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Can Crossover and Altered Magnitude Estimation in Neglect Be Explained by Contextual Effects?

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Abstract

Three studies that used experimental manipulations of stimulus context and correlational analyses were conducted to examine how contextual effects influence magnitude estimation and the crossover effect on line bisection. Previous work had shown that although orienting attention to one end of a line prior to bisection determines the direction in which crossover occurs, bias in magnitude estimation actually produces the crossover effect. The influence of contextual effects on magnitude estimation, however, was not examined in these previous models of crossover. Consequently, the purpose of the present investigation was to examine these effects. Subjects in the current studies were healthy controls and people who had right and left hemisphere injury due to stroke, both with and without spatial neglect. Study 1 examined the crossover effect for lines bisected with and without a stimulus context. Study 2 examined both stimulus order as well as response order context effects on magnitude estimation. Study 3 examined how much variance in magnitude estimation was accounted for by stimulus contextual effects and how stimulus context influenced the crossover effect. The results showed that contextual bias was ubiquitous but relatively small in the magnitude estimates of normal subjects. Contextual bias was exaggerated to a similar degree in subjects with right or left hemisphere injury due to stroke, but the amount of variance accounted by contextual bias was still quite small. A novel finding of study 2 was that contextual effects can be induced by previous responses to stimuli as well as by the magnitude of preceding stimuli in subjects with unilateral brain injury. This may be a contextual effect related to response perseveration. Finally, studies 1 and 3 indicated that contextual effects strengthened the crossover effect on line bisection, primarily on relatively short lines. Contextual effects, however,

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cannot fully account for the crossover effect, because crossover bisections were observed also in the absence of a stimulus context. It is concluded that the crossover effect is explained by biases in attentional orientation and magnitude estimation. Contextual effects represent one source of bias in magnitude estimation that influences the crossover effect by promoting contralateral errors on short line lengths (<2 cm).

Keywords

Altered magnitude estimation; Contextual effects

Introduction

Spatial neglect (neglect) is a neurobehavioral syndrome defined as the failure to respond, orient, or act on stimuli located contralateral to a focal brain injury that is not due to a primary motor or sensory problem [1]. Neglect typically follows lesions to heteromodal association cortex or to nuclei within the thalamus, basal ganglia, and brain stem [2–6]. Neglect is most commonly observed following lesion to the right cerebral hemisphere. Theoretical explanations of neglect focus on deficits of arousal, sensory attention, motor intention, or mental representations of space. Many patients with neglect demonstrate a pattern of behavior on the line bisection task known as crossover [7–10]. When given a range of lines to bisect, they err towards the ipsilesional end of long lines and the contralesional end of short lines. Crossover was initially considered to be paradoxical with respect to theories of neglect [11] because these do not predict contralesional errors [12].

A series of studies, however, showed that the crossover effect can be demonstrated not only in patients with neglect but also in neurologically normal subjects and in patients with unilateral lesions of the left hemisphere [13,14]. Crossover, therefore, is not caused by neglect, but neglect certainly seems to exaggerate the crossover effect. Mennemeier et al. [13–15] proposed and confirmed that two independent factors, present in normal subjects but exaggerated in neglect, account for the crossover effect: 1) bias in attentional orientation and 2) bias in magnitude estimation. By this account, all subjects form mental representations of lines, with spatial attention preferentially oriented or biased towards one end of the representation. The orientation/estimation hypothesis makes two primary assumptions about attentional orientation. First, in neurologically normal subjects, attention is anchored towards the right end of lines or similar stimuli due to a dominant influence of the left-hemisphere in directing attention contralaterally [16]. Second, in patients with unilateral brain injury, attention is anchored ipsilesionally, toward the side of the damaged hemisphere, as the intact hemisphere is released from inhibition by the opposing damaged hemisphere.

