language using a proficiency test could give specific measurements for this variable and result in a clearer evaluation.

To summarize, the five eye-tracking experiments highlighted one of the characteristics of the natural spatial bias, which is the initial leftward bias. This leftward bias occurs under natural conditions during the free viewing of scenes without the influence of endogenous goals, emotions, or expectations. Moreover, this bias is not caused by the location of the stimuli's low-level features or the photographer's preference to set the objects in the centre of the images, as all of these influential factors were taken into consideration in the five experiments. Nevertheless, the spatial bias is consistent among different samples of the population, specifically among bilinguals. As was shown in these experiments, LTR bilinguals demonstrated consistent leftward spatial bias when the free viewing task was primed with different languages in LTR texts, mirrored LTR texts, and different trajectories of moving-dots. However, the RTL/LTR bilinguals showed a modulation of the leftward spatial bias towards the right after reading RTL text primes, as well as after RTL moving-dot primes. In addition, RTL/LTR bilinguals demonstrated large variations of the magnitude of the spatial bias within subjects without any reference to specific cultural or biological factors. Therefore, the major outcome of this thesis is proving that the leftward spatial bias is a flexible behaviour that can me modulated by mastering languages with different reading directions. Table 10.1 summarizes the horizontal direction of primes used in the experiments and the horizontal direction of languages that the participants could read.

Table 10.1: The different direction of primes and languages for all the experiments. The table shows the reading direction of the participants' first and second languages. It also demonstrates the direction of the first and second primes used in each experiment.

	Experiments							
	1		2	3	4		5	
	(a)	(b)			(a)	(b)	(a)	(b)
1st language	RTL	LTR	LTR	LTR	LTR	RTL	RTL	LTR
2nd language	LTR	RTL	LTR	LTR	LTR	LTR	LTR	LTR
1st prime	RTL	LTR	LTR	LTR	LTR	RTL	RTL	LTR
2nd prime	LTR	RTL	LTR	mLTR	RTL	LTR	LTR	LTR

10.2. Interpreting the Results:

10.2.1. How Does the Reading Direction Habit Influence the Spatial Viewing Behaviour?

This thesis considered the scanning direction as a habit. Starting from the first grade in school, children practice on a daily basis moving their gaze towards the first word of a paragraph. This eye movement routine starts with a motivation to learn how to read and eventually becomes an automatic response; every time a text is exposed to a reader, the reader unconsciously moves his/her eyes towards the first word of that paragraph. Native RTL readers have practiced moving their eyes towards the right to start reading. On the other hand, native LTR readers automatically move their gaze towards the left to read. Therefore, the assumption was made that learning to scan a text in a certain direction for a long period develops that specific eye movement habit.

This habit effect can be visualized with the eye tracker when native RTL readers freely explore the images when being primed with RTL texts (Experiment 1(a)) or with RTL moving-dots (Experiment 4(b)). This also explains why native LTR readers who have poor RTL skills (Experiment 1(b)) and native LTR readers who read mLTR texts (Experiment 3) do shift their horizontal bias, as they have not develop a habit for a RTL scanning direction yet. Furthermore, this hypothesis does not necessarily engage language as a factor in the modulation process. This is because RTL moving-dot primes did not include written texts and, even so, had an impact on the horizontal spatial bias when prompted to native RTL readers (Experiment 4(b)).

10.2.2. Supporting Evidence

This thesis' major finding is supported by multiple behavioural studies, which showed that there is a natural leftward visuospatial bias caused by the right dominant attention network (Corbetta et al., 2008). The leftward bias is reported in the visual line bisection task (Chokron & Imbert, 1993; Rashidi-Ranjbar et al., 2014), grey scale task (Friedrich & Elias, 2014; Nicholls & Roberts, 2002), cancellation task (Rinaldi et al., 2014), aesthetic preference test (Chokron & De Agostini, 2000), and gaze-contingent window test (Jordan et al., 2013; Paterson et al., 2014; Pollatsek et al., 1981). In addition, this leftward bias has been modulated horizontally by the opposite reading direction habit.

The significant value of these studies comes from their cross-cultural comparisons after testing different RTL groups in their native countries, such as the chimeric face tests in Lebanon and Syria (Heath et al., 2005). However, more of these cross-cultural comparisons are required in the scientific field in order to generalize their theories and statements. For example, testing natural viewing bias across cultures can give the spatial bias additional clarification, specifically if tested among illiterate participants and RTL monolinguals.

