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Pseudoneglect: a review and meta-analysis of performance factors in line bisection tasks

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Abstract

An exhaustive qualitative (vote-counting) review is conducted of the literature concerning visual and non-visual line bisection in neurologically normal subject populations. Although most of these studies report a leftward bisection error (i.e., pseudoneglect), considerable between-study variability and inconsistency characterize this literature. A meta-analysis of this same literature is performed in which the total quantitative data set, comprising 73 studies (or sub-studies) and 2191 subjects, is analyzed with respect to 26 performance factors. The meta-analytic results indicate a significant leftward bisection error in neurologically normal subjects, with an overall effect size of between −0.37 and −0.44 (depending on integration method), which is significantly modulated to varying degrees by a number of additional task or subject variables. For example, visual bisection tasks, midsagittal-pointing tasks and tactile bisection tasks all lead to leftward errors, while kinesthetic tasks result in rightward errors. Tachistoscopic forced-choice testing methods reveal much greater estimates of bisection error (effect size = −1.32) than do manual method-of-adjustment procedures (effect size = −0.40). Subject age significantly modulates line bisection performance such that older subjects err significantly rightward compared to younger subjects, and to veridical line midpoint. Male subjects make slightly larger leftward errors than do female subjects. Handedness has a small effect on bisection errors, with dextrals erring slightly further to the left than sinistral subjects. The hand used to perform manual bisection tasks modulated performance, where use of the left hand lead to greater leftward errors than those obtained using the right hand. One of the most significant factors modulating bisection error is the direction in which subjects initiate motor scanning (with either eye or hand), where a left-to-right scan pattern leads to large leftward errors while a right-to-left scan pattern leads to rightward errors.

1. Literature Review

1.1. Visuospatial neglect

Visuospatial (or hemispatial) neglect syndrome entails difficulty reporting, responding or orienting towards stimuli located within contralesional hemispace, as defined in terms of retinotopic, egocentric (body-referenced) or allocentric (object-referenced) coordinate systems where such impairment is not due to either motor or sensory defects [2,5,7–10,24,37,54,55,63,75,94,99,111,119,128]. Left hemispatial neglect occurs far more frequently than neglect of right hemispace, and is usually a consequence of right inferior parietal or temporoparietal lobe damage, but may also arise subsequent to lesions of the frontal or cingulate cortex, or to a variety of subcortical structures [25,33,36,44,49,53,55,56,85,89,107,121–124]. The syndrome of visuospatial neglect has attracted enormous interest on the path of both clinicians and behavioral neuroscientists because the elucidation of its etiology and consequences offers the potential to both advance the basic understanding of the neural substrates of the spatial allocation of attention, and ameliorate the often severe disabilities of the numerous patients who suffer from this disorder.

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Of the many instruments used to study hemineglect, line bisection is one of the most frequently employed. Left neglect patients typically bisect horizontal lines significantly to the right of veridical center (e.g., as if they either ignore the majority of the left-hand side of the stimulus or are, alternatively, hyperattentive to the right-hand side). Visuospatial neglect has been described predominantly in the azimuthal (horizontal) plane; however, neglect may also be manifested in the altitudinal (vertical) and radial (depth) planes. Typically, patients neglect inferior (lower) space in the altitudinal plane, bisecting lines above veridical center [3,21,48,62,69,77,101]. In the radial plane, patients typically neglect proximal (near) space as evidenced by their bisecting of lines at a point distal to veridical center [62,88,113]. The neural mechanisms governing the allocation of attention to the azimuthal, altitudinal, and radial planes may be independent or quasi-independent [21,84,88,101,113].

1.2. Pseudoneglect

Neurologically normal subjects also systematically misbisect space during visual line-bisection or similar tasks, generally erring to the left of veridical center when bisecting horizontal lines, a phenomenon Bowers and Heilman [12] first referred to as 'pseudoneglect' [12,15–17,46]. Pseudoneglect has also been investigated in tactile and kinesthetic modalities by having subjects manually explore and bisect wooden or metal rods. Independent of modality, the magnitude of bisection errors in normal subjects (pseudoneglect) is much smaller than in neglect patients. One early study [106] indicated that normal subjects bisected lines veridically, and the smaller effect size of the pseudoneglect phenomenon has led to the suggestion by some that it may merely be an artifact associated with random sampling error in small sample sizes [93].

While the phenomena of neglect and pseudoneglect are, as their names suggest, often discussed as twin manifestations of a common underlying attentional asymmetry, there is as yet no unifying quantitative theory. The two phenomena have recently been shown, however, to possess similar susceptibilities to a variety of modulating variables [82], thus reinforcing the view that they are intimately related. This review and the accompanying meta-analysis attempt to comprehensively integrate the literature on the pseudoneglect phenomenon and to draw conclusions regarding the effects of the various moderating variables in bisection performance where possible.[2]

1.3. Visual line bisection

In visual bisection tasks, subjects generally are required to manually bisect a line drawn on paper. Bisection may involve indicating to the experimenter where subjective line center is by pointing with a finger or pencil or most often by actually marking the perceived midpoint with a pen or pencil. Although this paper focuses exclusively on a review of papers published in the English language, Wolfe [127] presents a scholarly review of several 19th century papers published principally in German.

1.3.1. Age

Most studies of pseudoneglect utilize university student subject pools, while subjects in the control groups of studies of visuospatial neglect are usually age-matched to the neglect patients. Most patients with the neglect syndrome are in or beyond their fifth decade of life. Understanding age-related changes in the brain mechanisms that underpin visuospatial attention is of both theoretical and practical value.

Fujii et al. [41] examined old, middle aged, and young subjects in a traditional line bisection task. Young and middle aged subjects did not err significantly from veridical center, while old subjects erred significantly to the right. Although not statistically significant, the three age groups did show a trend of greater rightward error with increasing age. Stam and Bakker [116] found rightward (of veridical) bisections in a sample of older subjects.

Bradshaw et al. [17] examined line bisection in preschoolers and found that dextral children erred to the left of veridical center whether they bisected with the right or the left hand. However, sinistral children erred to the left of veridical center with the left hand and to the right of veridical with the right hand, respectively. Similar results are reported by Bellatolas [34].

1.3.2. Sex

Very few studies have examined gender as a factor in line bisection performance. Most studies have used mixed sex subject groups [31,48,50,60,79,95,113,120] or failed to report the sex of subjects [4,6,9,11,40,57,95,103,111]. The majority of studies examining the influence of sex report non-significant effects [16,19,30,42,73,86,92,110,115]. However, Roig and Cicero [105] found that males erred more to the

[2] While various response criteria have been used to measure bisection performance, this review uses mean signed deviation from veridical center as a response measure since it captures both the direction and amplitude of bisection errors. Other measures used in the literature include (1) average unsigned error (the mean difference between true and perceived center, irrespective of the direction of the errors) and (2) measurements of the point of bisection relative to the starting position of the hand used to perform the bisection. These are less useful measurements since most theoretical models of pseudoneglect posit the contralateral control of visuospatial attention [65,66] and thus the direction in which subjects err from veridical line center is of central interest.

left of veridical center than females. Wolfe [127], on the other hand, reports that male subjects misbisect horizontal lines further to the right than do female subjects.

