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THEORETICAL/REVIEW

Reading/writing direction as a source of directional bias in spatial cognition: Possible mechanisms and scope

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Abstract

Becoming literate has been argued to have a range of social, economic and psychological effects. Less examined is the extent to which repercussions of becoming literate may vary as a function of writing system variation. A salient way in which writing systems differ is in their directionality. Recent studies have claimed that directional biases in a variety of spatial domains are attributable to reading and writing direction. This claim is the focus of the present paper, which considers the scope and possible mechanisms underlying script directionality effects in spatial cognition, with particular attention to domains with real-world relevance. Three questions are addressed: (1) What are possible mediating and moderator variables relevant to script directionality effects in spatial cognition? (2) Does script directionality exert a fixed or a malleable effect? and (3) How can script directionality effects be appropriately tested? After discussing these questions in the context of specific studies, we highlight general methodological issues in this literature and provide recommendations for the design of future research.

Keywords Spatial bias · Reading direction · Scanning habits · Directional bias

Cultural variability contributes to how individuals perceive, attend to, encode, and represent information. An important source of cultural variability is language (Blasi et al., 2022; Boroditsky, 2009; Chokron et al., 2009). Psycholinguistic research has shown that structural differences between languages affect how users of those languages encode and retrieve information (e.g., Garcia et al., 2020; Majid et al., 2004; McBride et al., 2022; Tang et al., 2006; Tosun & Vaid, 2018). Similarly, learning how to read and write in a language appears to have distinct cognitive repercussions (for a review, see Huettig & Mishra, 2014). These repercussions in part depend on characteristics of the writing system(s) in which a person becomes literate (Bassetti et al., 2012; Vaid et al., 2022). Given that a salient way in which writing systems differ is in terms of their directionality one may ask whether the experience of reading from left to right (LR) versus from right to left (RL) affects how individuals attend to, perceive, reproduce or evaluate spatial stimuli. This is the central issue examined in the present paper.

Directional spatial biases have long been of interest to neuropsychologists as indicators of the differential specialization of the two cerebral hemispheres. For example, in a standard attentional task used in neuropsychology—line bisection—the midpoint of a horizontal line is typically placed by participants to the left of the actual center (Jewell & McCourt, 2000). Directional spatial biases in this task were attributed to right hemisphere specialization for visuospatial processing and thus a greater allocation of attention to the left side of visual space (Bryden, 1982; Kinsbourne, 1970). However, the typical pattern of leftward displacement was not observed when the line bisection task was conducted with right-to-left readers (Chokron & Imbert, 1993). Thus, spatial biases need not always—or only—reflect cerebral laterality effects but could more parsimoniously be interpreted as script directionality effects—that is, effects arising from (left to right) directional reading and writing habits (Vaid, 2011). Script directionality biases may operate independently of or in interaction with hemisphere asymmetries (for a discussion of hemispheric asymmetry in a right-to-left script, see Rao et al., 2014).

Indeed, on many visuospatial tasks traditionally interpreted in terms of cerebral laterality, language users with

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a habitual right-to-left reading and writing direction show either a reduced left-side bias or a completely opposite directional bias favoring the right side. For example, in the chimeric facial affect judgment task, a widely used task commonly thought to reflect right hemisphere dominance, participants are shown pairs of faces with opposite half smiles and are to judge which face looks happier. Vaid and Singh (1989) tested biliterate readers of Hindi and English (LR), readers of Urdu and English (bidirectional readers) and monoliterate readers of Arabic (RL) on this task. Like countless previous studies on this task with American participants, Hindi–English readers perceived faces with a left-sided smile as happier. However, in sharp contrast to this robust pattern noted in previous work, Arabic readers deemed faces with a right-sided smile as happier, indicating that each group allocated more weight to the side on which reading started in their language. The bidirectional readers showed no consistent side preference. An effect of script directionality on facial affect judgments has been replicated in two other studies (Eviatar, 1997, Exp. 2; Sakhuja et al., 1996).

Script directionality effects have by now been reliably documented in spatial biases in representational drawing of objects or scenes (Faghihi et al., 2019; Garcia et al., 2020; Vaid et al., 2002, Vaid et al., 2011) and facial profiles (for a meta-analytic review, see Tosun & Vaid, 2014), in line length judgments (Singh et al., 2000) and in various other graphic production tasks (Tversky et al., 1991; Vaid, 1998). They have also been reliably observed in aesthetic judgments (Chokron & De Agostini, 2000; Friedrich et al., 2014; Pérez González, 2012; Smith et al., 2020; for a review, see Page et al., 2017), in reasoning tasks (Bettinsoli et al., 2020; Rey, 2010) and social cognition tasks (Bettinsoli et al., 2021; Chatterjee et al., 1999; Maass et al., 2007; Maass et al., 2009; Maass & Russo, 2003). Interest in the potential impact of script directionality effects has also extended to other domains such as product placement in advertising and consumer behavior.

Script directionality: Key questions

The present paper undertakes an analysis of studies that examine directional spatial biases that may be attributable to script directionality. Conceptually, an embodiment perspective underlies how a good number of studies of script direction have been described. In this perspective experience in moving one's eyes in a certain direction when reading and in moving one's limbs in a certain direction when writing creates perceptual and motoric "habits" that affect how we attend to and interact with stimuli in general, even outside the domain of language (Kazandjian & Chokron, 2008; Suitner & Maass, 2016). We use this perspective as our starting premise and structure our analysis around the following three questions:

1) What are possible underlying mechanisms (mediators) of script directionality effects and what variables might moderate the relationship between script directionality and spatial biases?
2) How malleable are script directionality effects?
3) What would a study need to look like, methodologically, in order to appropriately test script directionality as a plausible source of observed spatial biases?

In addressing these questions, we will provide examples from the literature, with particular emphasis on studies that have used tasks with real-world relevance (e.g., advertisement or social cognition). For a summary of these illustrative studies, see Table 1.

Script directionality effect: Mediators and moderators

In this section, we explore what factors may mediate or moderate script direction effects and discuss the conditions under which such effects are enhanced or impeded.

A *mediator* variable is a variable that accounts for the effect of the independent variable (in this case, reading and writing direction) on the dependent variable (i.e., side biases in spatial cognition). A *moderator* variable is a variable that describes under what circumstances the relationship between the independent variable and the dependent variable holds.

The most fundamental mediating mechanisms for the script directionality effect are perhaps the *mental time arrow* and *mental number line*. That is, the spatial mental models of time and magnitude are (implicitly) deployed in a variety of tasks to mediate the relationship between script direction and spatial biases (see Fig. 1). Studies that directly compared the mental time line or mental number line of LR readers versus RL readers will be first surveyed and then we will describe studies that claim to show how the orientation of these mental lines can pass on the script directionality effect to various domains of spatial cognition.

Subsequently, we will discuss the moderator role of six different variables, three categorical (order of mention, construal level, ambiguity) and three continuous (processing fluency as a stimulus feature, personal need for structure, and bidirectional reading and writing experience).

