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Bimanual-Vertical Hand Movements

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Abstract

Patients often demonstrate attentional and action-intentional biases in both the transverse and coronal planes. In addition, when making forelimb movements in the transverse plane, normal participants also have spatial and magnitude asymmetries, but forelimb spatial asymmetries have not been studied in coronal space. Thus, to learn if when normal people make vertical movements they have right–left spatial and magnitude biases, seventeen healthy, blindfolded volunteers had their hands (holding pens) placed vertically in their midsagittal plane, 10 inches apart, on pieces of paper positioned above, below, and at eye-level. Participants were asked to move their hands together vertically and meet in the middle. Participants demonstrated less angular deviation in the below-eye condition than in the other spatial conditions, when moving down than up, and with their right than left hand. Movements toward eye level from upper or lower space were also more accurate than movements in the other directions. Independent of hand, lines were longer with downward than upward movements and the right hand moved more distance than the left. These attentional-intentional asymmetries may be related to gravitational force, hand-hemispheric dominance, and spatial "where" asymmetries; however, the mechanisms accounting for these asymmetries must be ascertained by future research. (*JINS*, 2011, *17*, 732–739)

Keywords: Intention, Attention, Hand asymmetry, Coronal plane, Hemispheric specialization, Motor control

INTRODUCTION

Patients with hemispheric injury often demonstrate attentional and action-intentional spatial and magnitude-length biases in both the transverse and coronal planes. Studies of healthy right-handed people have revealed several attentional and action-intentional spatial asymmetries of the forelimbs. For example, in one of the earliest studies of normal subjects' spatial bias, it was demonstrated that on a horizontal (intersection of the transverse and coronal planes) line bisection task, healthy young adults exhibit a bias to the left of true center (Bowers & Heilman, 1980; Jewell & McCourt, 2000), even with eyes closed. Although most of the subsequent studies of normal subjects examined right–left biases in the transverse plane using horizontal lines, it has also been demonstrated that normal participants have an upward bias with midline vertical lines (intersection of the midsagittal and coronal planes) and a distal bias with midline radial lines (intersection of the midsagittal and transverse planes) (Mennemeier, Wertman & Heilman, 1992; Shelton, Bowers, & Heilman, 1990).

Normal subjects also demonstrate a spatial bias when attempting to draw horizontal lines with their eyes closed. For example, Graff-Radford, Crucian, and Heilman (2006) had blindfolded healthy subjects perform a bimanual horizontal line-drawing task in the transverse plane. This study revealed that as the two hands approached each other at the midsagittal plane, the right hand deviated closer to their body than did the left hand. Other studies (e.g., Fujii, Yamadori, Fukatsu, & Suzuki, 1996; Jeong, Tsao, & Heilman, 2006) have also demonstrated that when attempting to make horizontal movements in the transverse plane the left hemisphere-right hand has a proximal motor intentional bias. In addition, the right hand traveled less than the left, demonstrating a relative right hand-left hemisphere hypometria when making adductive horizontal movements in the transverse plane. It is not known, however, if there will be right or left deviations from midline for each hand when normal subjects attempt to make bimanual vertical movements in the middle of the body centered coronal plane (intersection of the coronal and midsagittal plains).

It is also unknown if the magnitude (length) of the movements will be affected by the hand used, the direction of movement (up *vs.* down), and the body centered position of

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these movements. Thus, the purpose of this experiment is to assess normal participants for these biases when they attempt to make bimanual vertical movements in the midsagittal plane. A better understanding of the spatial attentional and action-intentional biases demonstrated by healthy persons would better allow us to know what might be abnormal in patients with brain dysfunction, as well as the possible mechanism of these altered biases. This understanding may also aide rehabilitation research and the management of persons with brain damage. For example, research on horizontal biases in healthy persons has contributed to the understanding of persons with hemispatial neglect and has helped inform rehabilitation efforts (e.g., Barrett et al., 2006).