1.3.3. Handedness/laterality

Laterality is known to affect subject performance across a variety of cognitive and perceptual tasks with dextral (right-handed) subjects often differing markedly from sinistral (left-handed) subjects. Although the most commonly used indicator of the lateralization of cerebral dominance is hand preference, other indicators that have been examined in the pseudoneglect literature include ear advantage and hemisphericity style.

Very few studies have addressed the effects of handedness (or laterality) in visual bisection tasks. Most studies have limited testing to dextral subjects [19,23,30,31,38,41,42,48,50,60,61,62,79,84,87,91,94,97, 111,115,120,126]. Many, however, fail to disclose subject handedness [4,6,11,22,40,57,98,103,113,118].

Luh [73] found that both dextrals and sinistrals erred leftward of veridical center, although dextrals erred farther to the left than sinistrals. Scarisbrick et al. [110] found similar results, with dextrals erring farther to the left than sinistrals. Subjects erred farther left when using the left hand vs the right hand, with the difference between the two hands being greater for sinistral than for dextral subjects. Bradshaw et al. [17] found that sinistral children erred left with their left hand and right with their right hand, whereas dextral children erred left regardless of the hand used.

1.3.4. Hand used to perform bisection

In method-of-adjustment bisection tasks (and to some extent even in forced-choice tasks, where button presses are typically required), it is necessary for subjects to use their limbs in some fashion to make their bisection settings. Because unilateral limb use itself imposes an asymmetry of cerebral activation, it is of interest to understand how this might influence bisection performance.

Most authors report that subjects err to the left of veridical line center with either hand, although when the left hand is used subjects err farther left than when the right hand is used [13,19,42,80,97,101,105,110]. However, two studies found that when the right hand was used, subjects erred to the right of veridical, whereas when the left hand was used, subjects erred to the left of veridical [44,111]. Chokron and Imbert [31] report the opposite effect. Several studies [35,50,86] found no significant difference between left and right hand use in line bisection. Dellatolas et al. [34] note a significant interaction of the effect of hand used and subject age, with young subjects bisecting to the right of veridical using the right hand, and to the left of veridical using the left hand. Older subjects bisected to the left of veridical with either hand.

1.3.5. Eye of regard

Most studies of visual line bisection involve binocular inspection of line stimuli. Some studies, however, have investigated the effect of uniocular presentation. Monocular patching has even been proposed as a potentially therapeutic intervention in the case of hemineglect [22]; it seems reasonable to inquire whether there is a systematic effect of eye of regard on the magnitude of pseudoneglect.

Wolfe [127] comments that bisections made under uniocular conditions differ from those made binocularly without, however, noting the direction or magnitude of the differences obtained. Another early study by Brown [20] reported that bisection errors using the left eye deviated further leftward than those obtained using the right eye, or under binocular testing conditions. Kunnapas [67,68], however, reported the opposite result, that errors bisecting either lines or diamond figures using the left eye deviated further rightward than those obtained using the right eye. Kunnapas [67,68] additionally noted that these interocular differences were reduced when subjects viewed the line stimuli within a circular artificial visual field, although the interocular differences remained in the same direction. Olson [97] similarly examined the effects of unilateral eye use in line bisection with normal subjects and, like Kunnapas [67,68], found that subjects erred farther to the left of veridical center when viewing stimuli through the right eye. Butter and Kirsch [22] examined the effects of unilateral eye patching in neglect patients and a normal control group. No significant effect of eye patching was found for the control group. Similarly, Mefferd et al. [86] found no effect of eye of regard on line bisection performance.

1.3.6. Individual differences

Significant individual differences have been noted across a majority of line bisection studies [20,35,67,68,74,84,86,127]. Two studies of line bisection have specifically examined the issue of individual differences. Manning et al. [74] tested 11 male and 11 female subjects in a case series design and reported that some subjects erred right while some erred left, with between-subject variability in error magnitude being quite large. If some subjects make consistent leftward bisection errors while others make consistent rightward errors, the proportions of these so-called 'left-shifters' and 'right-shifters' selected in a particular experiment would largely determine its results. McCourt and Olafson [84] tested dextral male subjects and found substantial individual differences in bisection performance, although the majority of the variability was confined to individual differences in the magnitude, but not the sign, of misbisection.

1.3.7. Directional scanning

In the vast majority of bisection studies using method-of-adjustment procedures, subjects are allowed virtually unlimited time to manually or visually inspect the stimuli. Thus, the potential exists for subjects to adopt bisection strategies that involve systematic scanning eye or limb movements. It is therefore of interest to determine to what extent such scanning behavior influences perceived object midpoint in bisection tasks.

The effect of scanning on visual line bisection has been assessed by either controlling the direction of gross motor scanning (i.e., requiring the hand used to bisect to move in either a left-to-right or right-to-left direction) or by controlling the initial starting position of the hand or eyes so that the subject begins scanning from either the left or right end of the line. Since subjects in line bisection experiments are usually allowed to visually scan line stimuli for an unlimited amount of time, the direction of their visual scanning is uncontrolled. Four studies have specifically investigated the influence of visual scanning in normal subjects in line bisection tasks. Reuter-Lorenz and Posner [103] had subjects watch the experimenter trace a line with a pen, either from left-to-right or from right-to-left, before they were allowed to bisect the line. No differences were found between the left-to-right scan, the right-to-left scan, and a control condition in which subjects bisected lines without first viewing them traced by the experimenter. Bradshaw et al. [14] had subjects bisect a line by sliding it in a channel, with the subjects perceived line midpoint indicated by a stationary midpoint marker. In one condition subjects were asked to fixate on the marker placed at line midpoint, while in the other condition subjects were allowed free visual scanning. All conditions in the experiment produced leftward errors; however, central fixation increased error magnitude. Central fixation also produced greater leftward errors when subjects bisected the space between two light emitting diodes (LEDs) [13]. Chokron et al. [28] manipulated the direction in which lines were visually scanned during a passive bisection task and found leftward errors in the left-to-right scanning condition, and rightward errors in the right-to-left scanning condition. These results were irrespective of the reading habits of their French (who scan right-to-left while reading) and Israeli (who scan left-to-right) subjects.

Hjaltason et al. [57] found no significant effects of initiating motor scanning from the left vs the right side of a page containing the line to be bisected. However, Halligan et al. [44] found that subjects erred left when scanning was initiated from the left side of the page and erred right when scanning was initiated from the right side of the page. The effect was greater when the hand used to perform the bisection corresponded to the side on which scanning was initiated (e.g., when the right hand was used while scanning from right-to-left and vice versa). Brodie and Pettigrew [19] found that when subjects began scanning from the right they erred to the left of veridical center, although not as far left as when they initiated scanning from the left. Olson [98] found that scanning initiated from the left side of a line caused greater leftward error than scanning initiated from the right side of a line in a line bisection task. Chokron and Imbert [30] investigated the effect of reading style, a possible determinant of habitual scanning direction, on visual line bisection. French subjects (who read left-to-right) tended to err left while Israeli subjects (who read right-to-left) tended to err right, and report results similar to those of Halligan and Marshall [44] and Chokron and Imbert [29]. Ishiai et al. [59] measured eye movements in neurologically normal subjects and found that visual scanning of line stimuli occurs predominantly from left-to-right. Bisiach et al. [11] had subjects bisect lines in two conditions, one condition in which hand and bisection pointer movement directions were congruent with one another, and a second condition in which hand and pointer movement were not congruent with one another. Bisection errors in the two conditions were not significantly different.