Mediators of script directionality effect

Space–magnitude association and the mental number line

Spatial mapping of numbers, and more generally magnitude, is a universal cognitive strategy. For example, people make

Table 1 Summary of the studies reviewed with real-world relevance

Study	Field of study	Mediator/Moderator	Number of LR and RL readers	Number of distinct stimuli (number of trials if different from number of stimuli)
Cai et al. (2012, Study 1)	advertisement and consumer behavior (price estimation)	Space–magnitude association	37 LR readers	1
Cai et al. (2012, Study 3)	advertisement and consumer behavior (price estimation)	Space–magnitude association	60 LR readers	1
Romero and Biswas (2016, Study 1A)	advertisement and consumer behavior (healthy-unhealthy food selection)	Space–magnitude association	48 LR readers	1
Romero and Biswas (2016, Study 1B)	advertisement and consumer behavior (healthy-unhealthy food selection)	Space–magnitude association	93 LR readers	1
Romero and Biswas (2016, Study 3)	advertisement and consumer behavior (healthy-unhealthy food selection)	Space–magnitude association	109 LR readers	1
Romero and Biswas (2016, Study 4)	advertisement and consumer behavior (healthy-unhealthy food selection)	Space–magnitude association	169 LR readers	1
Romero and Biswas (2016, Study 2A)	advertisement and consumer behavior (healthy-unhealthy food selection)	Space–magnitude association	78 LR readers	1 (5 trials)
Romero and Biswas (2016, Study 2B)	advertisement and consumer behavior (healthy-unhealthy food selection)	Space–magnitude association	44 LR readers	1
Romero and Biswas (2016, Study 5)	advertisement and consumer behavior (healthy-unhealthy food selection)	Space–magnitude association	60 LR readers	1
Chae and Hoegg (2013, Study 1),	advertisement and consumer behavior (ad evaluation)	Space–time association	194 LR readers	1
Chae and Hoegg (2013, Study 4)	advertisement and consumer behavior (ad evaluation)	Space–time association	157 LR readers 133 RL readers	1
Zhang et al. (2019, Study 1)	advertisement and consumer behavior (ad evaluation)	Space–time association	98 LR readers	1
Zhang et al. (2019, Study 2a)	advertisement and consumer behavior (ad evaluation)	Space–time association	95 LR readers	1
Zhang et al. (2019, Study 2b)	advertisement and consumer behavior (ad evaluation)	Space–time association	109 LR readers	1
Zhang et al. (2019, Study 3)	advertisement and consumer behavior (ad evaluation)	Space–time association	296 LR readers	1
Chatterjee et al. (1999, Experiment 1)	social cognition (agency hypothesis)	Space–time association	27 LR readers	1 (18 trials)
Chatterjee et al. (1999, Experiment 3)	social cognition (agency hypothesis)	Space–time association	36 LR readers	2 (6 trials per stimulus)
Maass et al. (2009, Study 3)	social cognition (SAB)	Space–time association	30 LR readers 31 RL readers (bidirectional bilinguals)	2 (4 trials per stimulus)
Bettinsoli et al. (2021, Study 3)	social cognition (SIB)	Space–time association	67 LR readers 67 RL readers (bidirectional bilinguals)	3

Table 1 (continued)

Study	Field of study	Mediator/Moderator	Number of LR and RL readers	Number of distinct stimuli (number of trials if different from number of stimuli)
Maass et al. (2007, Study 1)	social cognition (behavior judgement)	Space–time association	72 LR readers	1 (12 trials)
Maass et al. (2007, Study 2)	social cognition (behavior judgement)	Space–time association	40 LR readers	1 (10 trials)
Maass et al. (2007, Study 3)	social cognition (behavior judgement)	Space–time association	20 LR readers 20 RL readers	1 (12 trials)
Bettinsoli et al. (2020, Study 1)	cause-effect perception	Space–time association	157 LR readers	1 (12 trials)
Bettinsoli et al. (2020, Study 2)	cause-effect perception	Space–time association	100 LR readers	1 (12 trials)
Mittelman and Andrade (2017, Study 1)	advertisement and consumer behavior (product preference)	Primacy effect	428 LR readers	1
Mittelman and Andrade (2017, Study 2)	advertisement and consumer behavior (product preference)	Primacy effect	67 LR readers	1
Mittelman and Andrade (2017, Study 3)	advertisement and consumer behavior (product preference)	Primacy effect	100 LR readers 102 RL readers	1
Rey (2010)	cause-effect perception	Space–time association	113 LR readers	1
Maass et al. (2014)	social cognition (SAB)	Order of mention	58 LR readers (SvO word order) 60 LR readers (vOS word order) 75 RL readers (SvO word order)	Task1: 1 (2 trials) Task2: 1 (4 trials)
Suitner and Giacomantonio (2012, Study 1)	social cognition (SAB)	Construal level	52 LR readers	1 (6 trials)
Suitner and Giacomantonio (2012, Study 2)	social cognition (SAB)	Construal level	62 LR readers	1 (8 trials)
Daugs et al. (1987, Experiment 1)	Education and learning (directional diagrams)	Ambiguity	57 LR readers	2
Chae and Hoegg (2013, Study 2)	advertisement and consumer behavior (ad evaluation)	Processing fluency	194 LR readers	1
Chae and Hoegg (2013, Study 3)	advertisement and consumer behavior (ad evaluation)	Personal need for structure	183 LR readers	1
Maass and Russo (2003, Experiment 1)	social cognition (SAB)	Bidirectional reading and writing	33 LR readers 79 RL readers (bidirectional bilinguals)	2 (2 trials per stimulus)
Shaki and Fischer (2008, Experiment 1)	Mental number line	Malleability of script directionality effect	18 bidirectional bilinguals	1 (320 trials)
Cai et al. (2012, Study 4)	advertisement and consumer behavior (price estimation)	Malleability of script directionality effect	117 LR readers	1
Mittelman and Andrade (2017, Study 3)	advertisement and consumer behavior (product preference)	Malleability of script directionality effect	413 LR readers	1
Suitner et al. (2017, Study 4)	social cognition (SAB)	Malleability of script directionality effect	80 LR readers	1 (40 trials)

Table 1 (continued)

Study	Field of study	Mediator/Moderator	Number of LR and RL readers	Number of distinct stimuli (number of trials if different from number of stimuli)
Kazandjian et al. (2011)	Mental time line	Malleability of script directionality effect	35 bidirectional bilinguals	Task1: 1 (9 trials) Task2: 1 (5 trials) Task3: 1 (5 trials)
Glaser and Hellmann (2017, Experiment 1)	social cognition (moral judgement)	Side advantage	35 LR readers	1 (5 trials)
Paladino et al. (2017)	social cognition (leadership)	Side advantage	455 LR readers	Task1: 1 Task2: 1

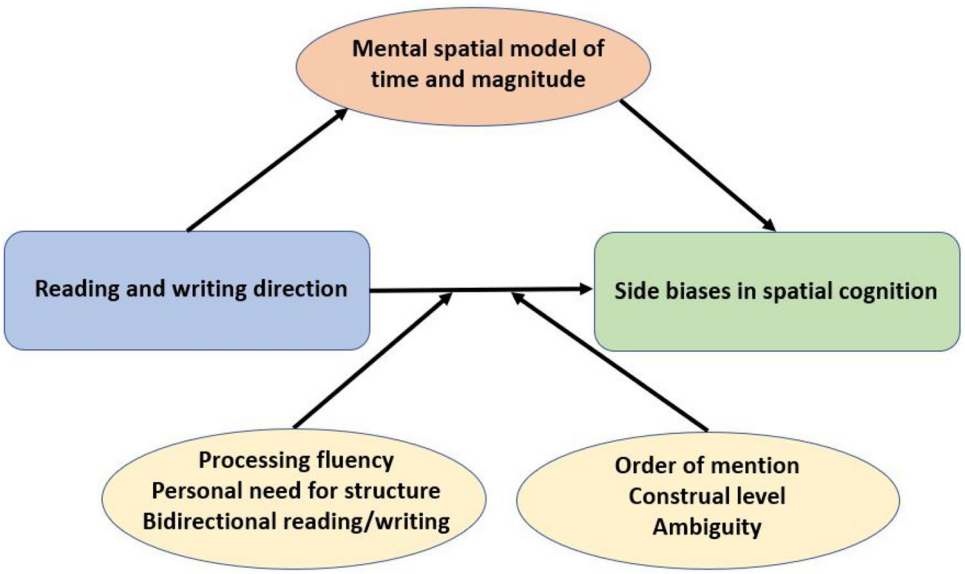

Fig. 1 Some mediation and moderator factors in the script directionality effect

an association between space and numbers (small and large; Dehaene et al., 1993), pitch (low and high; Rusconi et al., 2006), and time duration (short and long; Ishihara et al., 2008). The link between magnitude and space is also evident in the overlap of neural activation for spatial and numerical processing (for a review, see Hubbard et al., 2005). The combination of behavioral and neural evidence points to a spatial–magnitude association that is represented in long-term memory (for a discussion, see Fias & van Dijck, 2016).