In addition to the cultural interference in two of the five experiments in this thesis, another advantage of this work is that it introduced different primes into the experiments. The main reason for using primes was to test the flexibility of the horizontal bias. Experiment 1(a) and Experiment 4(b) clearly showed the dynamic effect of the scanning direction habit on the horizontal spatial bias for RTL/LTR bilinguals. These results are congruent with the few other behavioural studies that used primes in their experimental setup. For instance, when LTR/RTL bilinguals performed a SNARC test after being primed with RTL and LTR texts, they showed flexibility in changing the direction of the SNARC effect according to the direction of the prior reading tasks (Shaki & Fischer, 2008). Another example is in the gaze-contingent window test, where RTL/LTR bilinguals read LTR and RTL texts in an off-centre window and then showed a flexible directional bias according to the reading direction (Jordan et al., 2013; Paterson et al., 2014; Pollatsek et al., 1981). However, this priming effect is only noticed among RTL/LTR bilinguals.

10.2.3. Causes of Interindividual Differences among RTL/LTR Readers

The reading direction habit hypothesis supports the modulation of the spatial bias among native RTL/LTR readers but does not explain why there is a large variance between individuals in their RTL spatial bias. Therefore, the correlations between the RTL spatial bias and age, gender, first language, second language, second language proficiency, and the age of second language acquisition were tested.

Regarding the age factor, the sample of the native RTL/LTR group consisted of young and middle-aged participants. Their age was not correlated with the magnitude of the RTL spatial bias. For prospective studies, more diverse samples are required to investigate the effect of different age categories (children, young adults, and older adults) on the change of the horizontal spatial bias among native RTL.

Testing the participant's gender showed that there was no correlation between the RTL spatial bias and this factor. However, this outcome is congruent with previous reports testing the horizontal spatial bias in free viewing tasks for native LTR/LTR participants without reading primes (Ossandón et al., 2014).

Unexpectedly, the second language proficiency and age of second language acquisition variables did not show correlation with the RTL spatial bias. Several reports in the literature reviewed showed an impact of these two factors on multiple cognitive skills (Birdsong & Molis, 2001; Hull & Vaid, 2006; Yang, Yang, & Lust, 2011). Therefore, this thesis' finding were unexpected and suggest a profound role of habit formation on modulating the horizontal spatial bias.

After this analysis, one question remains: *Why is there a large variance between native RTL/LTR individuals in the magnitude of their horizontal spatial bias?*

To answer this, the following hypotheses are proposed.

10.2.3.1. Habit Strength

The activation of a habit occurs instantly when the context cue, which was previously linked to the habit, is displayed (Lally et al., 2010). However, in order to change a habit, new intentions and goals must be obtained to antagonize the previously-existing triggered signals. Changing a habit also depends on the strength of the habit, which can be evaluated using an individual's self-report questionnaire (the Self-Report Habit Index) (Wood & Rünger, 2016). For instance, weak, moderate, and strong smokers were trained to quit their smoking habit through a process that was related to the strength of the habit (Webb, Sheeran, & Luszczynska, 2009). Therefore, habit strength is a measurable factor that differs among individuals.

Based on similar studies, two assumptions could explain the magnitude of the RTL spatial bias. One assumption is that since there are two reading direction habits opposing each other in direction, the net result of the two opposing habitual powers will affect the magnitude of the RTL spatial bias. The other assumption is that the strength of the native language by itself is the dominant factor for the RTL viewing bias. Supporting evidence comes from Heath et al.'s study (2005), where the more the subjects were exposed to RTL texts in a daily basis, the stronger the rightward asymmetry score in the chimeric faces test in which they participated in was. To further investigate this theory, a test to measure the strength of the scanning direction habit can be developed and then be correlated with the RTL spatial bias. In brief, the strength of the two averaged different reading direction habits opposing each other or the strength of the native reading direction habit could lead to the large variability of the results among RTL individuals.

