Published in final edited form as:

Cogn Behav Neurol. 2012 June ; 25(2): 77–84. doi:10.1097/WNN.0b013e3182596118.

Line copying: Distinct “where” and “aiming” spatial bias in healthy controls

Priyanka P. Shah^{a,b}, Keith Gonzalez^{a,1}, and Anna M. Barrett^{a,b}

^aStroke Rehabilitation Research Laboratory, the Kessler Foundation Research Center, and Department of Physical Medicine and Rehabilitation, 1199 Pleasant Valley Way, West Orange, NJ 07052, United States

^bDepartment of Neurology and Neurosciences, The University of Medicine and Dentistry, NJ – NJ Medical School (UMDNJ-NJMS), United States

Abstract

BACKGROUND—Spatial bias may manifest differently in natural, implicit tasks such as reaching and grasping than arbitrary lab-experiment line bisection task. It is more difficult to quantify spatial processing in natural, everyday activities. Therefore, studying spatial behavior in an implicit lab-experiment task is crucial. Drawing tasks of copying lines or objects integrate spatial perceptual “where” input and motor-intentional “aiming” output, and may be more implicit because subjects are unaware that placement of their drawings will be assessed.

OBJECTIVES—In healthy controls, we examined how spatial displacement in a line copying task manifests spatial bias, and whether it is possible to dissociate “where” and “aiming” spatial bias in this task. We examined changes in the “where” and “aiming” spatial displacement in response to bottom-up versus top-down cues (hemi-space presentation and drawing direction).

METHOD—In 13 healthy controls, we collected subject-copied line displacements, and lengths in both the natural (left-right congruency) and reversed (left-right incongruency) viewing conditions to separate “where” and “aiming” spatial biases.

RESULTS—Subjects displaced lines leftward ($p = 0.01$) as they copied lines, which was primarily based on “where” bias. Subjects displaced lines in the direction of drawing movement irrespective of the viewing conditions consistent with induced “aiming” effects ($p=0.291$). Side of line presentation did not affect the “where” spatial bias. Copied-line lengths were not affected.

Keywords

“where” bias; “aiming” bias; line copying task; two camera video apparatus

1. Introduction

Healthy young adults typically err leftward when bisecting horizontal lines.^{1–4} This spatial bias may reflect the critical support of right brain cognitive networks.^{5,6} Bisecting a line

Corresponding Author: Priyanka P. Shah, MS, Stroke Rehabilitation Research Laboratory, Kessler Foundation Research Center, 1199 Pleasant Valley Way, West Orange, NJ 07052, Phone: 973-324-3582, Fax: (973) 243-6984, pshah@kesslerfoundation.org.

¹University Physicians Neurology Clinic, Tucson, AZ (Present address)

Keith O Gonzalez, MD, Stroke Rehabilitation Research Laboratory, Kessler Foundation Research Center, 1199 Pleasant Valley Way, West Orange, NJ 07052, Phone: 973-324-3569, Fax: (973) 243-6984

Present address: Department of Neurology (University Physicians Neurology Clinic)

University of Arizona, 2800 E. Ajo way, Tucson, AZ 85713, Phone: 520-694-8888, Fax: 520-874-2701, kog@email.arizona.edu

A. M. Barrett, MD, Stroke Rehabilitation Research Laboratory, Kessler Foundation Research Center, 1199 Pleasant Valley Way, West Orange, NJ 07052, Phone: 973-324-3563, Fax: (973) 243-6984, abarrett@kesslerfoundation.org

requires unbiased awareness of both the left and right hemispace, an intact internal map or representation of space, and an ability to plan, initiate and execute symmetric movements. The underlying mechanisms of spatial cognition, therefore, may be described as separable, consecutive stages of information processing, which include spatial perceptual-attentional “where”, representational, and motor-intentional “aiming” output stages. Previous research has demonstrated that spatial bias in healthy individuals may be a result of asymmetric activity at one or more of these processing stages. Directional and spatial line bisection errors may be a result of either “where” spatial unawareness or “aiming” spatial motor bias.^{1, 2, 7} Spatial “where” systems rely heavily upon visual input for symmetric awareness of the surrounding space. This input stage of visual-spatial processing is defined by visual perception, and therefore could be considered visual feedback dependent, or in other words, visually monitored. However, the spatial “aiming” systems depend may upon the stored internal motor representations to plan and initiate an action.^{8–10} By definition, the “aiming” stages of spatial processing are motor execution-related, rather than dependent upon visual feedback (feedback-independent).

Both spatial “where” and “aiming” systems in an intact brain rely upon multi-modal associative regions working synchronously. Stage-wise spatial processing may be differently engaged in natural, functional movements such as reaching and grasping than in arbitrary laboratory-experiment tasks such as line bisections. Examining spatial behavior in natural tasks may be more implicit, where subjects do not know what is being tested, or that they do not have to attempt to meet a performance standard¹¹, as compared with assessing spatial bias in an arbitrary lab-experiment task like line bisection, which is more explicit, requiring subjects to follow a set of instructions. Most research studies concentrate on spatial processing in explicit lab-experiment tasks rather than natural tasks because it is more difficult to quantify spatial processing in everyday activities. Natural spatial behaviors are less controlled, and may require complex kinesiological measurements to fully understand the underlying spatial behavior.^{12–14} However, studying spatial behavior in an implicit lab-experiment task, which may be mechanistically more like natural spatial behavior, is extremely important.