In this study, like the study of Graff-Radford et al. (2006), we use a simultaneous bimanual task because both clinical studies and studies of laterality in normal subjects suggest that alterations of attention and intention are more likely to be observed with bilateral than unilateral tasks (e.g., dichotic listening and extinction to simultaneous stimulation). Consistent with findings on movements in the transverse plane, we hypothesize that processing biases will be manifest as (1) systematic angular deviations from midline (midsagittal plane) and (2) as hyper/hypo-metric movements (longer/shorter distances traveled).

Previous investigations have also indicated that each hemisphere has a propensity to attend and intend to contralateral hemispace (Heilman, Bowers, & Watson, 1984). In accordance with this postulate, in a straight ahead pointing task, Chokron, Colliot, Atzeni, Bartolomeo, and Ohlmann (2004) reported that pointing was deviated toward the side of the hand used and toward the starting point, that is, the most leftward deviation was observed when participants used the left hand and started on the left side, whereas the most rightward deviation was observed when they used the right hand and started on the right side. In addition, whereas the right hemisphere is better able to attend and intend to both hemispatial fields, the left hemisphere primarily attends and intends to the right hemispatial field (Heilman & Van den Abell, 1979, 1980; Weintraub & Mesulam, 1987). Based on this right–left hemispheric asymmetry we predict a greater deviation of the right than left hand. In contrast, there is evidence to suggest that, in people who are right handed, the left hemisphere-right hand can perform more precise movements than the left including spatial accuracy (Haaland, Harrington, & Knight, 1999) and based on this "praxis asymmetry" the right hand should perform more accurately (deviate less) than the left.

Ungerleider and Mishkin (1982) as well as others (Bálint, 1909; Lissauer,1890), have described two visual systems, a ventral "what" and dorsal "where" system. Although these two systems were described in the visual modality, it is possible that even in the absence of vision spatial "what" and "where" computations may be, at least in part, mediated by these two systems. The ventral visual system primarily receives projections from the lower half of the retina, which primarily receives visual stimuli from the upper visual field. Since the "where" system is dorsal it is possible that "where" spatial procedures are better performed in lower than upper space, and prior research has indeed suggested that the "dorsal-where" processing system has preferential access to information from lower space (Rapcsak, Cimino, & Heilman, 1988). Whereas prior research has shown that the "dorsal-where" networks process visual stimuli, there is also evidence that these same networks are involved in spatial processing even in the absence of visual input. For example, Bonino et al. (2008) demonstrated that tactile spatial working memory activated the dorsal extrastriate cortical pathway in congenitally blind individuals. In this study, while moving their hands up or down, the participants' hands were in three portions of space (above, at, and below eye level). Because the task used in this study requires spatial navigation of the upper limb, we posited that these dorsal-where systems would influence performance on this bimanual vertical task and hence predicted that our participants would be more accurate (have less deviation in either direction) when working in lower than upper space.

Simultaneous bimanual vertical movements engage both attentional and intentional processes, but we are unable to empirically test the relative contribution of each to task performance. Attention and intention are highly intertwined and integrated processes (e.g., Heilman Watson, & Valenstein, 2003) that are difficult to dissociate in healthy persons and we are not aware of any task that is purely attentional or purely intentional. Because participants in this study are blindfolded and receive no visual feedback when performing these spatial movement tests, the participants probably had to rely more strongly on spatial motor planning (intention) and motor programming systems (i.e., praxis-deftness). Therefore, the experimental task used in this study is primarily a spatial-action-intentional test, but since the subjects do receive proprioceptive feedback, this task does have a sensory-perceptual-attentional component. Furthermore, when performing this task participants may image a vertical line and attend to this representation when guiding their actions.

In summary, the purpose of this study was to learn when patients attempt to draw vertical lines in their midsagittal plane if they have right versus left spatial biases, and if they have differences in the magnitude of their movements as a function of the hand used (right, left), the direction of movement (up, down) and egocentric spatial position (above, at and below eye level) of these actions.

MATERIALS AND METHODS

Participants

The participants were seventeen healthy volunteers (eight men and nine women) without a previous or current neurological or psychiatric disease. All participants were right-handed, as determined by the Edinburgh-handedness inventory (Oldfield, 1971). The mean age and education for these participants were 26.2 years (*SD* = 5.0) and 17.9 years (*SD* = 1.7), respectively. This study was approved by the Institutional Review Board (IRB) at the University of Florida and was completed in accordance with the guidelines of the Helsinki Declaration. Participants provided formal, IRB-approved written informed consent before participating.

