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Scanning of speechless comics changes spatial biases in mental model construction

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Abstract

The mental representation of both time and number shows lateral spatial biases, which can be affected by habitual reading and writing direction. However, this effect is in place before children begin to read. One potential early cause are the experiences of looking at picture books together with a caregiver, as those images also follow the directionality of the script. What is the underlying mechanism of this effect? In the present study, we test the possibility that such experiences induce spatial biases in mental model construction, a mechanism which is a good candidate to induce the biases observed with numbers and times. We presented a speechless comic in either standard (left-to-right) or mirror reversed (right-to-left) form to adult Spanish participants. We then asked them to draw the scene depicted by sentences like "the square is between the cross and the circle". The position of the lateral objects in these drawings reveals the spatial biases at work when building mental models in working memory. Under conditions of highly consistent directionality, the mirror comic changed preexisting lateral biases. Processes of mental model construction in working memory stand as a potential mechanism for the generation of spatial biases for time and number.

Keywords: Reading and writing direction; Spatial bias; Mental model; Cognitive flexibility; Language comprehension; Comics.

Introduction

There is mounting evidence suggesting that some dimensional abstract concepts such as time and number, but also emotional valence or social power, are mentally represented by analogical means: a spatial representation akin to a mental line. As space belongs to a more concrete conceptual level than time, mental lines are often brought up as supporting the progressive building of abstract concepts on more concrete ones (1,2; see 3–5 for recent reviews). But, what is the experiential origin of these mental lines? While different abstract dimensions may become understood by means of space because of different kinds of learning experiences (6), an important candidate for time and number lines is the directionality of habitual reading and writing (7–10).

The writing script is a cultural artefact with which literate people accumulate many hours of interaction during their lives. There is now a wide literature that suggests that habitual reading and writing direction (RWD) affects many levels of the cognitive system. At higher levels, besides time and number it can also affect how events (11,12) and sentences describing spatial scenes are represented (13), as well as the aesthetic experience of artists and the public alike (14). At lower levels, it induces spatial biases in lateral motion perception (15), word reading (16), perceptual span (17), visual exploration (18,19), and spatial attention (20).

Most of the studies on the effect of RWD cited above compare pre-formed groups (i.e., users of scripts with different directionality, illiterates, preliterate children...). By their very nature, they can provide only correlational evidence. Evidence of a causal relation between RWD and this wide family of spatial biases has so far been reported only by two studies that experimentally manipulated script directionality and assessed its effects. Casasanto and Bottini (21) presented Dutch readers with standard left-to-right (L-R), mirror reversed (R-L), up-down or down-up text and showed that all three non-standard reading conditions were able to induce congruent changes in the spatial location of past and future. Román, Flumini, Lizano, Escobar, and Santiago (22) used a similar rationale to show that RWD can cause biases in the construction of mental models from descriptions of spatial scenes such as “the square is between the cross and the circle”.

These studies prove that the direction of the script is a sufficient cause, able by itself to produce changes in spatial biases in at least some tasks. This is not to say that it is the only factor. Data from animals and newborns suggest a biological predisposition to count from left to right (23,24). Moreover, there are other kinds of cultural and bodily experiences which may also lead to the establishment of mental number lines (10,25).

However, recent studies have reported the presence of RWD-linked biases in number processing in pre-literate children. Shaki et al. (26) assessed directional counting preferences in English-, Arabic-, and Hebrew-speaking preschoolers, and observed that 4 year old children already show clear preferences to count in the same direction of the writing system of their language, a system which they have not yet started to use (see also 27–33 for consistent results in number tasks and 34 for time tasks). If RWD-linked lateral spatial biases in number and time appear before the acquisition of reading, what is driving their development? There are several possibilities. First, script directionality is linked to other graphic and material conventions such as the direction of frames in cartoons, page turning in books, the organization of calendars, and so on. As early as 4 months of age, children start accumulating many hours of picture book “reading” with their caregivers (35). Usually the caregiver sits with the baby in the lap, pointing towards the drawings in the correct order, directing the baby's attention to them in turn, and turning the pages of the book, what may provide a experiential ground for the development of early lateral directional preferences (8,25,26,31,36). A second possibility are directional counting routines. Children are introduced to counting earlier than to reading. They are often shown how to count objects and the adults usually count in their habitual RWD (25,27–31). A third possibility is based on finger counting routines. Finger counting provides a key grounding for number learning (37), and children start to count on their fingers earlier than they start reading (38). Among many other cross-cultural differences (39), speakers of L-R languages prefer to start counting on the left hand, while speakers of R-L languages prefer to start on the right hand (40). Therefore, imitation and training of finger counting patterns could also provide an experiential basis for the establishment of early spatial directional biases (29,40).