In this study, we examined stage-wise spatial processing in a lab-experiment task of copying an experimenter-presented horizontal lines after being instructed to draw rightward or leftward. This task may be more implicit than line bisection, because in drawing tasks such as copying a line or objects, subjects make placement choices (about horizontal and vertical coordinates) on a paper, and they are not aware that the placement of drawings will be assessed. Barrett and Craver-Lemley (2008) reported that spatial bias may manifest differently when assessed with explicit versus implicit spatial tasks.¹¹ Compared to line bisection, an implicit task such as copying a line may also temporally separate perceptual “where” and motor-intentional “aiming” spatial processing, as subjects may first attend to the experimenter-presented sample line (to left or right), and then plan rightward or leftward movements to copy the sample. In addition, line copying may involve more directional motor behavior than line bisection.⁷ These tasks may engage the specialized visuomotor and visuoconstructional functions in the right hemisphere,¹⁵ and manifest the underlying spatial “where” or “aiming” bias when placing drawings appropriately. Implicit drawing tasks have been extensively studied in stroke survivors with and without spatial neglect,^{7, 16} but mechanisms of spatial bias (“where” vs. “aiming” components) affecting line drawing in healthy controls are not well understood.

As the first aim of this study, we wish to learn whether it is possible to dissociate “where” and “aiming” spatial bias as subjects copy lines. In the current study, 13 healthy controls made decisions regarding the placement of the start and end points of the copied line after being instructed to move either rightward or leftward on the page. Subjects copied lines

under both natural and mirror-reversed viewing conditions. Schwartz et al. (1997) describes mirror-reversed viewing a testing condition in which hand movements in a workspace are reversed in direction as the subject views their hands indirectly on a video screen.¹⁰ In this condition, “where” or perceptual-attentional systems are acting in the hemispace opposite to that of “aiming” or motor-intentional systems, which allows dissociation of “where” and “aiming” spatial bias.^{1, 8, 10, 17} If the placement of drawn lines remain unchanged in the natural compared with reversed condition, it suggests that this spatial bias is relatively insensitive to visual feedback, and may be due to an output-related, motor-intentional or “aiming” bias. If, however, the direction of spatial bias changes between the natural and reversed condition, it suggests that subjects’ spatial bias is, in fact, dependent on visual input and thus, it may be primarily attributed to perceptual-attentional, “where” bias.^{10, 18}

Reversing the direction in which subjects move relative to what they see, as they copy lines, is one way of fractionating “where” and “aiming” spatial errors. Another method of distinguishing “where” vs. “aiming” bias is to use cues, or otherwise alter task conditions so as to selectively influence spatial processing.^{19, 20} Garza et al. (2008), using line bisection tasks in healthy controls, reported that a bottom-up, visual (feedback-dependent) distractor specifically influenced leftward “where” bias, while a top-down, motor cuing (feedback independent) instruction influenced spatial “aiming” errors.¹ Starting position of hands, when bisecting a line, can be a crucial determinant of task performance.^{21, 22} In Garza et al. (2008), healthy controls, while bisecting lines, erred in the direction of initial hand position or the start side and these motor cuing effects primarily affected “aiming” spatial bias.¹ Additionally, McCourt, Garlinghouse & Reuter-Lorenz (2005) demonstrated that unilateral visual cues such as line contrast, position and geometry significantly influenced the perceived midpoint in line bisection tasks.¹⁹ An experimenter standing on either the right or the left side of a line being bisected, is another example of a unilateral visual/attentional cue as in Garza et al. (2008).¹ In this case, healthy controls erred leftward in the presence of a left distractor, and rightward in the presence of a right distractor, and this shift primarily affected “where” spatial bias.

Therefore, as the second aim of this study, we wished to capture changes in “where” and “aiming” spatial biases as subjects copied experimenter-presented lines in response to specific task demands. Based on our previous research¹, we hypothesized that instructions to draw leftward or rightward to copy lines may primarily influence spatial “aiming” bias. Directional motor cues may induce a top-down, strategic motor-intentional “aiming” bias to displace copied-lines in the direction of hand movement. Alternatively, “where” spatial bias may induce a bottom-up spatial bias when a sample line is presented in the left vs. right hemispace.^{3, 20, 23} Along with static cues like in McCourt et al. (2005) and others, directional (left vs. right hemispace) presentation and thus, registration of stimulus characteristics, may also selectively influence spatial input stages, i.e., the perceptual-attentional, “where” systems lead to an orienting bias favoring the side of line presentation¹⁹. Subjects, therefore, may displace copied lines towards the side of sample line presentation.