Although this is a universal association, some aspects of this mapping have been shown to be culture specific. Differences in reading and writing direction, finger counting, and number-word systems across cultures can affect dimensions of the mental representation of magnitude in space (Göbel et al., 2011).

The mapping of magnitude into space is explained with the metaphor of a mental number line (MNL). According to this metaphor, numerical distance is mentally represented as spatial distance (Restle, 1970), and numbers are ordered on MNL from small to large. For example, odd-or-even judgments for small numbers (e.g., 1 or 2) are faster when responses are made with a left button press in comparison to a right button press. Accordingly, larger numbers (e.g., 8 or 9) are judged faster with a right button press rather than a left button press (the so-called SNARC effect; Dehaene et al., 1993). Even in tasks that neither require a lateralized movement like a right/left button press nor involve a numerical operation or judgement like odd-or-even decisions, smaller and larger numbers were found to shift attention to opposite sides of the visual field (e.g., Aulet et al., 2021; Dodd et al., 2008; Fischer et al., 2003; Galfano et al., 2006; Shaki & Fischer, 2014).

For example, Fischer et al. (2003) examined the spatial–numerical association (SNA) effect in a simple detection

task. Participants first fixated on a number (1, 2, 8 or 9) presented centrally for a brief exposure. After a short delay, a target appeared either to the right side or left side of the position of the previously shown number. Participants had to press the space bar with their preferred hand as soon as they detected the target. The results revealed faster detection for a target that appeared on the right side if it was preceded by a relatively large number (and on the left side if preceded by a small number). This corroborated the original SNARC effect without involvement of lateralized limb movement, explicit spatial task, or numerical judgment (for a similar finding, see Aulet et al., 2021; but see also Colling et al., 2020; Shaki & Fischer, 2018).

Even more interestingly, an eye-tracking study with a simple random number generation task found that participants' eye movements were aligned with the relative magnitude of the number they were about to speak out (Loetscher et al., 2010). The preceding eye movements were in line with the original SNARC effect in which smaller numbers were associated with the left side and larger numbers with the right side (for similar findings, see Hartmann & Fischer, 2016).

It was originally thought that the mental number line might have a universal left-to-right direction such that smaller numbers are imagined on the left side of greater numbers (Fischer et al., 2003). This view was corroborated by observing a left-to-right number-space association among preverbal infants (de Hevia et al., 2014) and some nonhuman animals like chicks (Rugani et al., 2015). Although these observations may speak to the evolutionary sources of space–magnitude association, they do not address cultural factors that influence the direction of this association.

Several studies show an effect of reading and writing direction on the orientation of the mental number line. For example, Zebian (2005) and Shaki et al. (2009) found a right-to-left direction of MNL among two groups of Arabic readers in magnitude classification and parity tasks, respectively. Lebanese and Palestinians associated smaller numbers with the right side of space and larger numbers with the left side. These findings underscore that the direction in which a person reads and writes affects perceptual and motor routines (see also Göbel et al., 2011; Winter et al., 2015).

Space–magnitude association in advertising and consumer behavior. We discuss two sets of studies—Cai et al. (2012) and Romero and Biswas (2016)—that illustrate the space–magnitude association in (presumably) left-to-right readers in contexts that have real-world relevance—that is, advertisement and consumer behavior.

Cai et al. (2012) examined the mental number line in the context of price estimation by consumers. In their Study 1, Cai et al. presented participants with two products (lamps) shown on opposite sides of a screen and asked them to estimate the price of each within a given price range. The location of the two lamps was counterbalanced. Consistent with an LR mental magnitude line, participants suggested a higher price for the product placed on the right than that placed on the left side of the screen. In another study (Study 3), Cai et al. showed participants a piece of paper with the picture of a single product (a snack) either on the left or right side and participants were to estimate the market price of the snack. Again, a higher estimation was given when the item was displayed on the right side than when it was shown on the left side (Cai et al., 2012).

Taken together, the findings by Cai et al. (2012) appear to show a clear effect of a left-to-right mental magnitude line. However, two features of the study limit its usefulness. First, participants' language background and native reading direction were not explicitly noted (although it was stated that participants were recruited from Shanghai and Hong Kong universities). Since the direction of a mental magnitude line corresponds directly to the direction of reading and writing, knowing the actual reading direction(s) of participants would have been informative in interpreting the findings. Secondly, only a single stimulus trial was used in each study, which severely limits the generalizability of the findings.

Romero and Biswas (2016) leveraged the relation between script direction and space–magnitude association to hypothesize that placement of food items in advertising can affect healthy versus unhealthy food choices. It is already established that healthy food items are perceived to be less heavy in weight (Deng & Kahn, 2009), lower in calories (Chandon & Wansink, 2007), less filling (Oakes, 2006), and less tasty (Raghunathan et al., 2006) than unhealthy food items. In addition, unhealthy food elicits more favorable affect (Shiv & Fedorikhin, 1999) and is seen as more desirable and tempting (Hofmann et al., 2010).

If one imagines these food characteristics on a continuous magnitude line, would one expect consumers to mentally associate healthy food with the left side of the space and unhealthy foods with the right side? That is, would food that is perceived as being less heavy, lower in calories, less filling, less tasty, less desirable/tempting and inducing less favorable affect—all of which characterize *healthy* food—be associated with the *left* side of the mental magnitude line with smaller values, whereas *unhealthy* food would be associated with the *right* side of the mental magnitude line with larger values?

Romero and Biswas (2016) examined this issue in a series of experiments. In Studies 1A and 1B, participants were to choose a food from a restaurant menu. Two menus were created, such that the healthy items were displayed on the left and unhealthy items on the right side or vice versa. Participants were indeed more likely to select a healthy food if the healthy items were displayed to the left of the unhealthy items.

When processing resources are limited, food choices are thought to be more affectively based and, thus more likely

to become unhealthier. But when processing resources are not limited, food choices are more cognitively informed and healthier choices are made (Shiv & Fedorikhin, 1999). Romero and Biswas (2016) showed that when the display order of healthy and unhealthy food items is congruent with the mental magnitude line (i.e., a healthy item is presented to the left of an unhealthy item), the food selection process becomes less demanding, and individuals are able to dedicate more cognitive resources to enable them to make a healthier choice.

Some potential alternative explanations for the Romero and Biswas (2016) findings were ruled out in a series of follow-up studies. For example, the researchers tested whether their findings could be due to an overall left-side bias. In their Study 3, Romero and Biswas included a control condition wherein the healthy and unhealthy items were aligned in a vertical orientation, in the center of the screen, one item placed on top of the other in a counterbalanced design. The results showed that presenting the healthy item on the left led to a higher tendency to choose the healthy items in comparison to the control condition. Importantly, however, displaying the unhealthy item on the left versus the control condition did not change the preference for choosing the unhealthy items.

Romero and Biswas (2016) also tested whether their findings reflected a primacy effect of gaze starting point, such that participants would prefer the healthy item when it is on the left side simply because their gaze started on that side. They ruled out this alternative explanation in Study 4 by manipulating gaze starting point and finding that it did not change the results: A healthier food item was more likely to be selected when it was positioned to the left of an unhealthy item, regardless of where the gaze started.

In two other studies (Studies 2A and 2B), Romero and Biswas (2016) investigated the mental representation of healthy versus unhealthy food items. In one study, participants had to put words of a word pair in two blank boxes, one on the left side and the other one on the right side of the screen. The word pairs included healthy–unhealthy food-related words (e.g., *nutrition–pleasure*) and fillers. In the other study, participants placed the names of a healthy food and an unhealthy food in two blank places on a restaurant menu, one on the right side and the other on the left side. Across both studies, participants associated healthy words and food names with the left side and unhealthy words and food names with the right side of space.