10.2.3.2. Normal Variability of the Brain's Structure and Function

With the use of fMRI, scientists have reported much evidence regarding interindividual structural alterations among healthy individuals while performing cognitive and behavioral tasks. The differences were found to be specifically located within the gray matter and white matter tracks. In motoric behavioral tasks, there were inter-individual differences in the structural integrity of the corpus callosum; the white matter track that joins the left and right hemisphere. Furthermore, in visual perception tasks, interindividual differences were detected in the structural parietal subregions. Adding to that, fMRI scans showed interindividual differences in the cortical thickness of the grey matter linked to attention areas (Kanai & Rees, 2011).

In addition to these innate interindividual structural differences in the human brain, cultural experiences can also contribute to reshaping the brain at a neural level (Han & Northoff, 2008a). In other words, the LTR reading habit strengthens the leftward attentional bias (towards the left hemifield), while the RTL reading habit opposes the natural leftward bias, leading to a weaker spatial bias. Hence, the large variability of the spatial bias among RTL readers could be due to the opposing of the attention lateralization module because of the incongruent scanning direction habit.

In brief, the interplay between the innate interindividual structural cortical differences and the interindividual differences based on different cultural experiences could have an impact on the wide spectrum of the RTL spatial bias magnitudes.

10.2.3.3. The Narrowing Selection of the LTR/LTR Group

When analysing the data presented in this study, it must also be noted that the RTL/LTR sample represents a diverse population while the LTR/LTR group represents a narrow selection of the population, mostly young university students, which are considered highly educated.

In fact, Western, educated, industrialized, rich, and democratic societies are the main targets of experimental studies and, eventually, scientific database. In fact, it is rare for the scientific community to perform empirical studies on a very large sample of populations; instead, small samples are used as representative. However, the outcomes of these experiments have been empirically generalized to all human species in the majority of the studies (Henrich, Heine, & Norenzayan, 2010). Thus, the data may represent a normal distribution of the data for the RTL/LTR group sample but a narrow spectrum for the LTR/LTR group sample.

In the literature regarding horizontal asymmetry, not all the papers specify the educational level/background of their samples. In addition, the interindividual variances in those studies are not reported. Experiment 5 is the first study, to my knowledge, to examine interindividual differences for a horizontal asymmetry test. In fact, even though some studies that have compared LTR university students with RTL/LTR university students detected changes in the horizontal asymmetry, the interindividual measurements are missing (Heath et al., 2005; Megreya & Havard, 2011; Smith & Elias, 2013; Spalek & Hammad, 2004). Hence, a broader sample is required in future studies to generalize the results obtained. In addition, a stronger focus is needed on the interindividual differences in these cross-cultural studies trying to find hidden factors affecting horizontal asymmetry.

10.3. Suggestions for Future Studies

This work is considered a good start for a prospective cross-cultural studies with illiterate groups, homogeneous RTL monolingual groups, and groups consisting of different RTL/LTR bilinguals with different levels of reading skills. While testing illiterates' behaviour on the horizontal spatial bias can show the effect of the attention lateralization system in deviating the viewing behaviour without the influence of the scanning habit, this thesis could not examine their horizontal spatial bias. Furthermore, few cross-cultural studies have compared the results of reading directions between illiterates and different groups with different reading directions. In a cross-cultural counting direction experiment, illiterate Ethiopian Hebrew speakers showed no preference to the left or right when performing the counting coins test (Shaki et al., 2012). However, in the chimeric faces test the results of the illiterate groups have been mixed. In fact, illiterate Arabic speakers showed a leftward bias (Heath et al., 2005) while illiterate Hindi/Urdu speakers showed no bias in the asymmetric score (Vaid & Singh, 1989). Heath has pointed to the role of computer technology in making it easier for tests to include illiterates and have a larger sample size as the reason for the different results found in Vaid and Singh's study. Thus, in order to understand the general role of the reading direction on the horizontal spatial bias, illiterate participants can be considered as a baseline group for better comparison results.

RTL monolinguals are also considered a valuable group that can be tested for horizontal asymmetry in cross-cultural studies. Even though a large difference in the results of RTL monolinguals in comparison to those of RTL/LTR bilinguals is not expected, studying the time course change of RTL monolinguals' spatial viewing bias will provide additional information. In the chimeric faces test the mean asymmetry scores for the different groups (monolinguals vs. different levels of bilinguals) showed a gradual reduction in the leftward bias parallel to the higher amount of time that the subjects spent reading RTL scripts in daily basis (Heath et al., 2005). In the oral SNARC test, RTL monolinguals showed a reverse oral SNARC effect, while RTL/LTR bilinguals showed no effect (Zebian, 2005). These studies showed that the more exposure the subjects have to RTL texts, the higher the effect is on the horizontal asymmetry score. Hence, testing groups with different reading skills in different reading directions can provide a better understanding for the gradual effect of the scanning direction on horizontal asymmetry.