Overall, in this study, we examined how spatial displacement in line copying, a more implicit lab-experiment task than line bisections, manifests spatial bias in healthy individuals, and whether it is possible to dissociate “where” and “aiming” spatial bias in this task. We also examined whether changes in the “where” and “aiming” spatial displacement can be captured in response to specific bottom-up versus top-down task demands or cues such as side of sample line presentation and direction of hand movement to copy lines. We also monitored the effects of line presentation and drawing direction on copied line *lengths*, and analyzed these data post-hoc.

2. Methods

2.1 Participants

Healthy individuals (n=13): seven males and six females (Mean age = 25.9 years, SD = 3.0 years; Mean education = 19.3, SD = 1.4 years) were recruited for this study. All participants were right-handed with no history of neurological or psychiatric disorders. Before recruitment and testing, all participants provided their informed consent.

2.2 Two Camera Video Apparatus

In this paradigm¹⁰, subjects were seated before a video monitor and a desk with a glass surface as they copied lines. A curtain was positioned between subjects and the workspace to block direct view of their hands. A 75-watt bulb behind the curtain illuminated the workspace and provided back lighting. In the natural condition, a camera above the workspace projected a movement-congruent image to the monitor: the hand in the right workspace appeared on the right side of the monitor, and in the left workspace, on the left side of the monitor. Rightward hand movement in the natural condition appeared rightward, and leftward hand movement, leftward. In the reversed condition, a camera below the workspace projected a shadow of subject's hand on the screen such that hand positions and hand movements were reversed, with the hand in the right workspace appearing on the left side of the monitor and the hand in the left workspace appearing on the right side of the monitor. Rightward hand movements in the reversed condition appeared leftward, and vice versa (Figure 1).

2.3 Procedures

Subjects drew horizontal lines with a black marker on a 216x280 mm sheet of paper after viewing sample lines of two lengths; samples were either 220x3 mm (64 trials), or 240x3 mm (64 trials) horizontal lines on a 216x356 mm sheet of white paper, centered on a 87 x 31 cm white board. During each trial, sample lines were presented approximately 600 mm to the left or right from the center of the monitor, at the same height, and about 700 mm from subjects' eyes. Subjects were allowed to move their head and neck freely while examining the sample lines. They were instructed to begin copying on the left or the right of a blank sheet, as they move their hands rightward or leftward respectively. Once subjects placed their marker on the sheet to start drawing, the sample line was removed.

Subjects copied lines presented in alternating blocks of four, beginning with the natural condition, followed by the reversed condition for four trials and so on. For half of the trials, lines were presented on the left, and for the other half, on the right. Side of presentation and drawing direction were assigned randomly.

2.4 Scoring

Distance between the veridical center of the paper and the center of the copied line was measured to the nearest millimeter, and is referred to as line displacement. The edge of the sheet was defined as the end if it intersected with the copied line. We used sign conventions as Barrett and Craver-Lemley (2008); rightward displacement is deemed positive and leftward displacement, negative¹¹. Because the effects of the viewing conditions (natural vs. reversed) were not part of the a priori hypotheses, subject-drawn line lengths were evaluated post hoc, and were recorded as a percentage of the sample length. These percentages also determined if subjects reproduced lines accurately.

2.5 Data

Analyses In this study, subjects copied experimenter-presented lines instead of bisecting lines. In the natural viewing condition, an image of the subjects' hand in right space appears on the right side of the monitor (and vice versa), and rightward hand movements appear rightward (and vice versa); thus, "where" and "aiming" spatial biases are aligned.¹⁰ When performing the same task in the reversed condition, subjects view a workspace left-right reversed from the actual workspace, with subjects' hands in right space appearing on the left side of the monitor (and vice versa), and rightward hand movements appearing leftward, (and vice versa). In the reversed condition, the direction of visual/"where" input and motor/"aiming" output information is no longer aligned or congruent but rather is shifted 180°. 1, 9, 10, 17, 18

Given what we state above about the natural and reversed conditions, we analyzed spatial bias based on changes in subjects' displacement errors in the natural versus reversed viewing conditions. If subjects' displacement errors remain unchanged between conditions, it suggests that this spatial bias is relatively insensitive to visual feedback and may be primarily due to motor-intentional or "aiming" spatial bias. However, if the direction of displacement errors changes between the natural and reversed conditions, it suggests that subject's spatial bias is dependent on the visual input and may be primarily due to perceptual-attentional or "where" bias.^{10, 18} It is important to note that this method of decoupling characteristics of spatial bias can only predict the relative role of "where" or "aiming" bias under specific task conditions.

Our second goal was to examine the effect of modality-specific task demands or cues on line displacement to capture changes in "where" and "aiming" bias separately. To examine whether "aiming" bias displaced lines toward the direction of hand movement, or whether "where" bias caused subjects to displace lines in the direction of line presentation, we performed repeated measures analysis of variance (ANOVA) using displacement as the dependent variable, and viewing conditions (natural, reversed), direction of hand movement (leftward, rightward), and sample line presentation (left, right) as within- subject parameters. To examine changes in line length with respect to modality-specific task demands as a post hoc measure, we performed a second, identical repeated measures ANOVA with line length as the dependent variable. Additionally, because gender differences may be relevant to line bisection performance,^{4, 8} we performed a post-hoc, repeated measures ANOVA including gender (female, male) as a between-subjects factor for both displacement and length measures.