Apparatus

The participant was seated in a chair, which was placed so that his or her eyes were approximately 40 cm in front of a smooth and flat wall. At this distance the subjects could easily reach the wall with either hand. We placed 21.59-cm by 27.94-cm sheets of white paper in front of each participant's sternum, the long side of the paper aligned with the subject's sagittal plane and the short side with their transverse plane. Markings on the wall helped guide the examiner's placement of the stimulus page to ensure that the long side was indeed vertical. On each piece of paper there were two small (5.5 mm in diameter) circles that were 10 inches (25.4 cm) apart, one at the upper portion of the paper and the other at the lower portion (2.54 cm from the top and bottom of the vertically positioned paper), and these two dots were aligned with the subject's midsagittal plane.

The participants were given two ballpoint pens, one to hold in each hand. After blindfolding the subjects with a bandana, the examiner guided the tips of each ballpoint pen to the starting position. The participants had the point of the pen they were holding in their right hand placed on the upper dot for one half of the trials, while simultaneously the pen in their left hand was placed on the lower dot (Figure 1). For the other half of the trials the up–down right–left hand positions were reversed. Participants saw the stimulus page only once during the explanation of the task, but were not offered the opportunity to practice or to receive feedback on their performance. Participants were then blindfolded and helped into position in a chair without armrests and faced a wall.

With the participant's body as the frame of reference, the papers were placed in three spatial positions: (1) Mid-eye level, such that the subject's eyes bisected the vertically placed papers (e.g., 13.97 cm from each end of the paper); (2) Above-eye level, such that the bottom of the paper was aligned with the subject's eyes; (3) Below-eye level, such that the top of the vertically positioned paper was aligned with the participant's eyes. Hence, there were a total of six experimental conditions: three positions of the paper (above, middle, below eye level) and two hand conditions, right hand on top and left on bottom or left hand on top and right hand on bottom. There were 12 trials for each condition for a total of 72 trials. These trials were performed within a single testing session and were randomized for each participant so that there were no systematic effects of fatigue or learning across conditions. These 72 trials took approximately 30 min to complete.

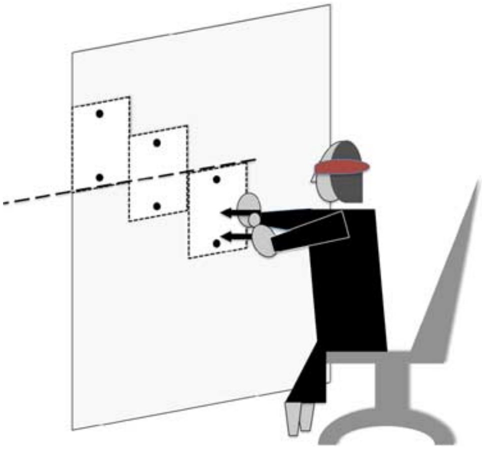

Fig. 1. Apparatus. This figure shows the position of participant and his/her hands in relation to each position of paper (above, eye level, and below).

Analysis

There are three dependent variables: (1) the absolute maximum value of the angle of the drawn line's deviation from the midsagittal plane (to measure the magnitude of error in degrees regardless of direction); this maximum value was used since many of the participants demonstrated an initial bias (away from their midsagittal plane) such that each hand deviated in a different direction; however, as these participants' hands approached each other they attempted to compensate by attempting to vertically align their hands. Thus, by measuring maximum deviation (e.g., rather than a weighted trajectory), we avoid confusing the bias with the latter attempt to compensate by alignment; (2) the right or left directional deviation of that angle (to measure direction of error); (3) the length of the drawn line by the left and right hands (to measure asymmetry of movement magnitude). The independent variables for this analysis are: hand (right *vs.* left), movement direction (upward *vs.* downward), and position of paper (above, below, at eye level). After inspection of the dependent variables for normality and statistical consideration of skewness and kurtosis, repeated-measures analyses of variance (ANOVAs) within subject were conducted for each dependent variable in the conditions mentioned above.