In a recent study, Göbel, McCrink, Fischer, and Shaki (41) tested the potential effect of picture book reading on the directionality of counting routines in pre-literate children. Firstly, they showed that the images of children's picture books follow the same directionality as the habitual script in their culture: in English books, agents tended to be placed on the left, objects on the right, and actions flowed from left to right. The converse occurred in Hebrew books (see also 10,44). Secondly, they presented either a L-R or R-L version of a picture book to pre-literate children, while the experimenter described the story to the child. As previously reported (26), English and Arabic children showed pre-established directional counting preferences consistent with the writing system in use in their culture. Crucially, when asked to count after the picture book experience, those preferences adjusted to the directionality of the book.

What are the mechanisms underlying this effect? After considering several potential alternatives, Göbel et al. (41) suggested that the presence of a story plot and the temporal markers in the linguistic description of the story activated a mental time line, and this spatial representation becomes associated to the directionality of the book. The mental time line then affects counting because space, time, and number are part of a common brain system for magnitude (43).

An important theoretical alternative explanation for these findings is based on working memory processes. One such account is the Mental White Board account proposed by Abrahamse, van Dijck, and Fias (44–47). Another one is the Coherent Working Models account, developed simultaneously and independently by Santiago and collaborators (13,48,49). Both accounts suggest that the mind treats working memory as an internal space which is used in an analogous way to external space, and that RWD establishes a tendency to place in internal space those concepts learnt through linguistic experiences in the same direction in which they are often experienced, mostly through written language.

How can the working memory accounts explain the change in counting directionality brought about by picture book exposure? Abrahamse et al. (48, p.5) suggest that numbers and other kinds of ordered sequences (e.g., letters, words) which have been experienced in written form become associated to horizontal space in the direction of the script. However, pre-literate children do not have these reading experiences. Because adults tend to count in their RWD, they may have learnt counting directionality from counting with their caregivers, and this may explain their pre-existing counting biases. They have also probably experienced visual letter sequences (i.e., the alphabet) in RWD, what may explain a similar (so far untested) pre-existing bias for letter sequences. But it is unclear how, under this view, experiencing a series of pictures in a book while listening the story from an adult can change the association of numbers with horizontal space. This account, thus, also needs to resort to a common coding system for time and number in order to explain the effect (41).

In contrast, the Coherent Working Models theory suggests a potential mechanism (outlined in 12, and presented in greater detail here) which is shared by time and numbers, as well as any other concept, concrete or abstract, to be represented in working memory. Under this view, the internal space is where the mind constructs mental models, either from external (perceptual), internal (memory), or linguistic input (50). In agreement with extended cognition views (51), we believe that the distinction between internal and external space is blurry. Moreover, the internal space is subjected to a pressure for coherence (49). As a result, when the child follows the pictures in the book together with the caregiver, the locations of the contents of his or her mental model of the story tend to be placed in a consistent way with the external locations of the signs of those contents (the pictures). This develops a tendency to place contents in the model, and to scan them, in a direction consistent with the input. This tendency generalizes to mental models which are used later on for different goals, such as counting a set of objects. Therefore, Coherent Working Models theory suggests that directional experiences exert their effects by establishing spatial biases for mental model construction in working memory. These biases are general, affecting the construction of subsequent models for different tasks, which may involve times or numbers.