4. Results

All significant effects and interactions resulting from the described ANOVAs are presented in this section.

4.1 Line Displacement

Repeated measures ANOVA with displacement as a dependent variable revealed significant main effects of the viewing conditions (natural versus reversed), and direction of hand movement (leftward versus rightward).

4.1.1 Displacement bias in the natural condition—First, we verified whether subjects in our study demonstrated leftward bias on an implicit line displacement task, as previously-reported in explicit line bisection.^{3, 4} Mean line displacement was calculated for all the natural condition trials (irrespective of sample line presentation and direction of hand movement). A paired-samples t-test (with respect to 0) indicated that there was a robust

displacement ($M = -2.08$ mm, $SD = 2.53$ mm; $t = -2.959$, $p = 0.01$, $d = 1.16$) to the left from the center of the page (Figure 2), consistent with previous studies of drawing placement bias.^{11, 15}

4.1.2 Displacement bias in natural vs. reversed conditions—Previously reported mean leftward bias in the natural condition changed to mean rightward bias in the reversed condition ($M = 1.47$ mm, $SD = 3.72$ mm). A paired-samples t-test (with respect to 0) indicated that the mean rightward bias in the reversed condition was not significant ($t = 1.426$, $p = 0.179$, $d = 0.56$). In context with the first aim, repeated measures ANOVA revealed that line displacement performance changed significantly from the natural versus the reversed conditions ($F(1,12) = 14.24$, $p = 0.003$, $\eta_p^2 = 0.54$). These results suggest that line placement bias changed with viewing conditions, i.e., it is primarily a feedback-dependent phenomenon. This suggests that the overall leftward displacement of drawn lines, relative to the center of the page, may be primarily dependent on “where” spatial systems.

4.1.3 Displacement bias in response to a modality-specific cue

Spatial “aiming” bias: We hypothesized that when subjects were instructed to draw in one direction (leftward vs. rightward), this would increase spatial “aiming” bias in that direction. In the natural condition, as predicted, when subjects drew rightward, they displaced lines to the right ($M = 0.04$ mm, $SD = 3.06$ mm); whereas when drawing leftward, they displaced lines to the left ($M = -4.20$ mm, $SD = 3.77$ mm). In the reversed condition, subjects again displaced lines in the direction of hand movement. They displaced lines leftward ($M = -1.38$ mm, $SD = 5.42$ mm) when drawing leftward, and rightward ($M = +4.33$ mm, $SD = 5.22$ mm) when drawing rightward. In addition, repeated measures ANOVA revealed that although there was a robust effect of direction of drawing movement on displacement ($F(1,12) = 11.63$, $p = 0.005$, $\eta_p^2 = 0.49$), the viewing conditions (natural, reversed) by direction of hand movement (leftward, rightward) interaction was not significant ($F(1,12) = 1.22$, $p = 0.291$, $\eta_p^2 = 0.09$). Thus, we found no evidence that the effect of direction of hand movement on displacement changed with the viewing condition. Since displacement in the direction of hand movement was independent of visual feedback, this is consistent with induced spatial “aiming” bias.

Spatial “where” bias: Displacement of lines to the left or right was not overall significantly influenced by presentation side (left, right) (no main effect: $F(1,12) < 0.001$, $p = 0.99$, $\eta_p^2 < 0.001$). Higher level interaction with viewing condition (natural, reversed) did not reach significance ($F(1,12) = 2.95$; $p = 0.111$, $\eta_p^2 = 0.20$). This suggests no robust effect of presentation side on “where” spatial bias influenced line displacement.

4.2 Additional Analyses: Line Length and Gender

We also evaluated the effect of drawing direction and presentation side on line length, and the influence of gender on “where” and “aiming” biases in this experiment.

4.2.1 Line Length—A paired-samples t-test (with respect to 100%) indicated that in the natural condition, subjects significantly underestimated line length ($M = 90.7\%$, $SD = 13.1\%$; $t = -2.56$, $p = 0.025$, $d = 1.00$). Subjects also significantly underestimated line length in the reversed condition ($M = 92.6\%$, $SD = 11.3\%$; $t = -2.34$, $p = 0.037$, $d = 0.93$, paired t-test comparing length to 100%).

Although subjects, in general, underestimated line length, viewing conditions trend revealed that subjects tended to draw longer lines in the reversed condition (percent mean difference (reversed - natural) = 1.93, $SD = 3.53$) but this did not reach significance ($F(1,12) = 3.90$, $p = 0.072$, $\eta_p^2 = 0.24$).