RESULTS

Angular Deviation

Because many of the lines drawn by the participants were not straight, the angle of deviation was measured from the point of origin to the point of maximal deviation from the mid-sagittal plane. The mid-sagittal plane was defined by the two dots on the upper and lower ends of the page. Rightward deviations from the mid-sagittal line were scored as positive and leftward deviations were scored as negative.

Within-subject repeated-measures ANOVAs were used to analyze the absolute value of deviation for each angle drawn to assess main effects of movement direction (upward, downward) and hand (right, left), as well as interactions (Table 1). Participants were more accurate in the below eye level spatial condition than in the other spatial conditions: $F(2,15)=9.45$; $p=.002$. In addition, participants were more

Table 1. Magnitude (absolute value) of angular deviation: main and interaction effects

Absolute angular deviation	Mean	*SD*	*F*	*p* value
Main effects				
Position of paper				
Above	9.6	0.67	9.45	.002
Eye level	9.0	0.94		
Below	5.9	0.80		
Direction				
Upward	10.2	0.98	18.24	.001
Downward	6.2	0.58		
Hand				
Right	6.5	0.63	14.28	.002
Left	9.8	0.90		
Interaction between position of paper and direction of movement				
Above				
Upward	13.6	1.30	11.03	<.001
Downward	5.6	0.64		
Eye level				
Upward	11.0	1.33		
Downward	7.0	0.93		
Below				
Upward	6.0	0.86		
Downward	5.8	1.08		
Interaction between direction of movement and hand				
Upward				
Right hand	8.2	1.04	0.80	.39
Left hand	12.2	1.33		
Downward				
Right hand	4.9	0.53		
Left hand	7.4	0.96		
Interaction between hand and position of paper				
Right hand				
Above level	7.1	1.02	2.1	.136
Eye level	7.4	0.82		
Below level	5.1	0.62		
Left hand				
Above level	12.1	1.11		
Eye level	10.6	1.27		
Below level	6.7	1.18		
Interaction between position, hand and direction				
Above				
Right				
Upward	10.1	1.70	2.52	.97
Downward	4.1	1.05		
Left				
Upward	17.1	1.95		
Downward	7.1	1.16		
Eye level				
Right				
Upward	8.8	1.39		
Downward	6.0	0.70		
Left				
Upward	13.2	1.72		
Downward	8.0	1.41		
Below				
Right				
Upward	5.6	0.99		
Downward	4.6	0.78		
Left				
Upward	6.3	1.09		
Downward	7.0	1.66		

accurate when drawing lines downward than in the upward direction: $F(2,15) = 18.24$; $p = .001$. Furthermore, subjects were more accurate using their dominant hand (right) than non-dominant (left) hand: $F(2,15) = 14.28$; $p = .002$. There was an interaction effect of direction of movement and spatial condition such that angles were more accurate with downward movements in the above space condition: $F(2,15) = 11.03$; $p = .001$). No other interactions were significant (Table 1).

To determine if participants had a right or left bias in the vertical (coronal) plane, we analyzed the direction or angle of deviation from the midsagittal plane. When using the right hand, the created angle was deviated toward the left hemispace and with use of the left hand, subjects deviated toward the right hemispace: $F(2,15) = 31.4$; $p = .001$). Other main effects including space and direction were not significant (Table 2).

Line Length

To determine if our participants exhibited vertical asymmetries in the magnitude or length of movement related to the hand used (right, left), the direction of movement (up, down), and the spatial location of the paper with respect to the eyes (below, above, and at eye level) or interactions between these conditions, we determined the distance traversed in the sagittal plane. To determine length, we located the end of the subject's drawn line, and then drew a perpendicular line from the midsagittal line, intersecting the end of the drawn line. This procedure was necessary because the subjects' lines were not straight (see Figure 2 for an example of the procedure by which length was determined). We then measured the length from origin dot to this perpendicular line at its intersection with the midsagittal plane (vertical distance).