The present research aimed at studying whether processes of mental model construction in working memory are a good candidate as the underlying mechanism for the directional picture book experience. As a first step in that direction, we set to demonstrate that this kind of directional experience is able to modulate those processes in adults. We thus used the adult equivalent to a children's picture book: a speechless comic book. Participants understood either a L-R or a R-L speechless visual novel and we assessed the effect of this experience on a task that taps directly onto the processes of mental model construction: the comprehension of auditory sentences such as “the square is between the cross and the circle”. Participants were asked to draw the described scenes and we used the lateral arrangement of objects in the drawings as an index of the spatial organization of their mental model (as it has already been used and validated in 12,26). It is important to note that those sentences do not have any agentic nor temporal structure. Any spatial bias in them will reveal biases in the construction of mental models of a very general nature.

Experiment 1

Method

Following recommendations of full disclosure (52), we hereby assert that the experiments presented in this paper are the first three experiments we have carried out in this research line, they were conducted in the same order as described here, and there are no additional dependent variables, design features, nor full experiments left unreported. All experiments in this article were approved by the Ethics Committee of the University of Granada. All materials, programs and raw data can be accessed at (53).

Participants. We set to collect the same sample size per condition as in Román et al. (22). Fourty psychology students from the University of Granada took part in the study. One participant failed to follow the instructions and was replaced (mean age 20.2 years; 7 males; 3 left-handed in the final sample). All of them were native Spanish speakers and only one knew a language with a different RWD (Arabic).

Materials. For the practice task, we used a published commercial speechless comic (54). The comic told the story of a fox to save her calf from a volcanic eruption on an island populated only by animals. It comprised 36 double-sided pages and 373 frames. The frames were of different sizes and shapes. Nowhere in the comic appeared any written text, not even for onomatopoeias or ambient noises. A mirror version was devised by mirroring each page and binding them on the right side, such that the pages were turned from left to right. Otherwise, the two versions were identical.

For the drawing task we used the same materials and procedure as in Román et al. (22). Nine geometrical shapes which could be drawn easily (square, rectangle, cross, rhombus, triangle, circle, trapezium, oval, pentagon) were combined into 40 sentences and randomly split into two lists of 20 sentences. The sentences described a between relation among three different shapes: “the square is between the cross and the circle”. Each participant was presented with only one list. The sentences were read aloud by a female speaker and recorded into independent sound files.

Procedure. Each participant read written instructions, signed an informed consent form and filled a biographical information questionnaire. The study was presented as an investigation on the understanding of speechless comics. No mention was done of the directionality of the mirror-reversed comic. Participants were told that they were going to see first a speechless comic, then carry out an ostensibly unrelated filler task consisting in making a number of drawings, and then they would answer three comprehension questions about the comic. The participants did not know the questions in advance.

First, the comic (in either its standard or mirror version) was placed in front of the participant and she was instructed to explore it at her own pace while always pointing with a finger at the frame she was watching. Then the comic was removed and a stack of 20 blank square sheets was put in its place. Then the auditory sentences were presented one by one in random order by an E-prime program through one loudspeaker. After listening to each sentence, the participant drew the described scene on a new sheet, put it aside, and pressed the space bar on a computer keyboard to advance to the next one. Comic, sheets, loudspeaker and keyboard were all centered in front of the participant. Finally, she answered the questions about the comic. Throughout the session an overhead camera recorded a bird's-eye view of the participant's hands. The recordings were used to analyse both the scanning pattern of the comic as well as the drawing task.