4.2.2 Length bias in response to modality-specific cues—Direction of hand movement did not significantly influence line length (main effect: $F(1,12) = 0.43$, $p = 0.522$, $\eta_p^2 = 0.03$), and neither did the side of sample line presentation (main effect: $F(1,12) = 0.15$, $p = 0.707$, $\eta_p^2 = 0.01$). We did not observe a significant interaction of viewing condition and presentation side ($F(1,12) = 2.0$, $p = 0.183$, $\eta_p^2 = 0.14$). Thus, we observed no evidence of altered testing conditions/cuing affecting “aiming” and/or “where” bias and copied line length.

4.2.3 Effects of gender—Repeated measures ANOVA of line displacement with gender as an additional between-subjects factor revealed no significant gender-related main effects, nor any higher level interactions (all p values > 0.10 , not significant), and a similar repeated measures ANOVA performed with line length as a dependent variable produced similar results (all p values > 0.10 , not significant).

5. Discussion

Barrett and Craver-Lemley (2008) reported that spatial bias may manifest differently when assessed with explicit versus implicit spatial tasks.¹¹ Therefore, in thirteen healthy controls, we explored whether leftward perceptual-attentional “where” bias and motor-intentional “aiming” spatial bias can be separated when we assessed line displacement during copying of experimenter-presented lines, a more implicit task than line bisections.^{1, 9, 10, 17} We predicted that the direction of subject-drawn line displacement might change with mirror-reversal if the primary bias were related to perceptual-attentional “where” bias. Furthermore, we wished to capture changes in “where” and “aiming” spatial bias in response to modality-specific task demands or cues. We hypothesized that instructions to move leftward or rightward on the page may increase spatial “aiming” bias in the direction of movement, and that presenting sample lines on the left or the right side of the subject may increase spatial “where” bias in the direction of the presented line.¹

We replicated a robust tendency to displace lines leftward, which is consistent with the leftward bias reported in line bisection tasks,^{4, 10, 11} as 13 healthy controls copied experimenter-presented lines. Healthy controls’ leftward bias in both an explicit, manual line bisection task and a more implicit drawing-based line copying task, supports right hemisphere dominance theories in spatial processing.^{11, 24–26} Previous authors examined if leftward bias in line bisection, may be influenced by subjects’ language-based visual scanning/reading habits.^{27, 28} In this study, all subjects learned to read from left-to-right, which may contribute to the displacement of copied lines toward the left. Future studies including subjects with different exposure to right-to-left versus left-to-right writing, may further clarify these issues.

We also observed that a primary “where” perceptual-attentional spatial bias may determine the direction the center of a line being drawn is displaced relative to the center of the page. That is, in the reversed condition, subjects displaced lines rightward, opposite to that observed in the natural condition. This result is consistent with previous research; Schwartz et al. (1997) reported that in 75% of subjects,¹⁰ leftward bias on line bisection task was attributed to “where” perceptual-attentional systems. Left-sided bias in peripersonal space reported by Garza et al. (2008) was also primarily based on perceptual-attentional, “where” bias.¹ These results, combined with significant leftward displacement bias, suggest that right hemispheric “where”, input-related spatial systems may be predisposed, causing subjects to err leftward.

Next, we explored whether it is possible to capture changes in “where” and/or “aiming” spatial bias by changing modality-specific task demands. Subjects were randomly instructed

to draw either rightward or leftward as they copied lines. We hypothesized that the instructed direction of drawing movement would increase “aiming” spatial bias in that direction i.e., moving leftward would cause participants to displace lines leftward; moving rightward would cause them to displace lines rightward. Our findings were consistent with this prediction. Subjects were not influenced by changes in the video viewing condition because subjects displaced lines in the direction of movement even when left-right viewing conditions were reversed, which by definition is “aiming” or motor-intentional in nature.

This finding is consistent with previous reports of spatial “aiming” motor cuing effects.^{1, 21} In line bisection task, Garza et al. (2008) reported an increased leftward motor-intentional “aiming” bias when subjects were instructed to start on the left as compared with trials when they started on the right, and this effect was also independent of natural versus reversed viewing conditions.¹ Similarly, there was a significant start side effect on line bisection performance in Halligan et al. (1991).²¹ However, they did not differentiate between “where” and “aiming” spatial mechanisms as in Garza et al. (2008) and the current study.¹ This suggests that healthy controls, using top-down motor-intentional, motor planning strategies influenced by motor cues, may err in the direction of the cue. In addition, Schwartz et al. (1999) suggested that a motor cuing condition that involves limb movements selectively increases spatial motor-intentional “aiming” bias.²⁹ Therefore, in this study, when subjects were instructed to draw leftward or rightward, cuing function of the hand movement in space²¹ may have biased the overall output causing subjects to displace lines toward the direction of hand movement. Lastly, we interpreted prior studies^{1, 30, 31} as supporting “aiming” spatial bias as a measure of feedback-independent spatial cognitive processing. However, we recognize that feedback-dependent and feedback-independent systems interact continuously in the healthy brain. Further studies examining how feedback is processed as “where” and “aiming” systems interact may help to clarify this issue.