To learn if there were any main or interaction effects of hand, movement direction, or paper position on line length, we analyzed the effect of these independent variables by using within-subjects repeated measures ANOVAs. First, there were no significant differences in line length as a function of eye level space: $F(2,15) = 1.18$; $p = .303$. Second, lines were longer with downward hand movements than upward: $F(2,15) = 8.5$; $p = .01$. Finally, the lines made by the right hand were longer than those of the left hand: $F(2,15) = 5.9$; $p = .03$. Of the possible interactions, in the above eye level and middle eye level conditions, upward drawn lines were shorter than downward drawn lines: $F(2,15) = 13.4$; $p = .001$). In the below eye level condition, the upward *versus* downward movements were not different. Other interactions were not significant. These results are also presented in Table 3.

DISCUSSION

Angular Deviation

The results of this study indicate action-intentional spatial biases are influenced by the vertical space of action, the direction of movement, and hand used. We found that in right-handed participants the right hand deviated less from the mid-sagittal plane than did the left hand. This is consistent

Table 2. Direction of angular deviation: main and interaction effects

Directed deviated angle	Mean	*SD*	*F*	*p* value
Main effects				
Position of paper				
Above	2.1	1.10	0.14	.87
Eye level	1.7	0.67		
Below	1.8	0.45		
Direction				
Upward	2.6	0.77	2.3	.15
Downward	1.1	0.78		
Hand				
Right	−4.0	1.07	31.4	<.001
Left	7.7	1.34		
Interaction between position of paper and direction of movement				
Above				
Upward	3.5	1.29	2.6	.89
Downward	0.8	1.29		
Eye level				
Upward	2.6	0.89		
Downward	0.8	0.77		
Below				
Upward	1.7	0.79		
Downward	1.9	0.75		
Interaction between direction of movement and hand				
Upward				
Right hand	−6.9	1.42	44.0	<.001
Left hand	12.1	1.37		
Downward				
Right hand	−1.0	1.07		
Left hand	3.3	1.71		
Interaction between hand and position of paper				
Right hand				
Above level	−4.3	1.30	9.5	.01
Eye level	−5.8	1.18		
Below level	−1.8	1.18		
Left hand				
Above	8.5	1.70		
Eye level	9.3	1.65		
Below	5.3	1.40		
Interaction between position, hand and direction				
Above				
Right				
Upward	−10.1	1.70	24.4	<.001
Downward	1.5	1.43		
Left				
Upward	17.1	1.95		
Downward	0.2	2.12		
Eye level				
Right				
Upward	−7.9	1.70		
Downward	−3.8	1.36		
Left				
Upward	13.2	1.72		
Downward	5.4	2.05		
Below				
Right				
Upward	−2.7	1.57		
Downward	−0.9	1.37		
Left				
Upward	6.0	1.22		
Downward	4.6	2.13		

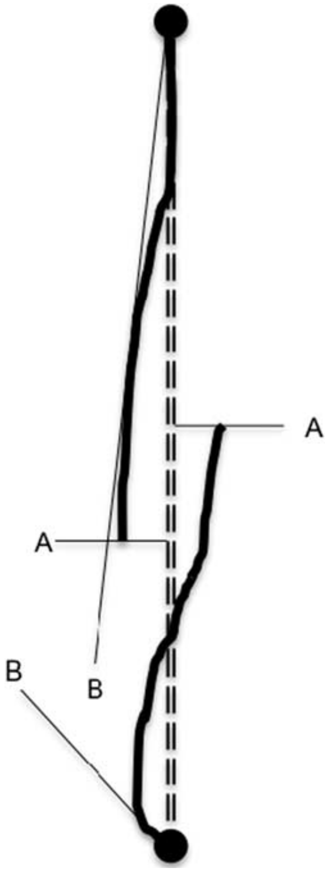

Fig. 2. Example of performance. This figure shows the measurement of the maximum distance travelled in the midsagittal plane (A), as well as most deviated angle (B). The dashed line shows the midsagittal line.

with our hypotheses and with previous investigations using the midsagittal plane pointing task (Cohen, Burtis, Williamson, Kwon, & Heilman, 2010; Heilman, Bowers, & Watson, 1983) and horizontal line bisection (e.g., McCourt, Freeman, Tahmahkera-Stevens, & Chaussee, 2001).