Design and Data Analysis. There were two experimental groups of 20 participants: standard (L-R) and mirror (R-L). Invalid trials occurred when the central object (e.g., the square in “the square is between the cross and the circle”) was drawn anywhere else than at the center, and also when the three objects were not in a linear configuration (e.g., forming a triangle). In valid trials, we coded the *model order* depending on the locations of the two side objects with respect to the central object. In a sentence like “the square is between the cross and the circle”, a drawing placing a cross to the left and a circle to the right of a square is a L-R model. A circle-square-cross drawing is a R-L model. Data were analyzed by means of binomial logistic regressions, using the experimental condition (standard versus mirror comic) as a categorical predictor of the presence of a L-R model or its absence (i.e., a R-L model). For each contrast, we show the Wald chi-square, the odds ratio, and its confidence interval.

In order to check whether the scanning directionality of the comic agreed with our expectations, we also coded the direction of the sequence of pointing movements from each of the frames as rightwards, leftwards, upwards, or downwards (when the movement was in an oblique direction, it was decomposed into its two spatial components).

Results and Discussion

The standard and mirror groups did not differ neither in the number of invalid trials (6 vs. 3, n.s.) nor in the average time of the comic exploration phase (820.7 vs. 788.9 sec.; $t(38) = 0.25$, $p = .80$). The results did not differ if left-handers or the Arabic bilingual participant were removed from the dataset. The average time of the following drawing phase was 293 sec. in the standard comic group and 310.5 sec. in the mirror comic group. All participants correctly answered the three comprehension questions.

Videotaped finger pointing confirmed that scanning mostly adjusted to expectations (see Figure 1). When only the horizontal axis is considered, both conditions showed a majority of movements congruent with comic directionality and their differences were significant (L-R movements: 32.13% in the standard group vs. 13.97% in the mirror group; $t(38) = 21.1$, $p < .001$; R-L movements: 13.82% in the standard group vs. 32.5% in the mirror group; $t(38) = -24.14$, $p < .001$). Unexpectedly, the standard group also produced more upward movements (18.49% vs. 16.67%; $t(38) = 3.23$, $p < .01$) and less downward movements (35.58% vs. 36.86%; $t(38) = 2.1$, $p = .04$) than the mirror group. So far, the causes of this difference in vertical movements is unclear.

Therefore, the two groups mostly performed movements congruent with the type of comic (standard or mirror) that they were scanning. However, in the analysis of the drawing task, the mirror group produced the same amount of L-R models ($M = 73.7\%$, $SD = 36$) than the standard group ($M = 74.9\%$, $SD = 35.3$; $t(38) = -0.1$, $p = .92$; Wald $\chi^2 = 0.259$, $p = .61$, *Odds ratio* = 1.087, 95% $CI = [0.79, 1.50]$). Thus, under the conditions of the present experiment, the exposure to standard or mirror-reversed versions of the comic did not introduce any differential spatial bias in the creation of mental models in language comprehension.

One possible reason for this null result is that the comic task was too unconstrained. While comic exploration generated many lateral movements in the expected directions, there were also a high number of movements in other directions. The irregular distribution of frames on the pages and their variation in terms of shape and size in the present comic, together with the lack of written text, may have induced difficulties in comprehension which in turn may have generated a number of movement reversals, repeated exploration of some frames, and so on (55). In order to test this possibility, we established the canonical (most efficient) exploration pattern for each page in each version of the comic by following the frames in strict narrative order and counting the number of movements in each direction. We then compared by means of one-tailed t-tests the percentage of movements actually performed by the participants in each direction with the canonical percentages. The standard group differed significantly from the canonical values in all four directions (Down: $t(19) = -3.9$, $p = .001$; Left: $t(19) = 3.32$, $p = .004$; Right: $t(19) = -15.5$, $p < .001$; Up: $t(19) = 12.3$, $p < .001$). The mirror group also differed significantly from the canonical values in three directions and marginally in one (Down: $t(19) = -1.9$, $p = .07$; Left: $t(19) = -7.8$, $p < .001$; Right: $t(19) = 2.5$, $p < .02$; Up: $t(19) = 6.87$, $p < .001$).

The frequent changes of scanning direction may preclude the consolidation of any directional bias, at least in the short practice time that was provided in the present experiment. Because picture books for children use simpler arrangements than the present comic and the child's attention is guided by their parents, it is likely that children who are exposed to picture books experience a more consistent directionality. In Göbel et al. (41) study, the book had only one picture per page, pictures had image-internal directionality and the turning of the pages provided between-pictures external directionality, both consistent with each other.