In future studies, it will also be useful to study the difference between bilinguals' and monolinguals' horizontal asymmetry. Bilingualism is known to help reduce the effect of the deterioration of cognitive abilities caused by aging (for a review of this, check Adesope, Lavin, Thompson & Ungerleider, 2010). At a neuronal level, bilinguals are superior to monolinguals in controlling attention, both in non-verbal and linguistic tasks. The variance between monolinguals and bilinguals is noticed while they switch between the two languages, which increases the individuals' controlling ability, leading to better attention control (Bialystok, 2009). Moreover, if bilingualism started during the childhood years, a stronger attention control ability is noticed (Kovács & Mehler, 2009; Yang, Yang, & Lust, 2011).

A further step can also be taken in this field by linking this type of behavioural studies with neuroimaging tests to find out how the spatial attention and language domains are related to the leftward bias in the higher cortical areas with/out reading. Combining neuroimaging techniques with behavioural studies will provide a general overview for how the brain adapts to different cultural experiences.

Studying the learning habit of a certain scanning directions, such as a habit of reading mirrored LTR texts or scanning RTL moving-dots for 31 days (the averaged time to form a new habit) for native LTR participants could confirm the role of forming a habit of scanning direction on modulating the leftward spatial bias.

10.4. Final Conclusion

In conclusion, the only factor that was evidenced to have a strong influence on the horizontal spatial bias is the habitual reading direction. Thus, forming a habit of moving the eyes in a certain direction (LTR or RTL) through daily exposure to reading scripts can reshape the horizontal asymmetry of the viewing behaviour, according to the scanning direction of the reading texts. Non-habitual reading (mirror reading) and oculomotor control (horizontal moving-dots) did not show a similar impact. Moreover, this thesis reduces the gap between the biological and cultural factors affecting the horizontal asymmetry of the visuospatial attention and sheds light on the characteristic features of this natural spatial bias.

Chapter 11. Appendices

11.1. Appendix A

UNIVERSITÄT OSNABRÜCK

Zaeinab Afsari
NBP department
Universität Osnabrück
Albrechtstraße 28
Email: zafsari@uos.de

Information/Consent

Dear participant,
You have voluntarily registered to participate in this study. You will now be informed about your rights and the procedure of the following experiment. Please read the following carefully.

1) Aim of the study
The goal of this study is to obtain new insights about the influence of cultural factors on overt visual attention.

2) Procedure of the study
In this study, you will be shown 180 images on a computer screen. Please study the images carefully.
To calculate your gaze position, you will wear an "Eye-Tracker"on your head. This device tracks the position of your eye with small cameras and infrared sensors. This is a standard psychometric procedure, and has been applied and tested numerous times. During our previous experiments with this device, no subject ever came to any harm. To begin with, the eye tracker needs to be calibrated. This takes about 5 to 15 minutes. The actual experiment takes another 30 minutes. The conductor of the experiment will be present in the room with you during the whole time, and will respond to any of your questions anytime.
After the experiment you will receive further information about the aim of the study. Please do not pass on this information to anyone else, to conserve the objectivity of potential participants.

3) Risks and side effects
This study is harmless and pain free for the subject according to the present standard of knowledge of the conductor of this experiment. You are not exposed to any particular risks by participating in this study, and there are no side effects that are known of. As the study in this constellation has not been done before yet, the occurrence of previously unknown side effects cannot be excluded.
Important: Please inform the conductor of the experiment immediately, if you suffer from an illness or are in medical care at present. Please tell the conductor of the experiment immediately, if you have ever suffered from an epileptic seizure. Please turn to the conductor of the experiment if you have any questions.

4) Abortion of the experiment
You have the right to terminate the experiment at any time and without giving any reasons. Your participation is completely voluntary and without any commitment. You will have no disadvantage if the experiment is aborted.

During the experiment, there is one opportunity for a break. The eye tracker can be taken off during this time. If you ever need another break, or need to go to the toilet, this is possible at all times. If you suffer from headache or any other displeasure at any time during the experiment, please inform the conductor of the experiment immediately.