1.3.8. Directional optokinetic stimulation

Pizzamiglio et al. [98] examined the effects of optokinetic stimulation both on neglect patients and on normal controls. The normal subjects erred to the left under all conditions; however, as compared to a no motion control condition, leftward moving optokinetic stimuli caused greater leftward error whereas rightward moving optokinetic stimuli caused less leftward error. It is interesting to note that leftward motion (which induces leftward error) will cause the slow phase of reflexive optokinetic eye movements (nystagmus) to proceed from left-to-right. Voluntary scanning (presumably saccadic) from left-to-right, on the other hand, induces *rightward* error, and vice versa [28]. Thus, while scanning produces prominent effects on bisection performance, finer points regarding the origin of this effect, its sensory vs motor components, etc., are very much in question.

1.3.9. Lateralized cues

Spatial cueing within the neglected hemispace has been used as a possible tool to ameliorate neglect. The theoretical foundation for this intervention is that a cue will act to recruit attention toward the cued region of space. It is therefore of interest to understand how cueing might modulate the degree of misbisection by normal subjects.

Cues in visual line bisection tasks typically consist of letters or geometrical objects (e.g., squares) placed at one end of the line to be bisected. Most authors report that bisections deviate from veridical in the direction of the cued end as compared to no cue control conditions [60,91,94,102]. However, two studies found no cue effects [79,113]. Fischer [38] used letter cues situated at both ends of a line; subjects were required to read the letters prior to making their bisections. Under conditions where subjects read the left letter cue first, they erred to the left, and vice versa. In short, subjects erred towards the first cue to which they attended. Fischer [38] also investigated the effect of cue proximity by positioning one of the cues closer than the other to the end of the line. Subject bisections reliably erred in the direction of the cue that was closer to line end. In a baseline condition in which no cues were present, Berti et al. [4] found a leftward bisection error. When cues were added to the left, right, or even both sides of the line, however, normal subjects erred to the right of veridical center.

Mefferd et al. [86] used a variety of lines having different types of terminators and reported highly significant effects on bisection error. In general, lines with arrowhead terminators which pointed rightward (e.g., >) produced leftward errors relative to those with leftward arrows (<), irrespective of which line end possessed the terminators. In cases where single terminators consisted of simple vertical stokes, however, bisections were drawn toward the end of the line that possessed the terminator. More recently Fleming and Behrmann [39] partially replicated Mefferd's [86] results, but found that lines terminated on each end by leftward arrows (<) induced absolute rightward errors.

Werner et al. [125] had subjects point toward the location of the midsagittal plane under conditions where a small luminous target appeared either straight ahead or 15° to the left or right of the objective midsagittal plane. Subjects erred left when the cue was in left hemispace, and erred slightly to the right when the target was straight ahead. Errors were further right when the cue was in right hemispace.

In a task performed in the dark, Bradshaw et al. [13] had subjects bisect the gap between two illuminated LEDs by moving a third LED mounted on a slide. The LEDs, which acted as the line endpoints, were varied in their brightness, flashing rate, and the timing of their onset and offset. In some conditions the properties of the endpoint LEDs were identical, whereas in others their properties differed. Subjects generally erred to the left of veridical midpoint, but errors in asymmetrical conditions were shifted towards LEDs that were faint, briefly presented, or flashing.

1.3.10. Line salience

Of current interest is the question of whether pseudoneglect derives from perceptual-level of higher-order attention asymmetries. One approach to answer this question has been to vary the salience, or contrast, of bisection stimuli with respect to their background.

Bradshaw et al. [14] varied the salience of the rods which subjects bisected by using black or white rods on either matching backgrounds (i.e., black on black, low salience) or opposite backgrounds (i.e., white on black, high salience). Subjects erred to the left of veridical center across all experimental conditions, although when the left half of a rod was low in salience compared to the right, subjects erred farther to the left of veridical. McCourt and Jewell [82] manipulated line salience by linearly varying the spatial contrast of lines along their length, such that lines possessed a high (100%) and low (10%) contrast end, relative to a neutral gray background. In agreement with Bradshaw et al. [14], bisection errors were biased in the direction of the lower contrast side of the line. Shuren et al. [114] varied stimulus salience by using lines composed of two segments of unequal height, where one side was longer than the other. Subject bisections tended to err towards the longer side of the line. Chieffi [26] used lines that possessed vertical (line or word) terminators that could be large or small, and paired them in both symmetrical and asymmetrical patterns. For lines oriented horizontally, vertically and radially they found that bisection errors, in asymmetrical pairs, were drawn toward the line end having the smaller terminator.

1.3.11. Spatial location

Due to the contralateral nature of central visual projections, visual stimuli located to the left of fixation are processed in the right hemisphere, and vice versa. Divided visual field studies have contributed much to our understanding of functional asymmetries in hemispheric organization. If pseudoneglect, as is frequently theorized, is a consequence of brain asymmetries in the allocation of spatial attention, then it is important and informative to understand how these inherent asymmetries interact with asymmetries imposed by variations in azimuthal stimulus placement.

Reuter-Lorenz et al. [102] found that right hemispace stimulus presentation induced rightward error and that left hemispace presentation produced leftward error. Luh [73] reported that subjects erred to the left under all conditions, with the errors being larger with left hemispace presentation than with center or right hemispace presentation. In the left and right hemispace conditions, but not in the midline condition, leftward error increased with line length. Mennemeier et al. [87] found that all spatial conditions produced rightward error, with right hemispace presentation producing the greatest rightward error while midline and left hemispace presentation produced a similar small degree of rightward error. Milner et al. [91] reported rightward error with right hemispace presentation and a similar degree of leftward error with midline and left hemispace presentation. In a second experiment, Milner et al. [91] reported that subjects judged centrally transected lines in a forced-choice task as being transected to the right of veridical center more often in left hemispace or at midline than in right hemispace.

Nichelli et al. [94] reported errors in the direction opposite to the hemispace of line presentation, with the error magnitude increasing as a function of line length. Three studies [23,42,103] report no effects of laterilized spatial presentation. McCourt and Jewell [82] found that dextral subjects erred slightly leftward at horizontal midline, made larger leftward errors with left hemispace line presentation, and erred to the right of veridical center with a right hemispace presentation. Nielsen et al. [95], however, report a pattern of centripetal (i.e., center-biased) bisection errors for lines presented entirely within the left or right hemifield.

McCourt and Jewell [82] investigated the effects of superior and inferior visual field line placement and found significantly greater leftward bisection errors for lines presented in the superior vs the inferior visual field.

1.3.12. Gaze direction

There are multiple spatial coordinate systems (e.g., object-centered, body-centered, head-centered, retinotopic) within which the location of stimuli may be referenced. Holding head and body orientation fixed, while manipulating direction of gaze in one way in which to disentangle the potentially separate influences of these coordinate systems.