Scanning eye movements and cuing effects influence spatial bias during line-based tasks.³² In this study, displacement errors in the direction of hand movement suggest a centrifugal pattern of errors, that is, subjects drawing lines from left-to-right (i.e., rightward) displaced lines to the right, and drawing from right-to-left displaced to the left. We did not control for or assess scanning eye movements in this study, and therefore we cannot convincingly comment on how overt orienting affected our findings. However, since subjects erred in the direction of hand movement regardless of natural versus reversed viewing conditions, scanning effects would have had to be independent of visual feedback. Lastly, orienting eye movements may continuously balance bottom-up, stimulus driven demands and top-down strategic goals. In this paradigm, direction of hand movement would be expected to reflect primarily top-down rather than bottom-up processing. Future studies capturing scanning eye movements while subjects copy lines in both natural and reversed viewing conditions might help clarify how scanning influences “aiming” hand movements.

Although a spatial motor preparatory cue appeared to alter “aiming” spatial bias, we did not observe any effect of cuing as induced by right- vs. left-sided line presentation, on “where” spatial bias. There was also no interaction of line presentation side with any other variables. Previous studies reported a significant effect of a visual cue on line bisection errors,^{1, 23} but in our study we did not observe this effect. As mentioned earlier, line copying may involve more directional motor behavior than line bisection⁷ reducing the magnitude of presentation side effects. It also may be that line presented in left versus right space was a less salient stimulus than a person on the left vs. right side, as in Barrett, Schwartz, Crucian, Kim, and Heilman (2000) and Garza et al. (2008),^{1, 23} which may have reduced the magnitude of an interaction between presentation side and viewing condition.

Subjects' judgment about line placement accuracy was not accessed in our study. It may be interesting in future studies to evaluate whether subjects are aware of their leftward placement bias, and if they can alter it. In addition, subjects implicitly underestimated line length significantly in both the natural and the reversed conditions. This hypometria is partly consistent with previous studies of magnitude in estimation. Stevens (1970) reported a regular underestimation of larger stimuli and overestimation of smaller stimuli in healthy controls.³³ In our study, the sample lines (220 and 240 mm) may be regarded as long and thus subjects' hypometria may be consistent with a previously-reported tendency to underestimate length when the stimulus is long.³⁴ Line length was not influenced by modality-specific task demands. Again, explicit line estimation judgments in future studies might clarify at what level the length under-representation occurred.

Our subjects frequently drew lines such that they were not exactly parallel to the top or the bottom edges of the sheet. Since subjects were not explicitly instructed to be cautious of angular placement of copied lines, observed diagonal orientation bias,³⁵ in our subjects, may reflect an intrinsic spatial bias not only with respect to a horizontal reference plane (right versus left hemisphere) but also with respect to the radial plane (distal versus proximal body space). Therefore, a line copying task may allow multidimensional monitoring of implicit spatial bias in healthy controls, which may be more similar to natural spatial tasks than line bisections or judgments. Spatial bias affecting near versus far space,^{27, 36} which have been attributed to separate underlying neural systems,³⁷ may contribute to such angular placement of lines, where end-points of drawn lines are either toward (distal) or away (proximal) from subjects' midsagittal plane. Diagonal bias, near/far bias and the potential brain hemispheric asymmetries underlying these effects will be important to evaluate in future studies of line copying.

We did not observe any main effects of, or interactions with, gender. Future studies of line copying tasks with larger sample sizes may provide a better understanding of gender-related differences, if any, that influence drawing and line copying.

We labeled "where" and "aiming" bias based on our spatial performance paradigm, and our previous work indicating that we may be able to fractionate perceptual-attentional ("where" spatial bias from motor-intentional ("aiming") spatial bias.^{1, 8, 18, 38, 39} Although the dorsal visual stream is also known as the 'where' system, we appreciate that "where" nomenclature for this classically-defined system is different, and denotes its contribution in the processing and transforming of information necessary for the visual control of action, whereas the ventral stream, also known as the 'what' system, contributes in visual object recognition.⁴⁰ Ungerleider and Mishkin (1982) also described this dichotomy by hypothesizing that the dorsal pathway is specialized for spatial perception, i.e., locating *where* an object is, and the ventral pathway is specialized for object perception, i.e., identifying *what* an object is.⁴¹ Although some studies indicate that dorsal cortical regions related to action may share common components with motor-intentional "aiming" spatial systems,⁴² the classically described "where" dorsal stream is not solely dedicated to spatial information processing; it processes a multitude of real-time action- and movement-related information.^{14, 43} In addition, dorsal visual-action systems focus on transformed visual input and representation stages. Likewise, the "aiming" spatial systems, as described earlier, process at representational and motor output stages.⁴³ Since our initial goal was to study the interaction of dissociable stages of spatial processing, we chose a task with visual-spatial computation components that may provide more opportunity to study variability in subjects' perceptual-attentional and motor-intentional capacity than do fundamental spatial functions such as reaching and grasping. Nevertheless, it is possible to capture the underlying characteristics of spatial bias in reaching, pointing or grasping objects.¹² Such studies, experimentally

utilizing kinesiological variables, might help clarify the relationship between dorsal visual and spatial “aiming” processing.