In the next experiment we submitted to a direct test the hypothesis that consistent directional practice is able to induce measurable spatial biases even after a very short practice. Experiment 2 showed the frames of the same comic in horizontal strips on a computer screen. Moreover, the frames in each strip appeared progressively, such that the participant was forced to pay attention to them in the correct order. This effectively limited the scanning pattern to either L-R or R-L order.

Experiment 2

Method

Participants. Fourty native Spanish speakers from the same population. A problem with two video files in the standard group prevented coding the drawing phase, so we randomly removed other two participants in the mirror group, resulting in 36 participants (mean age 20.1 y., 5 males, 6 left-handers, one bidirectional bilingual).

Materials and Procedure. Everything was as in Experiment 1 with the exception that the directional practice task did not use a printed and binded comic. The frames were scanned separately and presented by means of E-prime on a computer screen in four-frame strips. In the standard condition each trial began with a frame being presented on the far left position of the screen, followed by another on the near left, then near right, and then far right positions. The interval between frames lasted 2 sec. The prior frames of a strip remained on view until the whole strip was presented. Two seconds after the final frame was shown, the strip disappeared and a new one started. The mirror condition differed from the standard condition in that mirror-reversed frames were presented from right to left at the same four screen locations. Apart from equalling total presentation time (720 sec.) across conditions, this procedure forced participants to explore the comic using a highly consistent scanning pattern, removing vertical movements altogether, although still allowing some backtracking along the horizontal axis. After the comic task, participants performed the drawing task and finally answered the same three comprehension questions about the comic.

Results

There were 3 invalid drawings in the standard group and 3 in the mirror group. The results did not differ if left-handers or the Arabic bilingual were removed from the dataset. The average duration of the drawing task was 328.7 sec. in the standard condition and 322.8 sec. in the mirror condition. All participants correctly answered the three comprehension questions. Under the present conditions, the standard group scored significantly higher in L-R models (M = 89.9%, SD = 21.9) than the mirror group (M = 67.7%, SD = 34.1; Wald χ^2 = 48.6, p < .001, *Odds ratio* = 4.29, 95% CI = [2.85, 6.46]).

Because Experiment 1 revealed no effects of prior directional practice and both conditions produced the same number of L-R models (74.9% in the standard group and 73.75% in the mirror group), we used it as a control condition (see Figure 1). The standard group in Experiment 2 produced more L-R models than the standard group in Experiment 1 (M = 74.9%, SD = 35.3; Wald χ^2 = 25.6, p < .001, *Odds ratio* = 2.9, 95% CI = [1.92, 4.4]). Moreover, the mirror group in Experiment 2 produced less L-R models than the mirror group in Experiment 1 (M = 73.7%, SD = 36; Wald χ^2 = 3.59, p = .058, *Odds ratio* = 1.36, 95% CI = [0.99, 1.86]). A better control group comes from Román et al. (22). One of their groups carried out exactly the same drawing task as it was used here but without any prior exposure to directional stimuli. Therefore, their data are a good estimate of the number of L-R models to be expected in the drawing task (M = 83.5%, SD = 27.6). Again, the standard group in Experiment 2 produced more L-R models (M = 89.9%, SD = 21.9; Wald χ^2 = 4.2, p = .04, *Odds ratio* = 1.6, 95% CI = [1.021, 2.48]), and the mirror group produced less (M = 67.7%, SD = 34.1; M = 83.5%, SD = 27.6; Wald χ^2 = 29.75, p < .001, *Odds ratio* = 2.7, 95% CI = [1.88, 3.85]). This suggests that both kinds of directional experience (standard and mirror) affected pre-established biases, with the former exacerbating them and the latter reducing them.

These results demonstrate that the experience of scanning pictures in a given direction is able to bias the construction of mental models in working memory. They also suggest that, in order to generate this effect under conditions of short directional practice, scanning direction needs be highly consistent.