Chokron and Imbert [31] had subjects keep their heads facing forward during a visually guided pointed task while varying gaze direction. When subjects altered their gaze 15° left or right, they erred to the left or right of veridical line center, respectively. In a gaze-forward control condition, subject bisections did not differ significantly from veridical.

Bradshaw et al. [16] had subjects bisect lines while lying on their right or left sides and in a control condition where subjects remained upright. While the upright and lie left conditions produced a left error of similar magnitude, the lie right condition produced a significantly smaller leftward deviation.

1.3.13. Line length

Line length is of potentially critical theoretical importance with respect to determining the neural origin of bisection errors in neglect patients, who exhibit a seemingly paradoxical ‘crossover’ effect. This term refers to the tendency of neglect patients to bisect long lines to the right of veridical center, whereas short lines are bisected to the left of center [45,76].

Chokron and Imbert [30] investigated the effects of line length on visual line bisection with French and Israeli subjects. French subjects erred to the left of true center while Israeli subjects erred to the right of true center with error size increasing as a function of line length. Luh [73] reported that subjects erred leftward, with the error magnitude increasing with line length to a greater degree in left hemispace presentations than in right hemispace presentations. Halligan et al. [44] found that their subject erred leftward when bisecting with the left hand and erred rightward when bisecting with the right hand, with the magnitude or error increasing as a function of line length. Manning et al. [74] found that some of their subjects erred to the left of veridical center while others erred to the right, with error magnitude increasing as a function of line length in all subjects. Using an imaginal task, Werth and Poppel [126] reported leftward errors with short lines, rightward errors with long lines, and no errors with lines of medium length. Wolfe [127] reports that long lines are misbisected further to the right than are short lines. Three studies found no significant effects of line length [23,45,79]. McCourt and Jewell [82] found rightward errors with short lines and leftward errors with medium and long length lines. Finally, Marshall et al. [78] report that the crossover effect in neglect patients occurs only when lines of heterogeneous lengths are presented within single blocks of trials, and is not found when a homogeneous block of short lines is presented. If similar context-dependent effects of line length are shown to occur with respect to pseudoneglect, this may explain some portion of the between-study variability.

1.3.14. Vertical and radial line presentation

Studies examining vertical line bisection find that normal subjects err towards superior space, bisecting lines above veridical center [16,20,60,68,86,95,113,120]. Scarisbrick et al. [110], however, reported that the superior deviations pertained only to dextral subjects, whereas sinistral subjects showed no errors. Both Scarisbrick et al. [110] and Mefferd et al. [86] examined the effect of hand used to bisect and found no significant effects for vertically oriented lines.

In radial bisection tasks, normal subjects err away from personal space, bisecting lines beyond veridical center with respect to the observer’s body [48,60,113,120]. Shelton et al. [113] found no significant effects of cues or of spatial location for either radial or vertical line presentations. Jeerakathil and Kirk [61] found that when a vertical or radial line was labeled (cued) on one end with the word ‘TOP’ subjects line bisections were shifted slightly towards the label. Toth and Kirk [120] found similar results with subjects shifting towards pictorial top as defined by human silhouettes on the ends of vertical and radial lines. Manipulating the physical dimensions of the labels, however, Chieffi [26] found no such effects; bisections were instead biased in the direction of the physically smaller label and were not influenced by the label's semantic content.

1.3.15. Miscellaneous

A number of bisection studies report data that do not fall neatly within any of the categories listed above.

Birch et al. [6] requested subjects to indicate their midsagittal plane by pointing to the corresponding position on a luminous rod located 3 m in front of them. Normal subjects erred to the left when the task was performed in the dark and to the right when the task was performed under normal lighting conditions.

Jannerod and Biguer [60] report that eight of ten dextral subjects made leftward errors in a visual midsagittal-pointing task using their right hands.

Asymmetrical visual deprivation (confined to the right or left visual hemifield) for a duration up to one hour is reported not to affect subsequent line bisection performance [72].

Nielsen et al. [95] examined the effect of line geometry on bisection error by presenting trapezoidal figures and report no significant effect of stimulus shape. McCourt and Garlinghouse [81] found, however, that the perceived midpoint of trapezoidal figures was strongly drawn toward the wider end.

Increasing the height of bisection stimuli reduces the severity of rightward errors in neglect [47,49,118]. Similarly, McCourt and Jewell [82] found that increasing line height produced a systematic decrease in leftward bisection error in normal subjects. Stam and Bakker [116] likewise note that in a sample of normal older subjects, age-matched to a sample of neglect patients, bisections of circles were more veridical than were bisections of line stimuli.

Significant practice effects (sometimes extending over weeks of practice) have been noted to characterize performance on line bisection tasks [20,97]; see, however, [86] for a counter-example. The origin of these effects is not known.

1.4. Non-visual bisection

Non-visual bisection tasks generally require the subject to manually explore a rod with either the left or the right hand and to locate the center of the rod using tactile and/or kinesthetic feedback. Some studies have employed a task where subjects bisect an aluminum rod by moving a cursor within a channel running its length. This minimizes tactile information, making the task one biased toward the use of kinesthetic cues only. This type of task will be referred to as a kinesthetic task while the more general type of rod bisection will be referred to as a tactile task. Subjects in most of these studies wear lightproof goggles or a blindfold to eliminate visual information.

Also reviewed in this section are experiments utilizing a blind midsagittal-pointing task. This task requires subjects to point to the location in space in front of them, which corresponds to their midsagittal plane, making the task one of bisecting wholesale space rather than the bisection of an object with finite dimensions.

1.4.1. Hand used to perform bisection

Across eight tactile bisection studies investigating the hand used to perform bisection, three found no effect of hand used and no significant interactions between hand used and other performance factors [12,71,109]. Five studies found evidence that using the right hand to perform a bisection is associated with rightward error while using the left hand to perform the bisection is associated with leftward error [18,29,51,70,108]. However, two of these studies found the aforementioned effect only for rods positioned at the body midline, and not for rods positioned in left or right hemispace [18,51]. In addition, Sampaio and Chokron [108] found the effect only with the right hand and only in dextral (right-handed) subjects in both a tactile and a kinesthetic task. In seven tactile and visuotactile (i.e., tactile rod bisection under normal vision) experiments Bradshaw et al. [15] found that both hands erred to the left of veridical, with the left hand erring farther to the left than the right hand.

Chokron and Imbert [31] and Chokron and Bartolomeo [27] and Hjaltason and Tegner [58] reported that subjects in a midsagittal-pointing task erred to the right when using the right hand. Olson [97] similarly found rightward errors in a pointing task when subjects pointed with the right hand; leftward errors were associated with use of the left hand. Jeannerod and Biguer [60], however, report that nine of ten dextral subjects made leftward errors in a blind midsagittal-pointing task using their right hands. McCourt et al. [83] and Chokron and Imbert [29] similarly report leftward errors in a pointing task when subjects pointed using their right hand, and rightward errors when pointing with the left hand.