Acknowledgments

This research is supported by Kessler Foundation Research Center and National Institute of Health. We thank the subjects who took part in the experiment for donating their time, and Dr. Peii Chen for theoretical advice. This work was presented in a preliminary form at the 53rd meeting of the American Academy of Neurology (*Neurology*, 56 (8 Suppl 3):A187, P03.071).

References

1. Garza JP, Eslinger PJ, Barrett AM. Perceptual-attentional and motor-intentional bias in near and far space. *Brain Cognition*. 2008; 68(1):9–14.
2. Bultitude JH, Aimola Davies AM. Putting attention on the line: Investigating the activation-orientation hypothesis of pseudoneglect. *Neuropsychologia*. 2006; 44:1849–58. [PubMed: 16701730]
3. Nicholls M, Roberts G. Can free-viewing perceptual asymmetries be explained by scanning, pre-motor or attentional biases? *Cortex*. 2002; 38:113–136. [PubMed: 12056684]
4. Jewell G, McCourt ME. Pseudoneglect: a review and meta-analysis of performance factors in line bisection tasks. *Neuropsychologia*. 2000; 38(1):93–110. [PubMed: 10617294]
5. Heilman KM, Valenstein E. Mechanisms underlying hemispatial neglect. *Ann Neurol*. 1979; 5(2):166–70. [PubMed: 426480]
6. Mesulam, M. Principles of behavioral and cognitive neurology. Mesulam, M., editor. New York: Oxford University Press; 2000.
7. Geminiani G, Camaschella E, Mariani C, Alberoni M, Farina E. Direction and position factors in performance of line extension task by unilateral neglect subjects. *Neuropsychologia*. 2002; 40(11):1834–1840. [PubMed: 12062895]
8. Chen P, Goedert K, Murray E, Kelly KM, Ahmeti S, Barrett AM. Spatial bias and right hemisphere function: Sex-specific changes with aging. *Journal of international neuropsychological society*. 2011; 17:455–462.
9. Bisiach E, Geminiani G, Berti A, Rusconi ML. Perceptual and premotor factors of unilateral neglect. *Neurology*. 1990; 40(8):1278–81. [PubMed: 2381538]
10. Schwartz R, Adair JC, Na D, Williamson D, Heilman K. Spatial bias: Attentional and intentional influence in normal subjects. *Neurology*. 1997; 48:234–242. [PubMed: 9008524]
11. Barrett AM, Craver-Lemley CE. Is it what you see, or how you say it? Spatial bias in young and aged subjects. *J Int Neuropsychol Soc*. 2008; 14(4):562–70. [PubMed: 18577285]
12. Maraj A, Heath M. Antipointing: perception-based visual information renders an offline mode of control. *Exp Brain Res*. 2010; 202(1):55–64. [PubMed: 20012599]
13. Grierson LE, Elliott D. The impact of real and illusory target perturbations on manual aiming. *Exp Brain Res*. 2009; 197(3):279–85. [PubMed: 19565225]
14. Goodale MA, Westwood DA, Milner AD. Two distinct modes of control for object-directed action. *Prog Brain Res*. 2004; 144:131–44. [PubMed: 14650845]
15. Heller W. Hemispatial biases in children on the Draw-A-Person Test. *Developmental Neuropsychology*. 1991; 7:151–160.
16. Ishiai S, Sugishita D, Watabiki S, Nakayama T, Kotera M, Gono S. Improvement of left unilateral spatial neglect in a line extension task. *Neurology*. 1994:44.
17. Na D, Adair J, Williamson D, Schwartz R, Haws B, Heilman K. Dissociation of sensory-attentional from motor-intentional neglect. *J Neurol Neurosurg Psychiatry*. 1998; 64(64):331–338. [PubMed: 9527144]
18. Fortis P, Chen P, Goedert KM, Barrett AM. Effects of prism adaptation on motor-intentional spatial bias in neglect. *Neuroreport*. 2011; 22(14):700–5. [PubMed: 21817924]