Romero and Biswas (2016) also investigated the effect of spatial horizontal position of food items on consumption volume (Study 5). They showed participants a healthy and an unhealthy beverage placed on a table. After getting some nutrition information about the beverages, participants were asked to drink as much or as little of each beverage as they wished. Participants drank more of the healthy beverage only if it was placed to the left of the unhealthy one. When the healthy beverage was placed to the right of the unhealthy beverage, participants consumed an equal amount of each beverage. Impressively, it appears that spatial placement of food items influences not just participants' food choices but also their consumption.

The studies of Romero and Biswas (2016) were designed and interpreted with the presumption that participants were LR readers with a left-to-right mental magnitude line. Although it was noted that participants were recruited from Amazon Mechanical Turk or a U.S.-based university, the authors did not specifically control for language(s) that participants had acquired or had been exposed to. We will return to this issue in a later section.

Space–time association and the mental time arrow

Exposure to a particular reading and writing direction may influence a person's perception of temporal trajectory—that is, where in space an event starts and where it ends. For instance, an English speaker may point to their left when talking about an event that happened in the past or point to their right if talking about an incident expected to happen in future. In a classic study, Tversky et al. (1991) asked American (LR) and Arab (RL) school children to order pictures depicting breakfast, lunch, and dinner. American children ordered the pictures from left to right (breakfast on the left end), while Arab children positioned the same pictures in the opposite direction. These findings were extended by Ouellet et al. (2010); see also Santiago et al., 2007). In Ouellet et al. (2010), Spanish (LR) readers were faster in categorizing words referring to the past if the words were presented on the left side of the screen and were faster at categorizing words referring to the future when they were shown on the right side. This pattern was reversed amongst Hebrew (RL) readers.

Similarly, Gevers et al. (2003) demonstrated spatial organization of ordinal sequences of months (Experiment 1) and letters (Experiment 2). Dutch (LR) readers responded to the months in the beginning of the year faster with their left hand and responded faster to later months with their right hand. The same pattern of results was found in responding to the letters of the English alphabet (see also Gevers et al., 2004).

In another study, Chatterjee et al. (1999, Experiment 2) studied the directional representation of continuous events; he asked readers of English to imagine a single light source falling on a figure in motion (e.g., a staggering drunk) and to draw the trajectory of this light. Participants showed a strong tendency for drawing the trajectory as proceeding from left to right, consistent with their reading and writing habits. Following up on this study, Maass and Russo, (2003, Experiment 2) tested LR (Italian) and RL (Arabic) readers

on a task in which they had to rapidly decide whether the event described in a sentence read to them in their native language corresponded to a pictorial depiction of the event. The picture depicted the event proceeding either from left to right or from right to left (i.e., congruent or incongruent with reading direction). The results revealed that LR and RL readers were faster in responding to trials that were congruent with their habitual reading direction.

Space–time association in advertising. Chae and Hoegg (2013, Study 1) asked LR reading participants to evaluate a product that had a temporal aspect—that is, a weight loss program. Participants were assigned either to a control or priming condition. In the priming condition, they were to organize a list of seven movies based on their release dates in either a horizontal or vertical order. Then in the test phase, participants were asked to evaluate an advertisement showing before and after images. In a between-subjects design, the before and after images were either congruent or incongruent with the past–left and future–right mental associations among LR readers.

Participants' attitudes towards the product were assessed on five dimensions (good, favorable, effective, reliable, and likelihood of having side effects) and a composite measure of a product attitude index was obtained for each participant. The results showed that in the control and horizontal priming conditions, participants evaluated the product more positively in the congruent presentation of the ad. However, participants in the vertical priming condition did not show a preference. That is, LR readers thought of past–left and future–right associations of time and space, but a vertical representation of time overrode this association.

In a follow-up study, Chae and Hoegg (2013, Study 4) directly tested the effect of reading and writing direction by recruiting LR (English) and RL (Hebrew) readers. In a between-subjects design, participants imagined moving to a new house and looking for an antique-style or a modern-style lamp. Then they were shown a magazine advertisement with the lamp depicted either on the left or the right side of the page. Participants rated their attitudes towards the product on four dimensions (bad–good, dislike–like, unfavorable–favorable, and unappealing–appealing). As predicted, LR and RL readers showed opposite response patterns, consistent with their mental time arrow. That is, English readers in the modern condition favored the lamp on the right side, whereas they favored the lamp on the left side in the antique condition. However, Hebrew readers in the antique condition favored the ad with the lamp on the right side of the page, in accordance with a past–right and future–left time–space association.

Related research by Zhang et al. (2019, Studies 1 and 2a and 2b) demonstrated that products advertised with an image facing leftward were evaluated more favorably if participants' temporal focus was on the past. This pattern was reversed if participants' temporal focus was on the future. The temporal focus was experimentally manipulated by asking participants in a priming phase to think and write about a past or future event in their lives (Study 1) or by directly mentioning past-related (or future-related) words in a text that accompanied the image in the advertisement (Study 2).

Considering the findings of Chae and Hoegg (2013), Zhang et al. (2019, Study 3) also investigated the interaction of product facing direction (rightward vs. leftward) and position (left vs. right) in relation to the temporal focus of the consumers. An additive effect was found: in a past temporal focus condition, a leftward facing and left-positioned image led to the highest evaluation score. Additionally, facing direction had a stronger effect than position. For example, in the past temporal focus condition, the leftward-facing but right-positioned product image induced a better evaluation than the rightward-facing but left-positioned product image (see Palmer et al., 2008, for similar preferences in spatial composition of artworks).

The findings of Zhang et al. (2019) are notable because they manipulated facing direction and horizontal position simultaneously. However, the authors presumed an LR reading direction of their participants, who were recruited either from an east coast university in the U.S. or from Amazon Mechanical Turk, without explicitly asking about their language background. We return to this point in a later section.

Space–time association in social cognition—The spatial agency bias. Studies of social cognition have consistently shown that the mental time arrow mediates script direction effects. Chatterjee et al. (1999, Experiment 1) asked LR (English) readers to make drawings of stimulus sentences with verbs describing an action moving away from the agent (e.g., *the circle pushes the square*), towards the agent (e.g., *the circle pulls the square*), or a description of a state (e.g., *the circle loves the square*). Participants tended to place the agent to the left of the patient, regardless of verb type. This finding was replicated in Chatterjee et al. (1999, Experiment 3), where LR readers were faster in a sentence–picture matching task when the depicted scene had a trajectory from left to right, consistent with participants' reading direction. Placing the agent to the left of the patient naturally results in the agent facing rightward and the patient facing leftward. Chatterjee (2002) proposed an agency hypothesis, whereby groups perceived as more agentic are mentally and spatially represented on the *left and facing rightward*.

The agency hypothesis was later modified as the spatial agency bias (SAB) by Maass et al. (2009). According to SAB, spatial imagery is under the impact of reading and writing direction, such that *for LR readers, more agentic groups are envisaged to the left of less agentic groups*.

Importantly, designation of a group as more agentic or less agentic was based on stereotypical beliefs held about the group.

Maass et al. (2009, Study 3) compared SAB in LR (Italian) and RL (Arabic) readers. Participants received brief descriptions of hypothetical competitions between teams of men versus women or young adults versus older adults in scenarios such as a chess tournament or a volleyball game. For each hypothetical competition, participants had to draw the players of the two teams in the position they imagined them to be. Order of mention of the groups was counterbalanced to control for any preference for the first-mentioned group, which is often envisaged to the left (Chatterjee et al., 1999). Additionally, gender and age stereotypes were assessed. Over 80% of LR and RL participants perceived men and young adults as more agentic than women and older adults. Furthermore, an effect of order of mention of the agentic versus nonagentic group on spatial positioning bias was observed: When the agentic group was mentioned before the nonagentic group, LR readers imagined the agentic group on the left and RL readers imagined it on right side, consistent with their reading directions. However, when the nonagentic group was mentioned first, neither group showed a side bias. Even though the association between the first-mentioned group and the side that writing starts (Chatterjee et al., 1999) was partially replicated in this study, such an effect could not completely override the SAB effect from scanning habits in habitual reading and writing (for an implication of SAB, see Monahan & Romero, 2020, Study 4).