Comics have inherent directionality in two ways: first, there is the direction of scanning between frames; second, there is the directionality of the actions or character's orientation within a frame. Experiments 1 and 2 manipulated both sources of directionality simultaneously. In Experiment 3, we manipulated only internal directionality by presenting frames one after another at the center of the screen.

Experiment 3

Method

Participants. Fourty native Spanish speakers from the same population (mean age 21.2 y.; 9 male; 6 left-handed). None knew any language with different RWD.

Materials and Procedure. The only difference with Experiment 2 was that the frames were presented one by one at the center of the screen for 2 sec., thereby eliminating the possibility of scanning through them. In the standard condition all the characters moved and oriented to the right of the screen while in the mirror condition they did it to the left.

Results

There were 5 invalid trials in the standard group and 11 in the mirror group (n.s.). The average duration of the drawing task was 327.4 sec. in the standard condition and 337.7 sec. in the mirror condition. All participants correctly answered the three comprehension questions. Removing the directional scanning from frame to frame in the present experiment also removed any trace of spatial biases in the drawing task: The percentage of L-R models in the mirror condition (M = 76.3%, SD = 32.4) did not differ from the standard group (M = 81.3%, SD = 28.6; $t(38) = -0.5$, p = .

55; Wald $\chi^2 = 2.04$, $p = .15$, *Odds ratio* = 1.287, 95% *CI* = [0.91, 1.82]). This shows that the internal directionality of the drawings in the frames is not enough only by itself to induce spatial biases in mental model construction in language comprehension, at least with such a small amount of practice.

General Discussion

In the present study we tested whether the exploration of a speechless comic with either L-R or R-L directionality is able to induce congruent spatial biases in the construction of mental models in working memory. The first experiment used a commercial speechless comic and presented it in either its published form (L-R) or a mirror-reversed form (R-L), including a reversal in page binding. After exploring it for comprehension, participants in both groups drew auditorily presented descriptions of static spatial scenes, and their drawings showed an overall L-R bias which was not affected by comic directionality. We reasoned that this might be due to the frequent changes in directionality that were allowed by the unconstrained exploration of the comic. Thus, in the second experiment the same materials were presented using a procedure that forced highly consistent scanning movements from frame to frame. Now, the standard (L-R) condition exacerbated pre-existing L-R biases while the mirror condition significantly increased R-L mental models in the drawing task. The third experiment showed that the internal directionality of the images is not able on its own to induce these biases, at least with the small amount of practice provided.

Present results add to evidence by Göbel et al. (41) to suggest that exposure to picture books is one factor that can provide the kind of experience that induces the early start of spatial biases (8,26,31). It is noteworthy that, in the present experiments, the mirror comic succeded to change spatial biases only in the less ecological situation: when frame to frame scanning was constrained to the lateral axis. However, this less ecological situation for adults may be in fact more ecologically valid for children. Parents often spend a considerable amount of time watching picture books with their children from a very early age (35), showing them the pictures, pointing at them, pronouncing their names aloud and talking about them, all of them activities which direct the attention of the baby in a very clear and consistent manner. Moreover, children's picture books often display only one scene per page, as in the book used by Göbel et al., allowing scanning from scene to scene only along the lateral axis. These very consistent early experiences can generate initial spatial biases that will be later reinforced by the interaction with the written script, as well as by other consistent experiences such as the learning and use of counting routines, both of fingers (40) and other objects (26,27).

Göbel et al. (41) have shown that the direction of exploration of picture books is able to change the preferred direction of counting in pre-literate children. As predicted by the Coherent Working Models account (12,50), we hereby report similar directional influences in an adult analogue of Göbel et al.'s (41) materials (understanding a speechless visual narrative) in a task which directly assessed the processes of mental model construction in working memory. Under the theory, these biases can generalize to models later created for other tasks, including number and time tasks. As stated in the Introduction, the present study is only a first step toward establishing working memory as the locus of origin of early spatial biases in time and number. Future studies will need to show that the same directional experience as used here is able to induce spatial biases in time and number tasks in adults. It will also be necessary to evaluate the effect of picture book directionality on the same mental model construction task in pre-literate children.