Unlike attentional orientation, magnitude estimation is a concept that is not part of any contemporary theory of neglect. Magnitude estimation refers to the act of perceiving stimulus intensity. Stimulus intensity refers to the amount of a stimulus that is presented to a subject such as the length of a line, the weight of a held object, etc. The psychophysical power law holds that perceived intensity is a power function (a log-log relationship) of physical intensity [17]. Power functions are characterized by their exponents (equivalent to slopes in linear regression) and constants (equivalent to a y-intercept). Patients with neglect have been found to have lower exponents and higher constants than for normal subjects [9,13–15,18,19]. These alterations in the form of the power function signal a tendency or bias to underestimate the intensity of lesser stimuli in the range (e.g., the short lines) and to overestimate the intensity of greater stimuli (e.g., the long lines). Normal subjects also show this type of bias but to a much lesser degree than in patients with neglect [13,14], as will be described below.

Whereas bias in attentional orientation influences the direction in which the crossover effect occurs, bias in magnitude estimation actually produces the crossover effect [14]. If the mental representation of a line is an underestimation of the true line length, as predicted for long lines, the bisection mark will fall short of true line center. If the mental representation is an overestimation of the true line length, as predicted for short lines, the bisection mark will go past true line center in the opposite direction, resulting in a crossover effect. The direction of the crossover effect is typically described from long to short lines such as a right to left crossover effect in patients with left neglect. Subjects with unilateral right-hemisphere brain injury preferentially orient attention rightward, contralateral to the intact, left hemisphere. Their rightward bias causes them to make rightward errors on long lines, undershooting the true line center, and to make leftward errors on short lines, overshooting the true line center. Subjects with left-hemisphere brain injury show crossover in the opposite direction. Neurologically normal subjects show a less exaggerated crossover effect from right to left. Not only were these assumptions confirmed in an experimental study of the crossover effect, but the direction of the crossover effect could also be experimentally reversed for all subject groups - normal controls, right-hemisphere lesioned subjects with and without neglect, and left hemisphere lesioned subjects without neglect-when subjects were given a starting end point and asked to either copy or reproduce line lengths from memory [14].

Psychophysicists have known since the turn of the last century that when normal subjects estimate a range of stimulus magnitudes (e.g., length, weight, or loudness), they tend to overestimate lesser stimuli in the range and to underestimate greater stimuli in the range to a small degree [20]. This type of bias is referred to as a “contextual effect” in magnitude judgment. Contextual effects have a small but ubiquitous influence on the magnitude estimates of normal subjects, affecting a wide range of subjective evaluations, including sensory perception, attitudes, and social cognition [21]. Contextual effects are explained as a form of “response bias” known as sequential dependency in judgment [22]. Response biases refers to a class of experimental factors that are known to alter magnitude estimates [23]. Sequential dependency refers to an effect that is due to the ordering of stimuli presented in an experiment. For example, when estimating line lengths in a set of randomly ordered lines of different lengths, longer lines will tend to be underestimated and shorter lines overestimated due to the stimulus context in which they are presented.

Exaggerated contextual effects are plausible for how magnitude estimates are biased in patients with right hemisphere injury and neglect. However, it is possible that the systematic errors in judgment are not entirely due to stimulus context effects. Rather, magnitude judgements might also be overestimated or underestimated because of processing limitations that are inherent to sensory/perceptual systems (i.e., perceptual bias) and dysregulated by brain injury. If so, then a subject's estimate of stimulus intensity should be biased even when judgments are made independent of context (e.g., when a stimulus of only one magnitude is repeatedly presented). Cross [22] examined sequential dependency in line length estimation using neurologically normal subjects and found that first order context effects (i.e., the effect of the most recently judged stimuli on the current stimuli) only accounted for less than 1% of the variability in the subject's responses. Second order or greater contextual effects could not be demonstrated. Czekóová et al. [21] showed that first order context effects in judgements of emotional stimuli account for more variance than second order effects, but that sequences of stimuli preceding the first order context effect can nonetheless influence judgement. Even so, the small amount of variance accounted for by context effects, at least in normal subjects, seems unlikely to cause the rather large line bisection errors made by patients with neglect unless these effects were greatly exaggerated.

Marshall et al. [24] was the first to propose an explanation of the crossover effect based on the psychophysical concept of contextual effects. They examined the performance of six subjects with right-hemisphere brain injury and neglect on manual line bisection or a line bisection discrimination task similar to Milner's "landmark task". Each subject bisected sets of lines of a single reference length followed by sets of lines of the reference length interleaved with another line length. A significant rightward shift in bisection error was noted for reference lines when lines shorter than reference length were added, while a significant leftward shift in bisection error was noted for reference lines when lines longer than reference length were added. Both manual line bisection and discrimination tasks produced similar data. A later study also used a landmark test to examine how stimulus context influences the crossover effect in normal subjects. Normal participants were much less influenced by context than previous studies had shown for neglect patients.