SAB explains the association between the side that writing starts in a language and representation of more agentic social groups as a result of shared stereotypes in a society. For example, both men and women share the stereotype that men are more agentic (Abele, 2003). Another type of stereotype is that of an ingroup bias (e.g., Zaromb et al., 2018). Members belonging to a group perceive ingroup members more favorably than outgroup members. Bettinsoli et al. (2021, Study 3) found a spatial in-group bias (SIB) that was similar to SAB in terms of side bias and facing orientation. Namely, members of a group imagine their in-group members on the side that writing starts in their language and imagine the out-group members on the opposite side.

Given what has been discussed so far, does spatial trajectory of an action influence the perception of characteristics of the act as well? For example, will a runner be perceived as *faster* if one sees him/her crossing the finish line from the *left*? If so, what is the role of reading and writing direction in interpretation of actions one observes from others? Maass et al. (2007) hypothesized that interpretation of actions is also affected by agency biases relative to space in a manner that observers draw inferences about an act according to the position of the actor and in which direction his/her act evolves. Among LR readers, for example, greater agency, force, and power will be attributed to a scene that has a left-to-right trajectory than if the same scene unfolded from right to left.

To test this hypothesis, Maass et al. (2007) conducted two studies with LR readers and a third study with both LR and RL readers. In the first study, participants were presented with different versions of short video clips depicting the trajectory of a sporting action (i.e., scoring a goal in a soccer game). Native LR (Italian) readers had to rate how strongly and how fast the player kicked the ball and how beautiful the goal was. The results revealed an effect of the player's orientation and the trajectory of the goal. Evaluations of strength, speed and beauty of the goal were significantly higher when the trajectory of the goal was consistent with scanning habits of the participants (i.e., starting from the left side and proceeding towards the right side from the observer's view).

In the second study, a different event was presented: short film clips of aggressive acts were presented to a group of LR participants. Each clip showed two men, one of whom was hitting the other with his fist, kicking him, and pushing him to the ground. After watching each clip, participants rated how strong the person who hit the other appeared, how shocked/ traumatized the person who was hit appeared, how violent the scene appeared to them, and finally, which of the two people were more responsible for what happened. A composite measure of perceived violence was only marginally significantly affected by the direction of the scene trajectory. That is, left-to-right scenes were evaluated as more violent than right-to-left scenes. Regardless of the scene trajectory, the aggressor was judged as more responsible.

The third study by Maass et al. (2007) recruited both LR (Italian) and RL (Arabic) readers for soccer goal judgments. There was a strong effect of reading direction: Italian readers perceived a goal as being stronger, faster, and more beautiful when it took an LR trajectory whereas, Arabic readers evaluated the same goal as stronger, faster and more beautiful if it proceeded from right to left. Taken together, the findings of the three studies demonstrated that sport actions and, to a lesser extent, aggressive actions are perceived with more intensity if they have a trajectory consistent with a person's reading and writing direction. This finding is in line with the spatial agency bias.

Space–time association in cause–effect perception. In exploring other real-world impacts and implications of the mediation effect of a mental time arrow for the effect of script directionality, we discuss the case of causal relations. Perception of how one or multiple events lead to other events is a critical cognitive ability important for conceptual understanding and problem solving (Jonassen & Ionas, 2008). In a causal chain, the cause should occur before the effect; therefore, a temporal relation is involved in almost every causal relationship. There are two types of causal reasoning:

predictive and diagnostic. In predictive reasoning, we start from a known cause and search for possible effects. In diagnostic reasoning, however, causes of an event are worked out based on the observed effects.

As causes naturally precede effects, judgments about causal relations are faster, more accurate and are made with greater confidence for predictive than for diagnostic reasoning (Evans & Beck, 1981; Fenker et al., 2005; Tversky & Kahneman, 1974, 1977; White, 2006). The effect of predictive and diagnostic reasoning types, which is directly related to the temporal relation of cause and effect, was studied by manipulating the temporal order of presentation of cause and effect in a causal pair (e.g., Fenker et al., 2005). However, Bettinsoli et al. (2020, Studies 1 and 2) examined the effect of spatial order of cause and effect on perceived strength of a causal relation. They used sentences with the form "*x* has a link with *y*" and word pairs (each word presented in a separate box, where the two boxes were horizontally placed next to each other) to examine the perceived strength of the relation between causes and effects among LR readers. Causes and effects were presented simultaneously either in a CE (cause on the left side) or an EC (cause on the right side) spatial order. Regardless of stimulus type, a stronger correlation was perceived between a cause and its effect if the items were presented in a CE rather than an EC spatial order.

This advantage of a CE spatial order may reflect an alignment with an LR mental time arrow which, in turn, facilitated a cognitively more coherent type of reasoning, that is predictive reasoning (Bettinsoli et al., 2020, Study 6; Tversky & Kahneman, 1974, 1977). Bettinsoli et al. (2020) also argued that in a CE presentation, the LR readers encountered the cause first and it led to a stronger perceived causal relation because the first encountered element is more salient (MacWhinney, 1977). This interpretation is in line with findings of Fender et al. (2005, Experiment 3) that a delay between the presentation of the first and second words in a causal pair yielded a facilitating effect of CE (vs. EC) order of presentation.

Similarly, some other studies have interpreted the effect of script directionality in terms of what comes first to attention, arguing that what is presented on the side on which reading and writing starts will capture attention first. For example, in a consumer behavior study, Mittelman and Andrade (2017) showed that a verity bundle (i.e., a package with multiple products) was more likely to be selected by consumers if their favorite product was displayed on the side of the package that reading started in their language (i.e., the left side for LR readers). The authors speculated that the information that comes first to the attention of consumers will become the most important information and thus, takes on the most weight in making a decision. Everything else being equal, the element on the side that reading starts has a saliency advantage that gives it more weight. Moreover, the information that comes earlier in an online decision-making process is given more weight due to a primacy effect (see Dallas et al., 2019).

Bettinsoli et al. (2020) investigated previously learned causal relations but Rey (2010) used a computer simulation task to investigate if the spatial order of cause and effect could influence learning of a new causal relation. LR readers were required to read an introductory text about how neural networks operate. Then, they were exposed to an interactive computer simulation of the concept of neural networks that consisted of a net input (cause), an activity function (moderator), and an activity level (effect) that was the result of changes made by the participant on the cause and the moderator function. The causal connection was displayed either from left to right (cause placed on the left) or from right to left. Rey hypothesized that presenting the causal connection in the same direction as the participant's reading direction should facilitate the construction of a mental model of the causal relation.

After studying the computer simulation, participants performed a retention and a transfer test. Retention refers to the ability of storing information in the working memory and remembering or recognizing it later on. Transfer in this study's context is about internalizing the stored information in a way that it can be applied in another context. In addition, the amount of time spent studying the computer simulation was recorded. The results showed that LR readers who received the causal connection in a direction congruent with their reading direction performed better on both retention and transfer tests than those who received the causal connection in a right-to-left direction (Rey, 2010). But this difference only reached statistical significance for the transfer test. The time spent on the computer simulation was not significantly different between the two groups.

Script directionality and the mediating role of the mental time arrow can influence how causal connections are diagrammed in instructional texts (e.g., user manuals or educational resources). If the texts originate in an LR language and are translated into a language with an RL reading direction or vice versa, there are likely to be distinct repercussions on how the texts are engaged with (see Goldenberg & Tractinsky, 2021, on the sensitivity of translation between two languages that are read in opposite directions). Importantly, the effectiveness of health-related messages can also be impacted by the spatial presentation of cause and effect, as in graphical messages about the relation between drinking and its life-threatening consequences or the relation between smoking and cancer.

A limitation of the two studies reviewed in this section is that they only included LR readers. Even though it seems intuitive to expect an opposite effect among RL readers, it is important to actually test RL reading participants to support claims that reading direction underlies an observed effect.