Before potential mechanisms of this forelimb asymmetry can be discussed, it is important to note that the type of error made by the left hand is different in midsagittal line drawing and pointing tests than in the line bisection tests. For example, in the line bisection task the left hand, when compared to the right hand, deviates more to the left (McCourt et al., 2001). However, in the pointing test (Cohen et al., 2010; Heilman et al., 1983), and also in our line drawing task the left hand, when compared to the right hand, deviated to the right. The reason for the different left–right directions of spatial deviations in these tasks is not known; however, this dichotomy might be related to differences in hemispheric asymmetries of attention in relation to allocentric *versus* egocentric foci of attention. For example, in the line bisection task, the subject is required to find the middle of an object and hence action-intention is "allocentrically" oriented. In the midsagittal plane pointing task, while the subjects are asked to point to space they must attend to their own body's

Table 3. Line length: Main and interaction effects

Length of line	Mean	*SD*	*F*	*p* value
Main effects				
Position of paper				
Above	11.7	1.53	1.18	.301
Eye level	11.6	1.077		
Below	11.7	1.52		
Direction				
Upward	11.0	1.50	8.5	.01
Downward	12.3	1.46		
Hand				
Right	12.1	1.26	5.9	.03
Left	11.2	1.69		
Interaction between position of paper and direction of movement				
Above				
Upward	10.6	1.78	13.4	<.001
Downward	12.8	1.27		
Eye level				
Upward	10.8	1.24		
Downward	12.4	1.52		
Below				
Upward	11.6	1.47		
Downward	11.9	1.57		
Interaction between direction of movement and hand				
Upward				
Right hand	11.3	1.30	3.4	.09
Left hand	10.6	1.22		
Downward				
Right hand	12.9	1.70		
Left hand	11.8	1.69		
Interaction between hand and position of paper				
Right hand				
Above level	12.1	1.11	0.6	.57
Eye level	12.1	1.25		
Below level	12.1	1.42		
Left hand				
Above	11.2	1.95		
Eye level	11.0	1.50		
Below	11.3	1.63		
Interaction between position, hand and direction				
Above				
Right				
Upward	10.8	1.08	2.1	.14
Downward	13.5	1.14		
Left				
Upward	10.3	2.49		
Downward	12.1	1.41		
Eye level				
Right				
Upward	11.3	1.27		
Downward	13.0	1.23		
Left				
Upward	10.2	1.20		
Downward	11.8	1.81		
Below				
Right				
Upward	11.9	1.55		
Downward	12.3	1.29		
Left				
Upward	11.2	1.40		
Downward	11.4	1.86		

midsagittal plane and thus this task may be more "egocentrically" oriented. Studies of patients with hemispheric lesions and physiological studies of normal subjects all suggest that the right hemisphere is dominant for allocentric attention and intention (for a review, see Heilman et al., 2003). Thus, because attention-intention is more allocated to the left than right side of the line normal subjects performing the line bisection task often deviate leftward (Bowers & Heilman, 1980). Furthermore, this deviation is greater when the left hand is used because the left hand is primarily controlled by the right hemisphere and use of this left hand might also increase activation of the right hemisphere.

In contrast, unlike allocating attention-intention to allocentric space where there is a leftward bias (right hemisphere dominance), when allocating attention-intention to the body (egocentric space) the left hemisphere may be dominant. Support for this postulate comes from Mark and Heilman (1990) who found that normal participants' performance on the midsagittal plane pointing task was affected by their ability to see their body; when they were unable to see their body they deviated to the right of their midsagittal plane. However, when these same subjects were able to see their body, they corrected this deviation.

The reason for this rightward deviation is not known; however, many cognitive functions related to the body such as finger knowledge or right *versus* left orientation are mediated by the left hemisphere and when attempting to find the midsagittal plane, without seeing their own body, a person might have to activate their left hemisphere and this activation might cause a rightward spatial bias. In addition, when using their left arm to point, a person might compute their body's midline by estimating the left *versus* right half of their body. If with use of the left hand they activate their right hemisphere and attend more to the left half of their body or body image then this half will appear larger. Perceiving the left side of the body as larger than the right might then shift the percept of the midsagittal plane toward the right.