Ricci and Chatterjee [25] further examined contextual effects on line bisection in a series of three experiments utilizing 11 patients with right-hemisphere injury. In experiment #1, lines were bisected further to the left if preceded by a longer line and further right if preceded by a shorter line, essentially replicating the findings of Marshall et al. [24]. Experiment #2 established that context effects operate on both relatively long lines and relatively short lines. Experiment #3 examined crossover in two ranges of lines, one from 1 to 15 cm and one from 11 to 25 cm. Crossover occurred only on lines shorter than 4 cm. Ricci and Chatterjee noted that if contextual effects directly caused the crossover effect, then subjects should have made leftward errors on the short lines within both ranges. They concluded that line length exerts a greater influence on line bisection errors than does context.

These initial studies indicate that contextual effects influence line bisection errors and crossover phenomenon in subjects with right-hemisphere brain lesions and neglect. However, since no normal subjects or patients with left hemisphere injury were examined in these studies, it is unknown how much brain injury exaggerates contextual effects and if this is specific to neglect. The following series of experiments used experimental manipulations of stimulus context and correlational approaches to examine how contextual effects are altered by brain injury and whether they can account for the overestimation and underestimation of stimulus magnitudes that are associated with the crossover effect.

Study #1: Experimental Manipulation of Context

Rationale

Stimulus context was manipulated experimentally using a paradigm inspired by the psychophysical literature [22] to determine if the altered power function parameters and the patterns of crossover seen in patients with right hemisphere lesions and neglect could be changed or possibly even normalized by the removal of stimulus context. Subjects with unilateral right and left hemisphere lesions and normal controls were tested to determine how brain injury might exaggerate contextual effects.

Methods

Subjects—Subjects were 21 normal controls (NCS), 18 patients with unilateral right hemisphere lesions due to stroke (RHL) and 18 patients with unilateral left hemisphere lesions due to stroke (LHL). All brain-injured subjects were tested at least one-month post-stroke. Significant between-group differences were noted for age, $F(2,53)=4.74$, $p=0.013$. NCS subjects (M=72) were significantly older than LHL (M=59, $p=0.003$) but not RHL (M=65) subjects. Thirty-nine percent of RHL, 44% of LHL, and 50% of NCS subjects were male. Sixty-one percent of RHL, 67% of LHL, and 100% of NCS subjects were Caucasian. CT or MRI studies were available for 78% of RHL and 61% of LHL patients. Radiology reports were used to confirm lesion location in the case of missing scans. The Damasio and Damasio templates [26] were used to code lesions from CT or MRI scans when possible. A summary of lesion location appears in Table 1. The study was approved by the University's Institutional Review Board. All subjects gave written, informed consent prior to beginning the study.

Pretest Measures—All subjects completed the Mini-Mental State Exam (MMSE) [27] and a battery of custom-designed neglect tests prior to the experiment (see Table 1 for a summary of neglect test performance). The MMSE is a commonly used screening measure of mental status. Significant between-group differences were found for MMSE total scores, $F(2,50)=12.36$, $p<0.0005$. The RHL (M=22, $p=0.001$) and LHL (M=20, $p<0.0005$) groups had significantly lower MMSE scores than the NCS (M=28) group but did not differ from each other. The neglect tests consisted of line bisection, cancellation, a clock copying task, and double simultaneous stimulation within visual, tactile, and auditory modalities. Performance on each task was coded as consistent with the presence of neglect or not consistent with neglect. Line bisection was considered to indicate neglect if the average error size across line stimuli made by a subject was outside the 99% confidence limits established by the normal subjects. Cancellation was considered as showing neglect if two or more errors were made on the side of the page contralateral to brain injury. Clock copying was examined qualitatively for errors of omission contralateral to brain injury. Double simultaneous stimulation was considered abnormal if more than three suppressions were made contralateral to the injured hemisphere. Subjects in the RHL group failed a larger number of neglect tasks than the LHL or NCS groups. In addition to these measures, handedness was assessed by self-report, and visual fields were examined to confrontation. Nearly all subjects were right-handed. Three RHL subjects had visual field defects.