Moderators of script directionality effects

Order of mention

Earlier we talked about the relation between spatial and social asymmetries described by the spatial agency bias whereby more agentic groups are envisaged on the side of space that reading starts from. A study by Maass et al. (2014) demonstrated a combined effect of the order of mention and reading habits in SAB. Participants were readers of an LR language with a subject–verb–object pattern (Italian), readers of an LR language with a verb–object–subject pattern (Malagasy), and RL readers of a language with a subject–verb–object pattern (Arabic). On the one hand, when the subject and object were not mentioned in the task (e.g., *Draw the exchange of a gift between two people*) the reading and writing direction influenced the placement of the agent and patient in a scene. That is, the agent was positioned on the side that reading started in for each language. On the other hand, when the subject and object were explicitly mentioned (e.g., *The father caresses the son*), the order of mention dictated the positions of the agent and patient. Namely, the first mentioned sentential role was placed on the side that reading started in for each language. Thus, it appears that when the subject and object are not mentioned the SAB characterizes the pattern, whereas when they are explicitly mentioned the results follow the order of mention.

Construal level

In addition to the order of mention, other factors appear to enhance or impede the effect of reading and writing direction in SAB. Suitner and Giacomantonio (2012) found an effect of construal level (CL) on deployment of SAB in drawing interactive acts. According to research on construal level (Trope & Liberman, 2010), a high CL leads to more abstract and overall representation of events. However, a low CL results in more detailed and concrete representations that utilize the peripheral rather than the general information in a situation.

Across two studies, the construal level and psychological distance was manipulated (Suitner & Giacomantonio, 2012). In the first study, LR (Italian) readers were primed by writing either about what they would be doing in any day of the coming year either before (High CL) or after completing the task at hand (Low CL). Then participants were asked to draw the agent and the patient in six interactions described by verbs presented in the infinitive form (e.g., *to push*). The results showed an effect of CL on activation of SAB: participants in the high CL condition produced more drawings with the agent on the left side and with the action proceeding towards the right, which was consistent with their reading and writing direction.

While the drawing stimuli in their first study had minimal context (e.g., *to kiss*), in the second study, LR reading participants were primed similar to the first study but more low-level information was provided in the drawing task. The low-level information was the order of mention of the agent and the patient in the to-be-drawn stimuli (e.g., *A gives a flower to B* or *B receives a flower from A*). Even though there was an overall effect of order of mention, participants in the high CL condition produced more drawings with the agent on the left side, indicating the influence of the SAB. In the low CL condition, participants used the low-level information in deciding about the side placement of the agent and the patient. That is, participants in the high CL used SAB regardless of the order of mention but in the low CL the agent was placed on the left side only if it was mentioned before the patient.

The SAB and the order of mention effects were interpreted by Suitner and Giacomantonio (2012) in terms of off-line and online embodiments, respectively. Off-line cognitive embodiment refers to the employment of motor/perceptual representations that are established before one faces a situation (Wilson, 2002). SAB was formed off-line before the participants encountered the stimuli and it was most influential in the high CL condition. Online cognitive embodiment is, however, defined as the immediate effect of perceptual information on cognition (Niedenthal et al., 2005; Wilson, 2002). The order of mention effect was activated online after participants saw the stimuli, and it was most effective in the low CL condition.

Ambiguity

Educational pictorial diagrams are widely used in sports education texts. These diagrams are usually used for self-instruction because the learner can follow them step-by-step to master a particular movement. Daugs et al. (1987; Experiment 1) examined learning and recognition of sports movements through pictorial diagrams with two groups of LR participants. One group received diagrams with the horizontal array of the sequence of moves in an LR order and the other group received the same diagrams in an RL direction. The sequence of moves was depicted in line-drawings and each was presented for 15 seconds. Two sports movements were shown to both groups, a novel (learning) and a known (recognition) movement. For the novel movement, the sequence of moves was ambiguous in a way that performing the moves in either direction could work, one direction was forward and the other was backward. Eye-movement data were recorded while participants explored the diagrams. For the novel movement, participants had to execute it right after seeing the diagram. For the known movement, however, they had to arrange cards of single line drawings to present the sequence in the same order as was seen.

Results showed that participants tended to scan and assemble the moves of a sequence in an LR direction if the movement was ambiguous (i.e., the diagram could possibly go in either direction). For the ambiguous movement, the majority of the group that received the sequence in an LR direction executed the movement in the correct (forward) order but the majority of the group with the RL sequence executed the movement in the reverse (backward) order. In contrast, when the movement was not ambiguous and one and only one direction could be correct, participants were able to figure out the correct direction without being affected by their habitual reading and writing direction.

This study illustrates a condition under which the effect of script directionality is most likely to emerge. That is, individuals refer to their mental arrow that is congruent with their reading direction when handling an ambiguous task but they are able to suppress that mental orientation when there is more information available (see also Suitner & Giacomantonio, 2012).

It should be mentioned that Daugs et al. (1987) did not provide any demographic information indicative of the script direction of participants but assumed that an LR diagram was consistent with the habitual reading direction of participants. This assumption of an LR reading direction as the default is a common shortcoming in studies of script directionality.

Stimulus processing fluency and personal need for structure

We already discussed the work of Chae and Hoegg (2013, Studies 1 and 4), which demonstrated how time–space association can mediate the effect of script directionality on consumer evaluations of time-related products. Additionally, Chae and Hoegg (2013, Studies 2 and 3) examined the moderator effects of processing fluency as a stimulus feature and personal need for structure as an observer feature.

Chae and Hoegg (2013) exposed LR readers to a product with either a past or a future association or with no time association at all. Participants were asked to imagine that they had moved to a new house and were looking either for an antique-style or for a modern-style crystal lamp, or the type of furniture was not mentioned. Then, they were shown an advertisement either with the crystal lamp on the left side or the right side of a magazine page. Participants assessed the product on four dimensions (bad–good, dislike–like, unfavorable–favorable, and unappealing–appealing).

At the end of the second study, participants were asked to think about the advertisement and complete a processing fluency questionnaire (Lee & Aaker, 2004), which assessed difficulty of understanding, difficulty of processing, organization, structure, and clarity of the ad. At the end of the third study, participants completed a Personal Need for Structure questionnaire (PNS; Neuberg & Newsom, 1993), which measured the trait of personal dependency on structure of knowledge.

Overall, in the second and third studies by Chae and Hoegg (2013), participants in the antique-style condition preferred the product if it was displayed on the left rather than the right side of the page. In contrast, participants in the modern condition preferred the product if the ad showed the lamp on the right side of the page. But in the control condition, there was an equal preference for either ad. Processing fluency mediated the effect of lamp position on product attitude for both the antique and modern conditions in a direction consistent with the consumers' mental trajectory of time, which was shaped by exposure to an LR language.

Although individuals may not be cognizant of their spatial biases, they seem to put in a spatial schema of action that is congruent with culturally determined scanning habits rising from reading and writing direction (Maass et al., 2009). They do so possibly because it is easier and more fluent to process and feels right and natural to them (Suitner & Maass, 2011).

In addition, in the third study (Lee & Aaker, 2004), for participants high in personal need for structure, the pattern of results was consistent with the past–left and future–right heuristic. However, participants low in personal need for structure did not show a preference for either of the ads in either antique or modern conditions. This finding points to a moderating role of need for structure as an individual trait whereby individuals with a low need for structure have less tendency to rely on information structures and thus, are more flexible in creative thinking (Rietzschel et al., 2007) and less likely to make prototypical trait inferences (Moskowitz, 1993) or judge others based upon stereotypes (Neuberg & Newsom, 1993; Schaller et al., 1995).

Chae and Hoegg (2013) found a consistent effect of reading and writing direction on advertisement and product evaluation across multiple studies. This effect was moderated by processing fluency (an attribute of the stimulus) and personal need for structure (an attribute of the participant).

An important limitation of these studies is that they used a single stimulus; therefore, the representativeness of the findings is in question. Moreover, the effect of processing fluency was measured only by a self-report questionnaire. Studies that use other measures (e.g., psychophysiological measures) are to be encouraged.