1.4.2. Directional scanning

Of five studies investigating the effect of starting point in tactile bisection tasks, two found no significant effects [29,109]. Bowers and Heilman [12] found that starting from either the left or the right produced leftward error, although starting from the left produced greater leftward error. Levander et al. [71] reported that starting from the left produced leftward error while initiating scanning from the right produced rightward error. Sampaio and Chokron [108] reported that subjects generally erred to the right in both tactile and kinesthetic tasks, with left starts producing a smaller rightward error than right starts. However, this effect was inconsistent across sex, hand used, and handedness.

Chokron and Imbert [31] reported that subjects in a midsagittal-pointing task erred to the left when scanning was initiated from the left, and erred right when scanning began from the right. The magnitude of the pointing errors was larger when the subjects began scanning from positions farther to the right or left of veridical, respectively. Olson [97], however, reported no significant effect or motor scanning in a midsagittal-pointing task.

1.4.3. Stimulus length

Despite the fact that subjects in all tactile bisection experiments reviewed here bisected rods or similar stimuli of several different lengths, only two studies actually examined length as an independent variable. In no study was there a specific explanation for why stimulus length was varied, and data were collapsed across rod length in the statistical analysis. Presumably, length was varied to control practice effects that might result from the repeated performance of identical tasks.

Chokron and Imbert [29] found no significant effects of stimulus length in either tactile or kinesthetic tasks. Sampaio and Chokron [108] found no significant effects of stimulus length in a kinesthetic task or in a tactile task when subjects used their left hand. However, an effect was found in the tactile task when subjects used their right hand. When subjects used their right hand they tended to err to the right of veridical center and this effect increased as a function of line length. Laeng et al. [70] found that subjects erred rightward with very short rods, but erred leftwards when bisecting long rods.

1.4.4. Handedness/laterality

Only two studies of tactile bisection have investigated the effect of handedness on performance, all other studies used only dextral subjects [12,14–16,18,19,29,51,109]. Levander et al. [71] investigated handedness using dextrals, consistent sinistrals, and inconsistent sinistrals (e.g. employs either hand depending on activity) and found no significant differences. Sampaio and Chokron [108] found that in a kinesthetic task dextrality was associated with rightward error while sinistrality was associated with leftward error. However, in Sampaio and Chokron's [108] first experiment, which employed a tactile task, the opposite pattern of results was found, i.e., dextrality was associated with leftward error and sinistrality was associated with rightward error.

Brodie and Pettigrew [18] examined ear advantage for verbal information in dichotic listening tasks and its relation to tactile line bisection. No effect of ear advantage on bisection performance was found for constant error data.

Roig and Cicero [105] examined the effects of hemisphericity style on line bisection performance and found no significant effects. Hemisphericity style was assessed using an inventory with questions that when endorsed indicated a preference for activities associated with a particular hemisphere.

Finally, McCourt et al. [83] found no sinistrality effects in a midsagittal-pointing task.

1.4.5. Spatial location

In most studies of line bisection, the objects to be bisected are located on the midline, with the center of the stimulus falling in line with the subject's midsagittal plane. Several studies have, however, examined the effect of presenting the stimuli on the midline, or in left or right hemispace.

Sampaio and Philips [109] found leftward errors in tactile tasks and rightward errors in kinesthetic tasks regardless of hand used and regardless of the spatial location of the stimulus. In seven tactile and visuo-tactile studies Bradshaw et al. [15] found greater leftward errors when stimuli were presented in left hemispace.

Brodie and Pettigrew [18] found no significant main effects of spatial location. They did, however, report a spatial location by hand used interaction such that at midline the use of the right hand led to leftward errors and the use of the left hand led to rightward errors. Hatta and Yamamoyto [51] and Levander et al. [71] found the same effects for midline presentations as Brodie and Pettigrew [18], while Bowers and Heilman [12] found that at midline errors were leftward regardless of the hand used to perform the bisection.

In left hemispace presentations Hatta and Yamamoyto [51] found that subjects erred left using either hand, whereas Levander et al. [71] found that subjects erred to the right regardless of the hand used. Bowers and Heilman [12] reported that subjects erred right using the right hand, whereas using the left hand produced no significant error from veridical bisection. For stimulus presentations in right hemispace, Hatta and Yamamoyto [51] found that subjects erred to the right regardless of hand used. Levander et al. [71] and Bowers and Heilman [12] found that subjects erred left regardless of the hand used to perform the bisection.

Mark and Heilman [75] asked subjects to perform a pointing task in which they bisected a slit cut in a backdrop which was located at midline, or to the right or left of center. In this task subjects erred to the right, with the magnitude of errors increasing as the location of the slit was moved rightward. The only exception to this trend was a tendency for subjects to err leftward of veridical center in the farthest left slit condition.

1.4.6. Sex

Across ten studies that examined the effects of subject sex on tactile bisection performance, none found a significant difference between males and females [12,14–16,18,29,51,70,71,108,109].

McCourt et al. [83], using a midsagittal-pointing task, found that males erred significantly leftward whereas females did not, except when the task was undertaken in the luteal phase of their menstrual cycle.

1.4.7. Body orientation and gaze direction

In most bisection research, multiple frames of reference are confounded with one another when the subject performs the task in an upright position with the head forward and the stimuli presented at midline [8]. In this position, left and right visual hemispace and the left and right sides of the stimuli, subject's body and subject's head all coincide. Three studies have varied body orientation in tactile bisection tasks in order to investigate the contribution of different frames of reference.

Werner et al. [125] required subjects to blindly point toward the location of the midsagittal plane under conditions where their heads or eyes were turned left, right, or faced straight ahead. All space bisections deviated into right hemispace, but were relatively farther right when either the eyes or head was pointed leftward.

Chokron and Imbert [29] asked subjects to gaze 30° to the left or the right while keeping their head and body facing forward. Gazing left induced rightward error whereas gazing right induced leftward error. When subjects gazed straight ahead they erred left, but not so far as in the gaze right condition. Bradshaw et al. [16] required subjects to lie on their left or right sides while performing bisections, thus decoupling gravitational and visual frames of reference. In the 'lie-right' condition, subjects erred slightly to the left while in the 'lie-left' condition, subjects erred to the left but not as far from veridical center as in the 'lie-right' condition. An upright control condition produced the greatest leftwards error. Bradshaw et al. [15] had subjects turn their head either to the left or the right while keeping their eyes forward. The right head turn condition produced rightward errors while the left head turn condition produced leftward errors.

1.4.8. Rod orientation

Shelton et al. [113] examined rod bisection in the radial and vertical planes. Subjects bisected vertical rods towards inferior space, below veridical center. The effect of spatial location (left or right of midline) was not significant with vertical rods. In radial bisection subjects erred towards near personal space, bisecting rods closer to the body than veridical center. Subjects erred farther towards near personal space when the rods were placed closer to the subject's body.