Stimuli and Apparatus—The line stimuli were .1 cm in width, and of the following lengths - 0.5, 1, 2, 4, 10, and 20 cm. The lines were drawn individually on standard 11 × 17 inch legal paper. All line stimuli were viewed on a white tabletop and presented at body midline. Viewing distance was approximately 30 cm.

Procedures

Subjects bisected lines within two conditions (described below). All subjects bisected lines with either their dominant hand or the hand unaffected by stroke as needed to get the best possible performance. No restrictions were placed on head or eye movements. Subjects were asked to cut the line into two equal halves using a pencil. All subjects participated in two experimental conditions as follows:

Bisection without context—At the beginning of the experiment subjects bisected three lines of only one of the six lengths described above. Subgroups of NCS, RHL, and LHL subjects were created, one for each line length.

Bisection with context—After completing the no-context condition, all subjects proceeded to bisect the full complement of line lengths (three trials of each length) with the order of presentation being randomly determined.

Analyses—The data were graphed to illustrate the effects of context on crossover (Figures 1 & 2). For each group, the signed-percent error scores were graphed separately for context and no-context conditions. Bisection errors were represented as a percentage of objective line length. A negative sign was used to denote leftward bisection errors.

Power function parameters were also derived. Perceived line length was derived from line bisection data by doubling the distance from the attended end of the line [13,18,28]. The right-end is assumed to be the attended end for the RHL and NCS subjects while the left-end is assumed to be the attended end for the LHL subjects. This assumption was confirmed in the Mennemeier et al. [14] study. Power function exponents and constants are the log-transformed equivalent to the slope and y-intercept used in linear regression. For the no-context condition, power function parameters were calculated by summing data across the subgroups formed for each line length in each subject group. For the context condition, an individual power function was derived for each subject within each subject group. Ninety-five percent confidence intervals were calculated for each group using data from the context condition to facilitate statistical comparisons to the no-context condition.

Results

When context is present (Figure 1), the RHL and LHL groups crossed over from making ipsilesional errors on long lines to making contralesional errors on short lines, consistent with previous studies [13,14]. Also, consistent with expectations, the RHL group made the largest errors on the long line lengths. The NCS group made very small deviations from true line center except at the shortest line length. When context was absent (Figure 2), bisection errors were significantly altered for the brain-injured groups. Both the RHL and LHL groups continued to make ipsilesional errors on long lines but now also made ipsilesional errors on short lines. Both brain-injured groups still showed crossover errors but now made them for only the 2 cm length line. The NCS performed essentially the same way when context was absent as when context was present. This finding suggests that stimulus context has a greater effect on the bisection performances of brain-injured subjects rather than NCS and that context biases perception primarily for short lines in all three subject groups.

Power function exponents are summarized in Figure 3. The NCS group’s exponent for the no-context condition (M=1.02) fell within 95% confidence limits for the context condition (M=1.01, 95% C.I. 1.06–0.96). The 95% confidence for NCS included 1.0, the expected value for line estimation tasks [17]. The RHL group’s exponent for the no-context condition (M=0.948) fell within the 95% confidence limits for the context condition (M=0.93, 95% C.I. 1.17–0.69). The LHL group’s exponent for the no-context condition (M=1.02) fell within the 95% confidence limits for the context condition (M=1.05, 95% C.I. 1.68-.42). A significant difference was found; however, for exponents in the context condition. The exponent for the RHL group was significantly lower than the exponent for the NCS group, t(18.3)=−2.8, p=0.012.

Conclusions

Magnitude estimates of line length made by normal subjects were accurate. This result is consistent with previous psychophysical studies indicating that the power function exponent for estimates of line length is 1. Graphical analyses indicated that contextual effects were small in normal subjects, but with a greater influence on the subjects with unilateral brain injury, particularly on the shortest length lines. The absence of context did not alter bisection from context for the NCS group. In contrast, the absence of stimulus context promoted ipsilesional line bisection errors for both the RHL and LHL subjects except for the 2 cm length line where a crossover effect was observed.