To conclude, the present study shows that the mere exploration of a speechless comic is able to change pre-established spatial biases in the construction of mental models in language comprehension. This is consistent with the idea that mental model construction in working memory is a potential underlying mechanism of the effect of analogous experiences on early spatial biases in number and time tasks in pre-literate children (41). Present data also show that the strength of the effect of the directional experience is affected by several modulating factors, such as the amount and consistency of directional cues.

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Author contributions

A.R., A.F., and J.S. designed the study; A.R. and A.F. collected the data; A.R., A.F., and J.S. analyzed and interpreted the results; A.R. drafted the paper and A.F. and J.S. provided critical revisions; all authors approved the final version.

Competing interests

The authors declare no competing interests.

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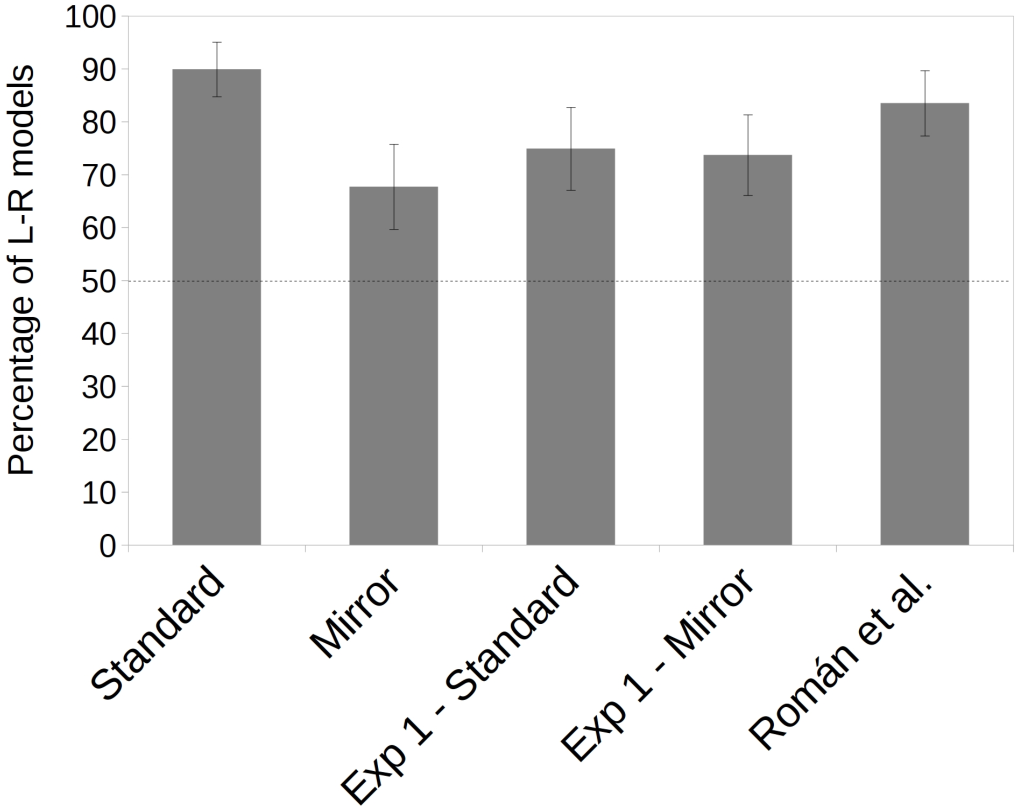

Figure 1: Percentage of L-R models in the drawing task in the Standard and Mirror groups of Experiment 2 compared to the same groups in Experiment 1 and to the control group without prior directional practice in Román et al. (22). The dashed line marks absence of bias. Error bars represent Standard Error of the Mean (SEM).