2. Meta-analysis

2.1. Rationale

The purpose of this section of the review is to *quantitatively* integrate the pseudoneglect literature, across all bisection modalities, in an attempt to draw general conclusions regarding the strength of the effect of the various modulating factors in bisection performance. As the preceding qualitative analysis amply illustrates, there is considerable variability (both across individuals and across studies) with regard to how various putative performance factors influence the magnitude (and even direction) of line bisection errors. Such inconsistency greatly limits the usefulness of traditional qualitative (i.e., vote-counting) literature reviews. Meta-analytic procedures, on the other hand, provide a powerful *quantitative* method for dealing with heterogeneity across groups of studies, and permits stronger conclusions to be drawn. Moreover, meta-analyses are less subject to the limitations present in individual studies where the relationships between variables may be affected by the particular samples used. In meta-analyses, effect sizes from individual studies (or from sub-studies within a single larger study) are combined using a weighting scheme to produce a singular effect size estimate. Effect sizes are then combined using an inverse variance-weighted formula in which effect sizes calculated from larger subject samples are given relatively greater weight. Effect size is a particularly useful quantitative measure because it allows the strength of the relationship between two variables to be determined independently from the original unit(s) of measurement. By convention, an effect size of ± 0.2 is considered to be a small effect, a value of ± 0.4 is a moderate effect, and a value of ± 0.6 or greater is considered a relatively large effect [32].

The meta-analysis that follows presents a unifying picture of the effects of various factors on bisection performance by quantitatively averaging effect sizes across studies. The outcome will provide a definitive answer to the question of whether or not pseudoneglect truly exists as an attentional/perceptual phenomenon.

2.2. Methods

2.2.1. Studies incorporated

Studies included in the meta-analysis were identified and selected by searching the Medline and Psyclit databases, using the search terms 'pseudoneglect', 'neglect', 'hemineglect', 'hemispatial neglect', 'visuospatial neglect', 'left-side underestimation' and 'line bisection'. This procedure identified articles on the topic of pseudoneglect as well as articles pertaining to the phenomenon of neglect, many of which present bisection data from neurologically normal control groups. Further, the bibliographies from papers identified using database searches were inspected, and additional relevant references not revealed by the database search were identified. In several instances personal communications with authors established relevant statistical values that were occasionally omitted from published articles (see Appendix). Selected studies were restricted to those appearing in English language journals. All studies selected for meta-analytic review employed either line bisection, rod bisection, or pointing tasks. The present meta-analysis considers bisection performance only for horizontally oriented lines.

2.2.2. Inclusion criteria

The meta-analysis examined the following performance factors in line (or space) bisection: (1) subject age; (2) bisection modality (e.g., visual, pointing, tactile, kinesthetic) and, for visual bisections, whether the psychophysical procedure was method-of-adjustment or forced-choice; (3) subject sex; (4) subject handedness; (5) hand used to perform bisections; (6) line length; (7) horizontal spatial position of the stimulus; (8) the presence/absence and location of visual cues; and (9) the direction of visual or motor scanning.

2.2.2.1. Subject age. The effect of subject age was assessed by calculating effect size estimates from studies that tested young subjects and from studies that tested elderly subjects. Subjects within studies were included in the 'young' category if either the mean or range of the ages of subjects in the study was less than 40, or if the subjects were described as students. Subjects within studies were included in the 'old' category if either the mean or range of the ages of subjects in the study was greater than 50, or if the subjects were described as elderly.

2.2.2.2. Bisection modality. The effect of bisection modality was assessed as follows. Visual bisection studies are studies in which subjects bisect visually presented lines. Studies were additionally stratified according to the psychophysical procedure used. Procedures were classified either as method-of-adjustment, in which subjects manually marked the perceived midpoint of lines, or as forced-choice, where subjects made decisions regarding transector location relative to perceived midpoint following the presentation of pretransected line stimuli. Pointing tasks require the subject to indicate the position of their midsagittal plane using their hand (or other hand-held instrument) as a pointer. This task is performed blindfolded. Tactile studies involve the non-visual manual bisection of rods or similar stimuli. In kinesthetic tasks subjects bisect an aluminum rod by moving a cursor within a channel running along the length of the rod. Because the cursor moves with the hand, vibrotactile information is minimized, making this bisection task one based primarily on kinesthetic cues.

2.2.2.3. Subject sex. The effect of subject sex was assessed by including males and females in the meta-analysis only if individual experiments included separate information on the performance of *both* male and female subjects.

2.2.2.4. Subject handedness/laterality. The effect of subject handedness/laterality was assessed by including dextral and sinistral subjects in the analysis if separate group data were available from subjects identified by the authors and left- or right-handed. It should be noted, however, that only rarely were these terms operationalized according to a standard neuropsychological instrument, e.g., [96].

2.2.2.5. Hand used to bisect. The effect of hand used to perform bisections was assessed by including studies that provided separate information on the performance of subjects when using *both* the right and left hands.

2.2.2.6. Line length. The effect of line length was assessed as follows. All line lengths were converted into units of degrees visual angle. In the absence of a specified viewing distance a value of 45 cm (i.e., comfortable reading distance) was assumed. Line length was categorized as either 'short' or 'long'. Lines designated 'long' subtended between 17.68 and 32.23° of visual angle; lines designated 'short' subtended between 1.27 and 16.44° of visual angle. Single studies were not required to have reported data from both length lines.

2.2.2.7. Spatial position of lines. The effect of azimuthal spatial position was assessed by calculating effect sizes from studies that included separate data on subject performance in at least one location: in left hemispace, at horizontal midline, and in right hemispace.

2.2.2.8. Cueing effects. Studies were included in the meta-analysis of cueing effects if they provided separate information for subjects' performance where *more than one type* of visual cue was presented.

2.2.2.9. Scanning effects. Studies were included in the meta-analysis of scanning effects if they provided separate information on the two scanning directions, e.g., 'left-to-right' and 'right-to-left'.

2.2.3. Effect size estimates

Using the means and standard deviations reported in the respective experiments, signed bisection errors from veridical were in all cases converted into single-sample *t*-statistics. These *t*-statistics were subsequently converted to effect size estimates (Cohen's *d*-statistic) according to the following formula [32]:

$$d = 2t/\sqrt{df}$$

Hedges' procedures [52] were used for all calculations, and integrated effect size estimates were calculated using the META software package [112]. In the few instances where means and standard deviations were not available to directly calculate *t*-statistics, *P*-values were used to estimate effect sizes [52]. Integrated effect size estimates were computed according to both random-effects and weighted-integration models. When individual studies included multiple experiments (or addressed more than one performance factor), separate effect sizes were calculated for each experiment or performance factor. When studies presented information sufficient to derive more than one effect size estimate for an individual experiment, effect size estimates were in some cases (e.g., in the overall analysis) aggregated using the arithmetic mean. This aggregation prior to meta-analytic integration is necessary to avoid the over representation of multi-experiment studies in the overall analyses. A grand total of 73 effect sizes (N_E), gleaned from individual bisections studies, or sub-studies, were ultimately recovered.

2.3. Results

An overall effect size estimate was calculated which incorporated all 73 effect sizes, comprising a total of 2191 subjects (N_E). There was significant heterogeneity of effect sizes within the sample. Only 24.9% of total variance could be accounted for by sampling error, which implied that further meta-analytic subdivision of the overall sample was warranted. A systematic analysis of theoretically meaningful (selected a priori) moderator variables was therefore conducted on twenty-six subsets of the overall pool of studies. The results of the separate meta-analyses are given in Fig. 1

2.4. Discussion

2.4.1. Overall analysis

The overall meta-analysis unambiguously reveals, in contrast to the highly variable nature of the literature, and occasional declarations to the contrary [93], the existence of a significant leftward bisection error (i.e., pseudoneglect) for line bisection and similar tasks (both visual and non-visual) when performed by neurologically normal subjects.