Contextual effects altered the size of the power function exponent in the RHL group relative to the NCS group, but only to a small degree. While the exponent was significantly decreased for the RHL group relative to NCS group only when context was present, the magnitude of difference between RHL and NCS in the context absent condition was nearly the same. Contextual effects may, therefore, have a smaller influence on power function parameters than the “perceptual biases” imposed by right-hemisphere injury. While this study provides some interesting preliminary data, it has a methodological issue that may limit interpretation. Power function exponents calculated for the no-context condition required the subjects to bisect lines of only one length. In contrast, power functions for the context condition were fitted to each subject’s data because they bisected a full complement of line lengths. Differences in how these exponents were derived may limit interpretations about how contextual effects interact with brain injury to alter magnitude estimation. Limitations of this study were addressed in the following experiments.

Study #2: Correlational Analysis of Contextual Effects

Rationale

A second study using a correlational method was performed to replicate the findings of study #1 and to address its methodological limitations. Subjects performed a loudness judgement task in addition to line bisection to assess generalization. We included a loudness task because contextual effects were hypothesized to occur across a variety of perceptual continua that required magnitude estimation. In addition, we examined first order stimulus context effects as well as first order contextual effects for previous responses. If a previous sensory experience can bias perception, then it is reasonable to expect that a previous response can do the same, especially for subjects with brain injury (e.g., response perseveration).

Methods

Subjects—Subjects were three RHL and six NCS who were recruited from the first study 3–4 months later. Subject characteristics appear in Table 2 (see subjects #4, #25, & #27 Table 1). Significant between-group differences were noted for age, t(7)=−4.6, *p*=0.002. NCS subjects (M=73) were significantly older than RHL (M=63) subjects. 67% of RHL and 67% of NCS subjects were male. CT or MRI studies were available for all three stroke subjects. Stroke involvement with regard to the Damasio Template Mapping System are provide in Table 1. The study was approved by the University’s Institutional Review Board. All subjects gave informed written consent prior to beginning the study.

Pretest Measures—All subjects had completed the same battery of neglect tests described in study #1 prior to the current experiment. All three RHL subjects showed signs of neglect across multiple tasks. All subjects were right-handed by self-report. Visual fields were examined to confrontation and revealed a field defect in one RHL subject. All subjects were evaluated using pure tone audiometric testing from 250 to 8000hz for each ear to determine if sufficient hearing was present to perform the loudness estimation study. A loudness threshold was determined for each ear at 1000hz using the method of limits. A clinical audiometer located in a sound-proof chamber was used to present all auditory stimuli. 1000hz thresholds did not differ between the groups (RHL M=22dB, NCS M=26dB). No between-ear differences were found for either group.

Stimuli—For the line bisection portion, each subject bisected lines replicating the context condition from study #1. In the loudness estimation portion, each subject rated the loudness of pure 1000hz tones. Six tones were presented six times each. Tones ranged from 10 to 60 dB in 10 dB even steps above the subject’s absolute threshold.

Procedures

Subjects performed the line bisection portion of the study first. Subjects then rated tones that were presented in three randomly ordered blocks of trials. In one block, subjects heard tones presented binaurally through a set of headphones (center condition). In the other two blocks, subjects heard tones presented from a speaker located either to the left (left condition) or the right (right condition) of the subject. The three spatial conditions described above were chosen because we suspected that patients with neglect may experience loudness differently depending on the location of its source. The speaker was located at ear level 100 cm from the subject. Subjects rated the loudness of the tones using 2-digit numbers between 10–99 for each trial (10=softest, 99=loudest). A modulus, or standard tone, representing the exact middle of the loudness range of tones, was presented to the subject before the study stimuli were presented. It was expected that a modulus helps to anchor a subject's judgments. Even though a modulus may not be needed if subjects rate the same stimuli three or more times [17], a modulus was used as a precaution in this study.