Bidirectional reading and writing experience

While LR and RL readers often show side biases in opposite directions, the direction and strength of spatial biases among bidirectional bilinguals can be different. Maass and Russo (2003, Experiment 1), for example, compared the representational drawings of events among Italian (left-to-right,

LR) and Arabic (right-to-left, RL) readers, who were also exposed to an LR script to some extent. The Arabic readers were either living in an Arabic speaking country or in Italy. Participants had to draw stimulus sentences like "*The girl pushes the boy*." The verb implied a subject-to-object (*to give*, *to push*) or an object-to-subject (*to receive*, *to pull*) trajectory and the gender of the sentential subject was counterbalanced.

The results revealed an overall left-to-right bias (i.e., positioning the agent to the left of the patient of a sentence), but this effect was significantly weaker among Arabic readers, suggesting an effect of reading/writing direction on event depiction. A right-to-left bias was significant only among Arabic readers who were living in an Arabic speaking environment. Importantly, there was a significant inverse correlation between the number of years spent in a country with an LR script and the size of the right-to-left bias among the Arab participants. The more time an Arabic reader lived in an LR speaking country, the smaller the right-to-left bias they demonstrated in the event drawing task. This proportional relation between the length of exposure to an opposite script direction and spatial bias highlights the importance of recording, reporting and controlling for the language(s) of participants in any script directionality study. We elaborate on this point in the final section.

Malleability of script directionality effect

To better understand the nature, scope and parameters of the script directionality effect, it is crucial to devise studies that examine whether the effect can be moved around, whether it is manifest only under certain conditions, and whether it interacts with other factors.

To examine if the script directionality effect is malleable, Shaki and Fischer (2008, Experiment 1) conducted a study on space–magnitude association with Russian–Hebrew bilinguals. Participants were primed by either reading a Russian paragraph (written from left to right) or a Hebrew one (written from right to left) before performing a parity judgment task. The bidirectional bilinguals showed opposite mental number line orientations depending on whether they were primed with their LR or RL written language. This led the authors to conclude that there is a causal relation between script directionality and MNL orientation that is flexible and depends on the available spatial orientation in working memory (for similar findings, see Román et al., 2015).

Cai et al. (2012) conducted different studies on the effect of reading direction on price estimation that also made reference to the MNL. In their Study 4, they aimed to examine whether the orientation of the mental magnitude line and as a result, price estimation, can be manipulated. Participants were primed by either looking at the image of a ruler (small–large numbers placement) or a clock face (large–small numbers placement) before being asked to estimate the price of two products. Two products (staplers) were located on the left and right sides of the screen. Participants estimated a significantly higher price for the stapler that was placed on the right side only if they were primed with the ruler image. Participants who looked at the image of a clock face before the task demonstrated a reversed effect but it did not reach statistical significance.

Thus, even though the orientation of a mental magnitude line is strongly affected by habitual reading and writing direction, it is flexible and can be manipulated (Fischer et al., 2009; Fischer et al., 2010; Shaki & Fischer, 2008). The findings above suggest that although the MNL is generally oriented in the same direction as one's reading direction, it is quite malleable.

Likewise, Mittelman and Andrade (2017) showed in a consumer behavior study that some stimulus features were capable of overriding the effect of script directionality. In selecting packages containing assorted salty or sweet snacks with different orders of product display, LR readers selected the bundle that displayed their favorite product on the left. But this selection criterion was not in place if their favorite product was most saliently displayed, regardless of its position. That is, consumers prefer the bundle whose package displays their most favorite product on the same side that their reading starts from or the bundle that displays their most favorite product most conspicuously. One may interpret this as a top-down process in the former case and a bottom-up process in the latter case. That is, reading and writing direction forms a mental model that is part of top-down attentional processes but this model can be bypassed by a bottom-up process that makes certain visual elements more salient.

Another fascinating example of the malleability of script directionality is found in the gender–space association in SAB. Suitner et al. (2017, Study 4) used a gender categorization task wherein participants were presented with profiles of men and women that were either looking rightward or leftward. In the stereotypical condition, the majority of the pictures of men faced rightward while the majority of pictures of women faced leftward, consistent with gender spatial biases in SAB. In the counterstereotypical condition, the majority of males faced leftward and the majority of females faced rightward. Finally, in the control condition, the number of rightward versus leftward looking profiles was equal across males and females.

The output of this gender categorization task, which was named The spatial association task, is an overall index of stereotype-congruent spatial association (ScSA) where higher scores of ScSA indicate higher SAB. The results of a pilot study with LR (Italian) readers revealed no significant difference in ScSA between the stereotypical and control

conditions. Therefore, Suitner et al. (2017, Study 4) only included the control and counter-stereotypical conditions in the main study. The main study recruited an equal number of male and female LR (Italian) readers, who were also assessed on benevolent sexism scales before and after the spatial association task.

The results revealed that the ScSA index was lower in the counter-stereotypical condition than in the control condition. In other words, the spatial agency bias was reduced by getting exposed to unconventional spatial orientation of male and female profiles. Further analyses showed the typical SAB in the control condition, that is, greater accuracy in categorizing rightward male and leftward female profiles. Consistent with the authors' hypothesis, in the counterstereotypical condition, a rightward bias was formed for female profiles, whereas no spatial bias was demonstrated for male profiles.

Thus, it appears that the association between gender and space is malleable and can be unlearned and even partly replaced with a new association by visual exposure to atypical associations. More impressively, after controlling for preexperimental benevolent sexism, the postexperimental self-reported level of benevolent sexism was reduced by exposure to the counterstereotypical condition (but not by exposure to the control condition). This finding indicates that not only do individuals use space to reveal their social and abstract attitudes (e.g., stereotypical beliefs about gender and agency) but that space can also be deployed to modify such attitudes, at least temporarily.

Although script directionality effects are in some cases malleable, this is not always the case. For example, Kazandjian et al. (2011) gave a sequential-actions sentence–picture arrangement task to bidirectional bilinguals after priming them with their LR or RL written language. In the arrangement task, sequences of sentences like "*C brushed his teeth, ate a banana, and left for school*" were auditorily presented to participants. Then, they were given three photographic images corresponding to three key actions from that sequence to organize in the order that best depicted the auditory stimulus. Participants employed a time trajectory arrow consistent with the reading and writing direction in their native language, regardless of the reading direction they were primed with. Spatial representation of time trajectories is, thus, primarily dependent on habitual reading direction and is not as flexible as that of magnitude.

Taken together, these examples underscore the importance of the task. In some cases (e.g., relation between gender and space), the effect of script directionality can be easily overturned by a simple priming manipulation. In other cases (e.g., direct relation between time trajectories and space), the effect of reading direction may not be as flexible, specifically when auditory stimuli are used. Clearly, there is much more to be done to explore the question of malleability of the script directionality effect and how it may depend on task demands.

Methodological issues and scope of script directionality effect

Research on spatial side biases, like many other fields of psychology, has tended to assume that findings derived from the typically studied population (members of Western societies and users of English) should generalize to less studied populations, even though the basis for such claims of universality is increasingly being questioned (Blasi et al., 2022; Henrich et al., 2010; Share, 2021). As most neuropsychological research was largely drawn from populations that were left-to-right in their reading/writing habits the effect of reading and writing direction on spatial biases was hidden in plain sight and not initially considered as a potential confound (Vaid, 2022). When a few studies with RL readers suggested that it could not be ignored, reading and writing direction was initially treated as a "nuisance" variable. It was only when more and more studies seemed to point to scanning biases across different domains that this variable began to be taken seriously and its mechanisms and scope began to be examined (see Vaid, 2011, for further discussion). Somewhat ironically, there is now a tendency to invoke script directionality effect even though participants are (still) drawn from a homogeneous (left-to-right) population.