2.4.2. Age effects

Young subjects err to the left in line bisection studies, while older subjects tend to err to the right of veridical center. This finding is of particular importance with respect to reconciling the neglect and pseudoneglect literatures, since most studies pertaining to pseudoneglect utilize college-age subject populations. Studies of neglect, on the other hand, most frequently use control subjects who are matched in age with neglect patients who are usually in their fifth to seventh decade of life.

The effect of age on bisection performance most likely arises due to asymmetric changes in the brain mechanisms of spatial attention across the two hemispheres. If spatial attention within each hemifield is controlled principally by the contralateral hemisphere [65,66], then the shift from leftward errors in young subjects to rightward errors in older subjects implies an age-related decrease in the ability of the right hemisphere to allocate spatial attention. This conclusion is consistent with the hypothesis that the right hemisphere is subject to more rapid aging than the left hemisphere [43,90,104].

2.4.3. Modality specific effects

Midsagittal-pointing tasks, visual line bisection tasks, and tactile bisection tasks all produce moderate size leftward errors. Interestingly, rather large rightward errors are observed in the kinesthetic task. Only three studies contributed to the kinesthetic analysis, however, and were all conducted in a single laboratory; therefore the generality of this conclusion must await independent experimental confirmation.

Forced-choice procedures produce significantly larger effect size estimates than do method-of-adjustment procedures. This is undoubtedly a consequence of the elimination, minimization or control of the many confounding factors associated with the method-of-adjustment, such as systematic visual scanning and the use of gross motor responses [35,82,84].

2.4.4. Sex differences

A modest sex difference can be detected in which males evince a slightly greater leftward error than do females. It has been suggested that the male brain may

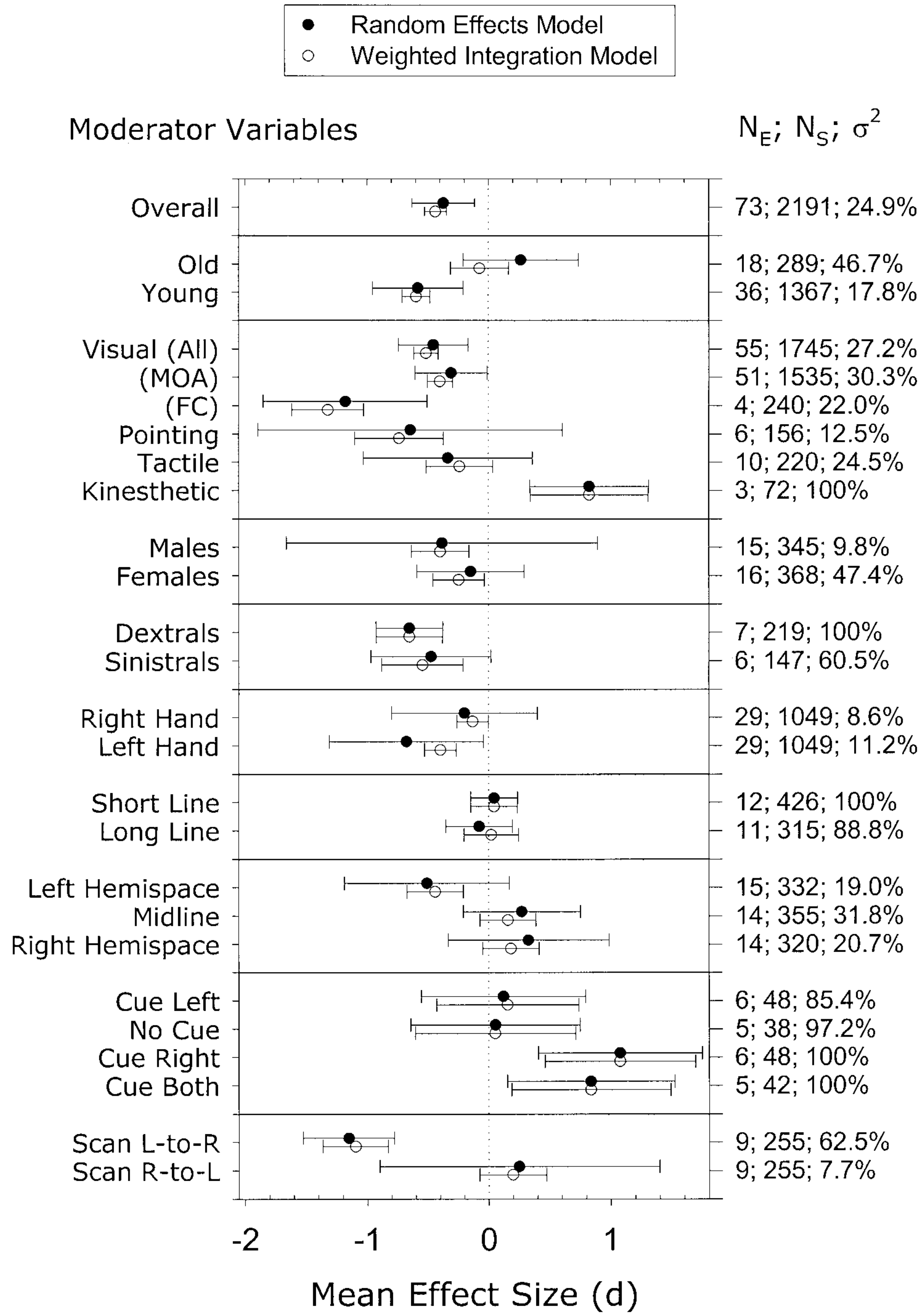

Fig. 1. Mean effect sizes (*d*) and 95% confidence intervals for the 26 meta-analyses conducted as part of the review. Filled symbols are means based on a random effects model; open symbols reflect means based on a weighted integration model. The conclusion of the analyses are very similar for both models. The moderator variables tested in specific meta-analytic comparisons are labeled on the left-hand side. Labels to the right side of the figure indicate the number of independent effect sizes (studies or sub-studies) which contributed to each meta-analysis (N_E), the total number of subjects these effect sizes were based upon (N_S), and the percent of the total variance which can be explained in each case by random sampling error (σ^2). When effect size distributions are relatively homogeneous, a larger proportion of total variance will be accounted for by random sampling error.

be more highly lateralized with respect to visuospatial attention [83,104], but the meta-analytic results reveal that this difference is modest as assessed by line bisection.

2.4.5. Handedness/laterality effects

Both dextrals and sinistrals demonstrate an overall leftward deviation, where dextral subjects are biased slightly more leftward than sinistral subjects. This is not unexpected if the sinistral group included subjects who are left-lateralized for spatial attention, and who therefore might be expected to make rightward errors.