Analysis—Power function exponents were derived for the loudness task separately for each of the three spatial conditions. Log-transformed objective loudness in dB was regressed on log-transformed ratings of loudness and power functions used to calculate the exponents. The effects of context and of previous responses were evaluated using three, zero-order correlations (see Figure 4). Three correlations were calculated as follows: (1) correlation of Stimulus1 with Response 1, i.e., the stimulus effect, 2) correlation of Response 2 with Stimulus 1, i.e., the stimulus context effect, and 3) correlation of Response 2 with Response 1, i.e., the response perseveration context effect. Correlations were calculated separately for the line bisection and loudness tasks. In the case of line bisection, signed error was evaluated, while for loudness, the subjects' ratings of loudness were evaluated.

Results

Exponents from the loudness task are summarized in Figure 5. A significant effect of subject group on exponent size was observed, F(1,7)=42.0, $p<0.0001$. The RHL group had lower exponents than the NCS group. No main effect of spatial location was found, nor did location interact with group. Correlational results are summarized in Table 2 for line bisection & Table 3 for loudness estimation. The correlation coefficient for the stimulus effect was significant for both tasks in both groups. Whereas the stimulus effect was the only significant correlation coefficient for the NCS group, both the stimulus context effect and the response perseveration context effect were also significant for the RHL group.

Conclusions

Study #2 replicated two essential findings from study #1: 1) that context effects are small in normal subjects, and 2) that context effects are exaggerated in RHL patients relative to NCS. These findings were not limited to line bisection task, because they were also true for loudness estimation. Additionally, contextual effects due to previous stimulus intensity and to previous responses were both significant and exaggerated in the RHL group but not in the NCS group. It is concluded therefore that previous responses as well as previous stimulus intensities bias magnitude judgements in RHL subjects. Since no LHL subjects participated in study #2, it cannot be determined if these effects are specific to neglect versus a more general consequence of brain injury.

Study #3: Correlational Analysis of Contextual Effects

Rationale

Study #3 sought to replicate the findings of the studies #1 and #2 using data from an independent sample and a new correlational approach. Study #1 had methodological limitations but suggested that contextual effects may be exaggerated by brain injury. Study #2 provided evidence of enhanced contextual effects in RHL subjects but utilized a small sample that was recruited from study #1. In addition, study #2 was unable to establish if exaggerated contextual effects were unique to subjects with RHL and neglect or if they represent a more general consequence of unilateral brain injury.

Methods

Subjects—Line bisection data were taken from a previously published study of 20 patients with unilateral right-hemisphere lesions (RHL), 9 patients with unilateral left-hemisphere lesions (LHL), and 11 normal control subjects (NCS) [29]. Mean ages were 65 years for the RHL group, 66 for the LHL group, and 72 for the NCS group. The groups did not differ in handedness or age. All brain-injured subjects were at least two months post-injury, and the RHL and LHL groups did not differ in overall lesion chronicity (RHL M=14 months, LHL M=15 months). Less than 10% of each group had visual field defects. CT or MRI studies were available for 85% of RHL and 73% of LHL patients. Radiology reports were used to confirm lesion location in the case of missing scans. The Damasio and Damasio templates [26] were used to plot lesions from CT or MRI when possible. These lesions have been published elsewhere. The study was approved by the University's Institutional Review board. All subjects gave written informed consent prior to beginning the study.

Pretest Measures—Subjects completed a custom short battery of tests that provided a composite index of neglect symptoms, including alertness, body kinesis, mood, orientation to external stimuli, extinction, limb akinesia, and motor impersistance, drawing, copying, and cancellation tasks. Criterion reference ratings were made for each subtest and then were summed to derive the composite index. Higher scores indicate a greater degree of neglect symptoms. Both LHL and NCS groups obtained a lower index score than the RHL group (F=8(2,28), $p<0.001$) but they did not differ from each other.

Stimuli—Line stimuli were 0.5, 1, 2, 5, 10, 30, 50, and 80 cm in length and 0.2 cm in thickness. Three trials of each length were completed. The lines were drawn individually on standard 11 × 17 inch legal paper except for the 50 & 80 cm lines. All of the line stimuli were viewed on a white table-top and presented at midline. Viewing distance was approximately 30 cm.

Procedures

All subjects bisected lines with either their dominant hand or the hand unaffected by stroke as needed to get the best possible performance. No restrictions were placed on head or eye movements. Subjects were asked to cut the line in half.