19. McCourt ME, Garlinghouse M, Reuter-Lorenz PA. Unilateral visual cueing and asymmetric line geometry share a common attentional origin in the modulation of pseudoneglect. *Cortex*. 2005; 41(4):499–511. [PubMed: 16042026]
20. Reuter-Lorenz PA, Kinsbourne M, Moscovitch M. Hemispheric control of spatial neglect. *Brain Cognition*. 1990; 12(2):240–266.
21. Halligan PW, Manning L, Marshall JC. Hemispheric activation vs spatio-motor cueing in visual neglect: a case study. *Neuropsychologia*. 1991; 29(2):165–76. [PubMed: 2027432]
22. Varnava A, McCarthy M, Beaumont JG. Line bisection in normal adults: direction of attentional bias for near and far space. *Neuropsychologia*. 2002; 40(8):1372–8. [PubMed: 11931941]
23. Barrett AM, Schwartz RL, Crucian GP, Kim M, Heilman KM. Attentional grasp in far extrapersonal space after thalamic infarction. *Neuropsychologia*. 2000; 38:778–784. [PubMed: 10689053]
24. McCourt ME, Garlinghouse M. Asymmetries of visuospatial attention are modulated by viewing distance and visual field elevation: pseudoneglect in peripersonal and extrapersonal space. *Cortex*. 2000; 36(5):715–31. [PubMed: 11195917]
25. Bradshaw JL, Nettleson NC. The nature of hemispheric specialization in man. *The behavioral and brain sciences*. 1981; 4:51–91.
26. Suchan J, Karnath HO. Spatial orienting by left hemisphere language areas: a relict from the past? *Brain*. 2011; 134(Pt 10):3059–70. [PubMed: 21624927]
27. Barrett AM, Crosson JB, Crucian GP, Heilman KM. Far bias on radial line bisection task: measuring perceptual-attentional and motor-intentional bias in normal subjects. *Cortex*. 2002; 38(5):769–778. [PubMed: 12507045]
28. Chokron S, Imbert M. Influence of reading habits on line bisection. *Brain Res Cogn*. 1993; 4:219–222.
29. Schwartz RL, Barrett AM, Kim M, Heilman KM. Ipsilesional intentional neglect and the effect of cueing. *Neurology*. 1999; 53(9):2017–22. [PubMed: 10599774]
30. Barrett AM, Burkholder S. Monocular patching in subjects with right-hemisphere stroke affects perceptual-attentional bias. *Journal of Rehabilitation Research and Development*. 2006; 43(3):337–346. [PubMed: 17041819]
31. Barrett AM, Crucian G, Schwartz R, Heilman K. Adverse effect of dopamine agonist therapy in a patient with motor-intentional neglect. *Arch Phys Med Rehabil*. 1999; 80(5):600–3. [PubMed: 10326927]
32. McCourt ME, Garlinghouse M, Slater J. Centripetal versus centrifugal bias in visual line bisection: focusing attention on two hypotheses. *Front Biosci*. 2000; 5:D58–71. [PubMed: 10702377]
33. Stevens SS. Neural events and the psychophysical law. *Science*. 1970; 170:1043–1050. [PubMed: 5475633]
34. Mennemeier M, Salem J, Hartley S, Jewell G, Lamar M. Are context effects due to perceptual or response biases? *Journal of the International Neuropsychological Society*. 2000;6.
35. Mark VW, Heilman KM. Diagonal spatial neglect. *J Neurol Neurosurg Psychiatry*. 1998; 65(3):348–52. [PubMed: 9728947]
36. Wilkinson D, Sakel M. Visual neglect in horizontal and radial space: when left goes right, proximal goes distal. *J Int Neuropsychol Soc*. 2011; 17(5):943–7. [PubMed: 21991592]
37. Heilman KM, Chatterjee A, Doty LC. Hemispheric asymmetries of near-far spatial attention. *Neuropsychology*. 1995; 9(1):58–61.
38. Khurshid S, Longin H, Crucian G, Barrett AM. Monocular patching affects inattention but not perseveration in spatial neglect. *Neurocase*. 2009; 15(4):311–7. [PubMed: 19370480]
39. Fortis P, Goedert KM, Barrett AM. Prism adaptation differently affects motor-intentional and perceptual-attentional biases in healthy individuals. *Neuropsychologia*. 2011; 49(9):2718–27. [PubMed: 21663753]
40. Milner, AD.; Goodale, MA. The visual brain in action. In: Mackintosh, N., et al., editors. *Oxford Psychology Series*. New York: Oxford University Press; 1995.
41. Ungerleider, L.; Mishkin, M. Analysis of visual behavior. In: Ingle, D.; Goodale, M.; Mansfield, R., editors. *Two cortical visual systems*. Massachusetts: The MIT Press; 1982. p. 549–586.

42. Ghacibeh GA, Shenker J, Winter K, Triggs W, Heilman K. Dissociation of neglect subtypes with transcranial magnetic stimulation. *Neurology*. 2007; 69(11):1122–7. [PubMed: 17846411]
43. Barrett, AM. *The Roots of Cognitive Neuroscience: Behavioral Neurology and Neuropsychology*. Oxford University Press; 2011. Perceptual-attentional “where” and motor-intentional “aiming” spatial bias. in press

Figure 1. Standard two-camera video desktop apparatus¹⁰ (from Schwartz et al., 1997, with permission). In the natural condition, camera above the workspace was active to project a direct view of subject's hand. In the reversed condition, camera below the workspace was active to project a shadow of subject's hand so that hand movements and screen view are reversed.

Figure 2.

Subjects displaced lines in the direction of hand movement, irrespective of the viewing conditions (natural versus reversed). Leftward hand movement caused subjects to displace lines leftward (right-hand bar) and rightward hand movement caused them to displace lines rightward (central bar). Compare the overall natural performance (left-hand bar) with instructed rightward versus leftward drawing performance (Repeated measures ANOVA, ** = $p < 0.01$; see text).