Regarding the main effect of direction, downward movements were overall more accurate than upward movements. The mechanism that accounts for this asymmetry is not known; however, since the work of Lissauer (1890) and Bálint (1909), it has been known that ventral temporal–occipital lesions cause visual object agnosia (defects in object recognition) and dorsal parietal–occipital lesions produce what has been called "optic ataxia" where patients are impaired when attempting to grasp or touch an object in space, such as the examiner's finger (defect in spatial–motor programming). Ungerleider and Mishkin (1982) replicated this dichotomy in monkeys demonstrating two visual processing systems, a ventral "what" system that is important in object recognition and a dorsal "where" system important in guiding movement in space. In addition, patients with parietal lesions are more likely to be inattentive to (i.e., neglect) stimuli in lower space (Rapcsak et al., 1988) and patients with ventral temporal–occipital lesions are more likely to be inattentive to stimuli in upper space (Shelton et al., 1990) Thus, downward movements may be primarily controlled by the dorsal system that is superior at spatial guidance than is the ventral system, which controls upward movements.

The gravitational or "plumb line" hypothesis is an alternate, but not contradictory explanation for the superior accuracy of downward movements. According to this hypothesis, the goal of the movement was to move vertically in the midsagittal plane, and when moving downward *versus* upward the subjects could have used the force of gravity to help guide their movements.

The final main effect was the position of the paper with respect to the participants' eye level. The results indicate that when performing this task below eye level the subjects were more accurate than when performing at eye level or above eye level. These results are consistent with the dorsal stream hypothesis mentioned above and thus help provide converging evidence for the superiority of the dorsal *versus* the ventral systems in the spatial guidance of hand movement. Some may question whether this advantage is the result of practice; indeed, it is true that many human activities are performed below eye level. However, the causal relationship between performance and brain processing biases cannot be known. That is, perhaps spatial processing is particularly good below eye level because of the brain's dorsal-where preference, or perhaps the dorsal-where preference evolved to match the high rate of activities performed in that space. The results described here simply demonstrate the phenomenon for the first time during bimanual vertical movements.

Line Length

Our results also revealed two main effects of line length: the right hand moved a greater distance than did the left, and downward movements were longer than upward movements. We had no a priori hypotheses that would have predicted these results of line length, but did develop several post hoc explanations for these magnitude asymmetries. In regard to hand used, right handed people are normally less accustomed to using their left than right hand and therefore might have allocated more attention to their left hand when it was being used. Stimuli that receive greater attention appear to have a greater magnitude and this leftward focus of attention might have altered (increased left *vs.* right) estimates of magnitude. Our results and this hypothesis, however, are not consistent with the work of Graff-Radford et al. (2006) who in their horizontal bimanual task found that the left hand moved more than the right. Thus, the reason that the right hand is relatively hypometric when compared to the left with bilateral horizontal movements and relatively hypermetric with vertical movement remains to be determined.

In regard to direction (down *vs.* up), the transparent explanation would be that it is easier to go with the force of gravity than against gravity. However, attention is also related to effort and the greater the effort exerted to make a movement the greater attention a person may allocate to that movement. As mentioned above, estimates of magnitude are influenced by the allocation of attention, and items that receive greater attention appear to be larger than items that receive less attention. Thus, upward movement might have appeared longer than downward movement because going against gravity requires more effort, but in actuality downward movements were longer.

Whereas there have been a multitude of studies examining brain impaired patients' right and left attentional and intentional biases in the transverse plane (e.g., horizontal line bisection), there has been a paucity of studies investigating deficits in the coronal (vertical) plane. In this study, we demonstrated biases during healthy participants' performance of a simultaneous bimanual vertical line drawing task. It may be valuable for future studies to assess patients with brain impairments, as well as unilateral movements in both brain impaired and normal subjects. In addition to helping us better understand normal brain function, these studies may help uncover disabilities that were previously unknown as well as help to provide strategies for rehabilitation (e.g., Barrett et al., 2006).

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