Analysis—Error scores were derived from line bisection data using a signed-percent error score approach, identical to that used in study #1. Bisection errors were represented as a percentage of objective line length. A negative sign was used to denote leftward bisection errors. A signed percent index of context was derived for each line bisection trial using the following formula: Previous line length - current line length/current line length

Using this formula, context is expressed as a value that ranged between −3000% and +3000%. Negative values indicate that the line currently being bisected was preceded by a longer line. Positive values indicate the reverse situation. The index is expressed as a percentage of current line length. Signed percent error scores were correlated with the index of context.

Results

Results are summarized in Figures 6 through 8. Figure 6 represents data from the NCS group. Figures 7 and 8 represent data for the RHL and LHL groups, respectively. For the NCS group context was not significantly associated with signed percent error, r(168)=0.041, p=0.599, R2=0.002. For the RHL group context was significantly associated with signed percent error, r(293)=−0.174, p=0.003, with context accounting for ~3% of the variability in error size. Examination of Figure 7 suggests that in the RHL subjects context facilitated the crossover effect by enhancing leftward bisection errors on short lines. For the LHL group, context was significantly associated with signed percent error, r(176)=0.168, p=0.026, with context accounting for ~2.8 % of the variability in error size. Examination of figure 8 suggests that in LHL subjects context serves to enhance rightward bisection errors on short lines thereby facilitating a crossover effect in a similar manner to that of RHL subjects but in an opposite direction.

Conclusions

Context had a small effect on the bisection errors of neurologically normal subjects. This result is consistent with Cross [22], who found that serial dependencies in judgement account for less than 1% of the variance in the magnitude estimates of normal subjects. In contrast, stimulus context effects were exaggerated in a similar manner and degree in both the RHL and LHL groups, and context effects only accounted for about 3% of the variance in bisection error. The primary way in which stimulus context influenced the crossover effect was again to enhance contralateral (or contralesional) errors on short lines.

General Discussion

Context effects were ubiquitous across the three experiments of this study. They were consistently small in normal subjects and exaggerated in both RHL and LHL subjects in a similar manner and to a similar degree. As such, exaggerated context effects were not specific to subjects with neglect. However, study #2 indicated that they might be more pervasive in neglect--induced by previous responses as well as previous stimulus intensities. These observations parallel those made in previous investigations of the crossover effect on line bisection [13,14]. While crossover is exaggerated by neglect, it is neither specific to neglect nor to right hemisphere injury. Crossover also occurs to a lesser degree in NCS and subjects with left hemisphere injury. Further, neither crossover phenomena nor contextual effects are specific to line bisection because they occur for judgements of other types of stimuli such as in the loudness estimation data of experiment #2.

A novel finding of this study was to show that contextual effects can be due to previous responses as well as to the previous stimulus intensities. While our interpretations are limited here because they are based on only three RHL subjects with neglect, the findings suggest that contextual effects may have multiple sources. Focusing on only one source, like stimulus contextual effects, might be insufficient to account for the exaggerated forms of bias that occur in subjects with brain injury. Whereas one type of contextual bias may not account for the degree to which magnitude estimates are biased in subjects with brain injury and neglect, a combination of bias from several sources might be sufficient to do so. Further studies are needed to examine how multiple types of contextual bias contribute to performance errors in neglect.

Can crossover and altered magnitude estimation in neglect be explained by contextual effects? Our previous studies have shown that the direction of crossover is explained by biases in attentional orientation and that biases in magnitude estimate produces the crossover effect [13–15,29]. Contextual effects are just one form of response bias that influences magnitude estimation [23]. The current study shows that contextual effects influence the crossover effect on line bisection primarily by enhancing contralateral errors on short lines – by making them consistent. Interestingly, when Ricci and Chatterjee [25] examined how contextual effects influence the crossover effect on two ranges of line lengths - one spanning 1 to 15 cm and the other spanning 11 to 25 cm - crossover only occurred on lines that were shorter than 4 cm. A crossover effect could not be induced by stimulus context in the range made up of longer lines. In experiment #1, although the absence of context largely eliminated the crossover effect for the smallest length lines (i.e., the 0.5 and 1 cm lines) in both the RHL and LHL subjects, both groups still made crossover bisections on the 2 cm line. Consequently, it appears that an absolute line length can trigger a crossover effect (~2–4 cm), even in the absence of stimulus context. Beyond that length, stimulus context does not appear to be potent enough to induce a crossover effect in line bisection. Contextual effects, therefore, influence the crossover effect by biasing magnitude estimation, particularly for short lines, but they cannot account for crossover bisections in the absence of context, as was the case in study #1.