2.4.6. Hand use effects

Bisection errors with either hand are generally leftward, although there is a relative bias in the direction of the hand used to perform bisections. The effect of hand is consistent with the activation-orientation theory of neocortical function [65,66], where manual bisection gestures of the left hand, for instance, result from an initial activation of the contralateral (right) motor cortex. This, in turn, may cause a generalized activation of contralateral (right) cerebral cortex that is superimposed on an overall right-hemisphere bias in spatial attention. This would tend to exacerbate hemispheric asymmetry and increase leftward error compared to right hand use, which would tend to equilibrate hemispheric arousal, and lessen leftward bisection errors.

2.4.7. Line length effects

Because the line length categories into which the extant data could be partitioned were crude (i.e., ‘long’ vs ‘short’), little evidence was found for a significant modulating effect of line length.

2.4.8. Line position effects

The relative pattern of results suggests that subjects tend to make centrifugal bisection errors, i.e., the perceived midpoint of lines deviates towards the horizontal spatial position of the line stimulus. In absolute terms, these data indicate a modest rightward error, an outcome which is inconsistent with the pattern of leftward error revealed by the overall meta-analysis. This discrepancy arises due to the particular characteristics of the subjects comprising the relatively small number of studies used to derive this particular effect size, and is indicative of the large variability that characterizes line bisection studies.

2.4.9. Cueing effects

With respect to the effect of visual cues, as for line position, it is the relative pattern of results that is perhaps the most informative. Here, both leftward cues and no-cue control conditions produce leftward bisection errors relative to rightward cue to double cue (left and right cues presented simultaneously) conditions. In absolute terms, a general rightward error exists which is inconsistent with the general leftward error found in the overall meta-analysis. Again, we interpret the absolute rightward error as a byproduct of the small number of studies that contributed to this subanalysis (5 or 6), and of the large variability that characterizes this literature.

2.4.10. Scanning effects

One of the largest effects revealed by the meta-analytic treatment of the line bisection literature is the effect of scanning. Subjects err in the direction from which scanning is initiated. Subjects scanning from left-to-right err significantly to the left of veridical line midpoint, whereas subjects scanning from right-to-left make modest rightward errors.

3. Conclusions

Perhaps the clearest conclusion to be drawn from the qualitative review is that enormous variability and inconsistency characterizes the line bisection literature with regard to the influence of most of the performance factors under review. As intended, however, the meta-analytic treatment of these data permits the unequivocal conclusion that an overall leftward bisection error of moderate effect size does exist, when the pseudoneglect literature is analyzed comprehensively and quantitatively. Several performance factors were additionally discovered to significantly modulate this overall effect.

Performance on bisection tasks is generally similar across tactile, visual line bisection and midsagittal-pointing tasks, whereas kinesthetic tasks may produce a very different result. Confirmation of this possibility awaits further empirical studies.

The effect of age on bisection performance is clear: young subjects err to the left, while older subjects tend to err to the right of veridical center. The implications of this finding are fascinating, as they suggest there are rather large age-related changes in cerebral organization with respect to the neural substrates of attention.

Scanning, in terms either of gross motor factors such as limb use, or with respect to oculomotor factors, such as the direction of visual scanning of the stimulus, emerged as one of the strongest modulating factors of pseudoneglect. Subjects err towards the side from which a motor or oculomotor scan originates. When left uncontrolled, this effect undoubtedly constitutes a large confounding influence in many line bisection studies.

It has often been suggested that some of the variability across studies may be due to subject samples that are heterogeneous in terms of sex and/or laterality. Inconsistencies regarding the effects of sex across studies may, in part, result from studies having selected different proportions of females who were in various phases of their menstrual cycle, since menstrual phase has a modulating effect on the apparent location of the midsagittal plane [83]. Most studies that do report sex effects, however, indicate a somewhat stronger leftward error for males than for females, in agreement with the meta-analytic results.

The qualitative review suggests that laterality may be a confounding factor in many bisection studies, since some investigators carefully screen subjects using a standard instrument [96], whereas other rely on undisclosed criteria whose reliability and validity cannot be gauged. Where extant data are available, however, the meta-analytic result suggests that laterality exerts only a weak modulating influence on pseudoneglect. Familial sinistrality has rarely, if ever, been measured or reported in bisection experiments, and it remains possible that the effects of latent sinistrality [1] may explain some variability across studies.

The qualitative review illustrates that individual studies find conflicting results, but the meta-analysis reveals that subjects misbisect lines in a direction towards the hand used to perform the bisections. In addition, bisection errors are made in a direction toward the hemispace in which the stimulus is presented. Thus, subjects err relatively rightward when lines are presented in right hemispace, or when using their right hand; they err relatively leftward when lines are presented in left hemispace, or when they are using the left hand to make bisections. Bisection error for lines presented at midline are determined largely by which hand is used to bisect. In studies that fail to control the direction of motor or oculomotor scanning, it is likely that the hand used to bisect also determines the direction of scanning. For example, bisecting with the right hand may promote a right-to-left scanning motion.

The effect of azimuthal spatial position is consistent with the activation-orientation hypothesis [65,66]; the displacement of line stimuli from midline likely causes an increase in cerebral activation within the contralateral hemisphere. A similar explanation has been offered for the effects of lateralized cueing.

The bisections made by neglect patients show rightward error with long lines, are more accurate with medium length lines, and actually crossover to reveal leftward error with very short lines [44–46,49,117,118]. A similar crossover effect has been reported in three studies using neurologically normal subjects [70,83,126] in which subjects erred left on medium and long length lines/rods but erred rightward when bisecting short lines/rods. The present meta-analysis does not capture or reflect this effect, however, because the crossover does not occur until line length is less than 3° [82], whereas our criterion for the 'short' line category included lines ranging from 1.27 and 16.44°.

The methodology of future research on spatial attention using line bisection tasks needs to include greater control over a number of extraneous variables. The forced-choice tachistoscopic line bisection procedure [35,85,96], which eliminates (or minimizes) gross motor and systematic scanning oculomotor movements [59], clearly emerges as a more powerful instrument to explore asymmetries in spatial attention than is the traditional method-of-adjustment procedure.

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Appendix. Index to studies contributing to the meta-analysis

The letters enclosed within square brackets following selected references indicate that the referenced publication contained data that contributed to the calculation of an effect size estimate in at least one meta-analysis. By referring to the index below, readers may determine which specific publications contributed to the various meta-analysis.

A: Bisection Performance (All Modalities).
B: Visual Bisection (Method of Adjustment and Forced-Choice).
B_{MOA}: Visual Bisection (Method of Adjustment).
B_{FC}: Visual Bisection (Forced-Choice).
C: Midsagittal-pointing Task.
D: Tactile Bisection Task.
E: Kinesthetic Bisection Task.
F: Young Subject.
G: Old Subject.
H: Male Subjects.
I: Female Subjects.
J: Dextral Subjects.
K: Sinistral Subjects.
L: Hand Use.
M: Short Lines.
N: Long Lines.
O: Line Position (Left Hemispace).
P: Line Position (Midline).
Q: Line Position (Right Hemispace).
R: Cue Left or Right Side.
S: No Cue.
T: Cue Left and Right Sides.
U: Directional Scanning.
Z: Some information derived from personal communication with author(s).

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