Methodological considerations

Directly compare LR and RL readers

To claim that an effect is likely due to script directionality warrants a research design in which there is a direct comparison—in the same study—of individuals with differing script directionality exposure and experience. Quite a few studies have met this standard. Yet studies conducted predominantly in western countries may have difficulty in recruiting enough numbers of RL readers (see Tosun & Vaid, 2014), although bidirectional RL readers are often more available in these countries. One way this problem can be addressed is by greater global collaboration among researchers to enable data collection in countries with a dominant RL written language. Moreover, online studies can recruit RL readers through crowdsource services (e.g., counterparts of Amazon Mechanical Turk) in countries with a dominant RL language, although this is not ideal given the likelihood of linguistic heterogeneity among formally schooled individuals in these countries.

Account for bidirectional reading

Along the same lines, it is important to recognize that script directionality effects also extend to the interpretation of the performance of bidirectional readers—that is, one would expect them to behave somewhere in between LR-only and RL-only readers, depending on their literacy practices and length of exposure to each script. As such, more fine-grained characterization of the onset, length of exposure or even medium of instruction of a particular writing system is warranted to get a more accurate assessment of the strength of script directionality effects when including RL readers who also learned an LR script (or vice versa). Bidirectional readers, contrary to RL-only readers, may show no side biases or a side bias in the same direction as LR that is reduced in size and strength (Flath et al., 2019; Hernandez et al., 2017; Kazandjian et al., 2011).

Considering bidirectional readers as a separate group (or considering bidirectional experience as a continuous variable) opens up new questions to be explored. For example, previous research showed that the number of years of exposure to an opposite reading direction can change the size of the script directionality effect (Maass & Russo, 2003). Yet we do not know whether the age of becoming a bidirectional reader (i.e., age of language acquisition) or the first learned directionality (LR vs. RL) would matter. Future research should attend more to individual differences among bidirectional readers as this is arguably a sizeable population and one that has been undertheorized in the literature to date (see Vaid, 2022, for further discussion).

Avoid proxy measures

Another limitation in this literature is the lack of control of reading direction of participants when they were recruited in a place with a dominant LR language. The geographical location of a study should not be assumed to be a proxy for reading direction, especially considering the likely increasing population of bidirectional bilinguals in western countries due to migration of various kinds. Most studies are conducted in universities, where there is a good chance that students may either come from a country with an opposite reading direction, or where the LR readers may have studied an RL language. This elevates the chance of having bidirectional bilingual participants. For studies conducted in countries with a dominant RL language there is an increasing chance of having bidirectional reading participants due to the early teaching of English at schools and exposure to western advertisements.

Address generalizability

Another important methodological concern noted particularly in studies of side biases in advertisement and consumer behavior was the use of a single-stimulus design. Clearly, having a reduced set of stimuli greatly limits the representativeness of the findings. It is critical that research investigating directionality biases in real-world domains incorporate larger numbers of stimuli and trials to ensure that issues of generalizability and power are satisfactorily addressed.

Incorporate real-time measures

A further opportunity for methodological improvement is the use of more fine-grained online measures including, for example, eye tracking or electrophysiological measures to measure the amount of cognitive workload in processing of spatial information that is congruent versus incongruent with one's reading and writing direction. Self-report measures such as processing fluency and feeling right are informative tools but should be backed up with other methods in future research.

Expanding the scope

In addition to opportunities for methodological improvements, there are important questions regarding the scope of the effect that await investigation.

Examine RL brain-damaged populations

There is a major gap in our understanding of the clinical neuropsychological aspects of the script directionality effect (Kazandjian & Chokron, 2008). In particular, there is hardly any study that has looked at hemispatial neglect in brain damaged populations among readers of RL scripts. Given the increasing demonstration of script directionality effects on tasks that were assumed to be impervious to scanning biases and thought to be measures of right hemisphere function, it becomes all the more important that neuropsychological studies examine how script directionality may interact with hemisphere functional asymmetry by including in the design both right-to-left and left-to-right populations.

Consider moral and epistemic judgments

Previous studies have shown that stereotypical beliefs about agency in relation to gender and age affect representational spatial biases. Less explored are how reading direction may be subtly used by individuals to form mental spatial models in social interactions among individuals differing in political affiliation, racial or ethnic group identity, or occupational status (e.g., boss vs. employee or doctor vs. nurse).

Some research suggests that the side of space that reading and writing starts in attracts more attention and has more influence on subsequent decisions. Further research is required to investigate the effect of side biases across a variety of contexts such as perception of morality, judgments of true versus fake news, scientific versus mythical information and epistemic judgements in general. For example, is a fake news item more likely to be perceived as truthful by an LR reader if it is presented on the left (vs. right) side of the visual space?

As an example, in a moral judgment task, LR (German) readers were presented with vignettes about moral transgressions such as sexual relationship between second cousins, shoplifting, and stealing library books (Glaser & Hellmann, 2017, Experiment 1). In each trial, the vignette's text box was displayed either on the right or the left side of the screen. Participants were to rate the extent to which they found the behavior and the actor of the behavior morally reprehensible. Interestingly, a moral transgression act was judged more harshly if the vignette was presented on the right side of the screen. A similar pattern was found in judgments of transgressors but it did not reach statistical significance.

Theorize side biases

It might be the case that for LR readers, events and behaviors presented on the left side are perhaps interpreted and judged more favorably but further research is indeed required to be able to make such general conclusions. Such an interpretation may be read in two ways: (1) It presumes a mental emotional intensity line that is in line with the MNL and goes, for example, from less morally reprehensive to more morally reprehensive (see Holmes & Lourenco, 2011). (2) It is not about emotional magnitude per say but is about a better-worse (or more favored–less favored) polarity associated with space (as in the spatial agency bias and spatial in-group bias) that does not only apply to emotions but applies to epistemic judgements in general as was discussed earlier (see, e.g., Pitt & Casasanto, 2018). Future empirical investigations should decide which interpretation is supported.

Another social advantage of the side that reading starts from was shown in a study on spatial cues of leadership (Paladino et al., 2017). Left-to-right (Italian and English) reading participants associated the left and up spatial positions with leading (vs. subordinate) roles in an organization. Even though these studies can be considered as good starting points, more extensive investigation of the effect with both LR and RL readers is required.

Integrate body specificity hypothesis and script directionality

Finally, there is another line of research to be considered that intersects with the script directionality effect in perception tasks—namely, the body specificity hypothesis (BSH), which proposes that a person's right- or left-hand dominance leads to a preference for the corresponding side of space (Casasanto, 2009, 2011). According to BSH, abstract concepts with a positive valence (e.g., *honesty*) are associated with the right side and abstract concepts with a negative valence (e.g., *sadness*) are associated with the left side in the mind of a right-handed person. The mental representation of a left-handed person is associated with an opposite pattern.

Besides the distinct effects of reading and writing direction (e.g., associating more agentic with the left side and less agentic with the right side by LR readers in SAB) and handedness (e.g., associating good with the right side and bad with the left side by right-handers in BSH), the intersection of handedness and reading direction effects may exert a joint influence in determining the direction and/or degree of side biases in perception. For example, Casasanto et al. (2022) showed that the interaction of script directionality and handedness effects resulted in reducing the left–past and right–future association among left-handed LR readers in comparison to right-handed LR readers. Casasanto (2016) refers to the effects of cultural and bodily experiences as "experiential relativity" effects that do not necessarily need to be all activated at one time and that can be even reversed under certain conditions. The potential interaction of apparently opposite patterns of these effects on mental mapping of "the better side" deserves a full investigation in future experimental research. Until then, we cannot readily offer an insightful reconciliation of the two effects.

Conclusion

This paper asked three main questions about the well-documented effect of reading and writing direction on spatial biases. First, what are the underlying mechanisms of the effect and which factors mediate and moderate it and which conditions can enhance or impede the script directionality effect? Second, how rigid or flexible is the script directionality effect? And last, what are methodological limitations of the existing literature, and how can these be addressed to improve the state of our knowledge and to expand the scope of inquiry of script directionality effects? In addressing these questions, illustrative studies of spatial biases in real-world contexts were presented as examples of the issues discussed. Although usually under the radar, the direction in which one reads and writes has been shown to exert a

wide-ranging effect on our spatial cognitive functioning. It deserves a closer look.

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