5) Confidentiality

The regulations of data security are closely observed. Personal data will not be passed on to a third party. The data obtained from you will be anonymised and only processed or published in this form.

6) Declaration of consent

Please confirm the following statement with your signature:

"Hereby I confirm that the conductor of this study informed me about the preceding points. I have read and understood this declaration. I agree with every one of the points.
I hereby authorize the analysis of the data obtained from me in this study for scientific purposes and authorize the anonymised publication in scientific papers. I was informed about my rights as a participant and I consent to participate voluntarily in this study."

....

Place, Date, Signature

....

For minors, signature of legal guardian

11.2. Appendix B

UNIVERSITÄT OSNABRÜCK

Zaeinab Afsari
zafsari@uos.de
NBP/Cognitive Sciences
Osnabrück University

Subject Questionnaire for Eye-tracking Experiments

Disclaimer: all data will be processed confidentially, but if you do not want to answer a question, feel free to leave it blank

For reasons of experimental methodology, we have to record your name. However, no connection between your name and personal details will be stored in our archive.

Note: If you answer is "none" or "nothing" please write that down to differentiate it from not giving an answer.

First and last name:.................................

(Again, we don't store your name in any way together with the answers you give in this questionnaire. So please don't hesitate to give honest answers.

Age:.................... years

Heights: .... cm

Gender: □ male □ female

Vision aids: □ Glasses □ Contacts □ none

Ocular Dominance: □ Left □ Right □ Unclear

Handedness: □ Left □ Right □ Unclear

Vision Acuity: □ Test passes □ Test failed □ not tested

Educational degree: □ elementary school □ middle school

□ High school □ University degree □ none

Current occupation: □ pupil □ civil service/social year/ Army □ student □ working □unemployed □ retired

Time spend in front of a screen on a normal day (in hours)………………. Hours

In which countries you have been raised?

Country 1: ………………….. How many years:…………………

Country 2:……………………How many years:…………………

Country 3: ………………….. How many years:………………..

How many languages do you speak (including mother language)…………….

Language	Age when start to read and write	In which country	Hours spend daily to practice	Proficiency (excellent, very good, good, poor)
1.				
2.				
3.				
4.				

How many eye-tracking studies you have already participated in?............

Alcohol consumption: □ Daily □ At least once a week □ At least once a month □ Less than once a month □ Never

Alcohol consumption yesterday and/or today:………..cups

Coffee consumption: □ Never □ less than 1 cup a day □ 1-3 cups a day □ 3-5 cups a day □ more than 5 cups a day

Coffee consumption today: ……………. Cups

Black/Green tea consumption: □ Never □ less than 1 cup a day □ 1-3 cups a day □ 3-5 cups a day □ more than 5 cups a day

Black/Green tea consumption today:……….. cups

Tobacco consumption: □ Never □ Less than one pack a day

□ 1-2 packs a day □ more than 2 packs a day □ on a regular basis

Tobacco consumption today:…………… cigarettes

How calm/agitated to you feel? □ I am very calm □ I feel very agitated
□ I don't feel particularly calm, nor agitated.

How tired/awake are you? □ I am very tired □ I am very awake
□ I am neither particularly tired, nor awake

Medication taken during the last 3 days :…………………………………………….

Psychiatric diseases:………………………………………

List of Abbreviations

V1	The primary visual cortex
IPs	Intera-Parietal sulcus
FEF	Frontal Eye Field
TPJ	Temporo-Parietal junction
VFC	Ventral Frontal Cortex
IFG	Inferior Frontal Gyrus
MFG	Middle Frontal Gyrus
RT	Reaction time
SLF	Superior Longitudinal Fasiculus
LTR	Left-to-right
RTL	Right-to-left
FFA	fusiform face area
SNARC	Spatial-Numeric Association of Response Codes
mLTR	mirrored left-to-right

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Disclaimer

All the experiments reported in this thesis conforms to the National and Institutional Guidelines. Experiments involving human subjects conforms to the Declaration of Helsinki.

I hereby confirm that I wrote this thesis independently, and that I have not made use of resources other than those indicated. I guarantee that I significantly contributed to all materials used in this thesis. Further, this thesis was neither published in Germany or abroad, except the parts indicated above, and has not been used to fulfill any other examination requirements.

I also confirm that I requested for paid proofreading services for this thesis.

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