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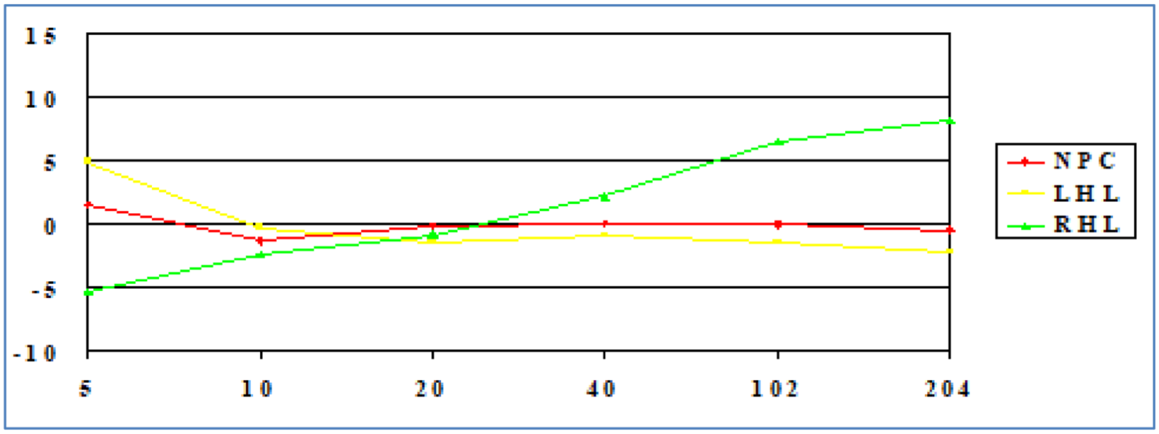

Figure 1.

Line Bisection Error: Context Condition. NPC: Non-Patient Controls, LHL: Left Hemisphere Lesion, and RHL: Right Hemisphere Lesion. The y-axis shows the signed percent error scores (a negative sign denotes leftward bisection errors). The x-axis represents each line length (in mm).

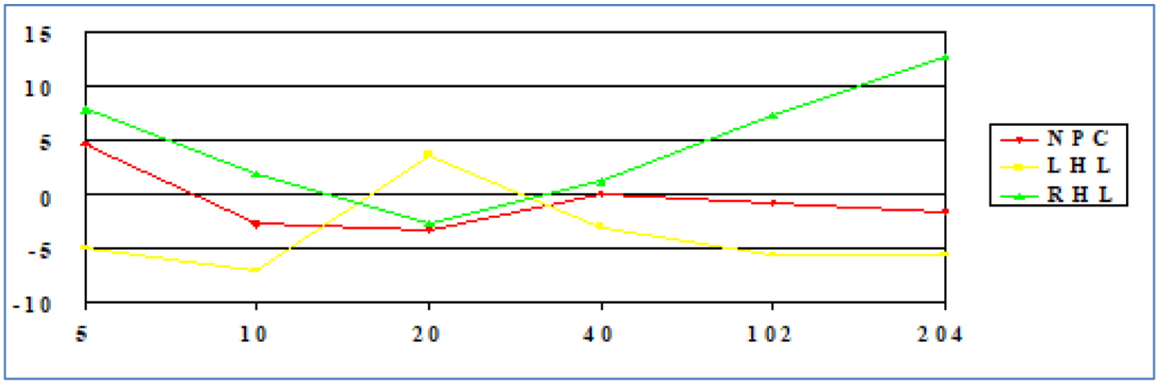

Figure 2.

Line Bisection Error: No-Context Condition. NPC: Non-Patient Controls, LHL: Left Hemisphere Lesion, and RHL: Right Hemisphere Lesion. The y-axis shows the signed percent error scores (a negative sign denotes leftward bisection errors). The x-axis represents each line length (in mm)

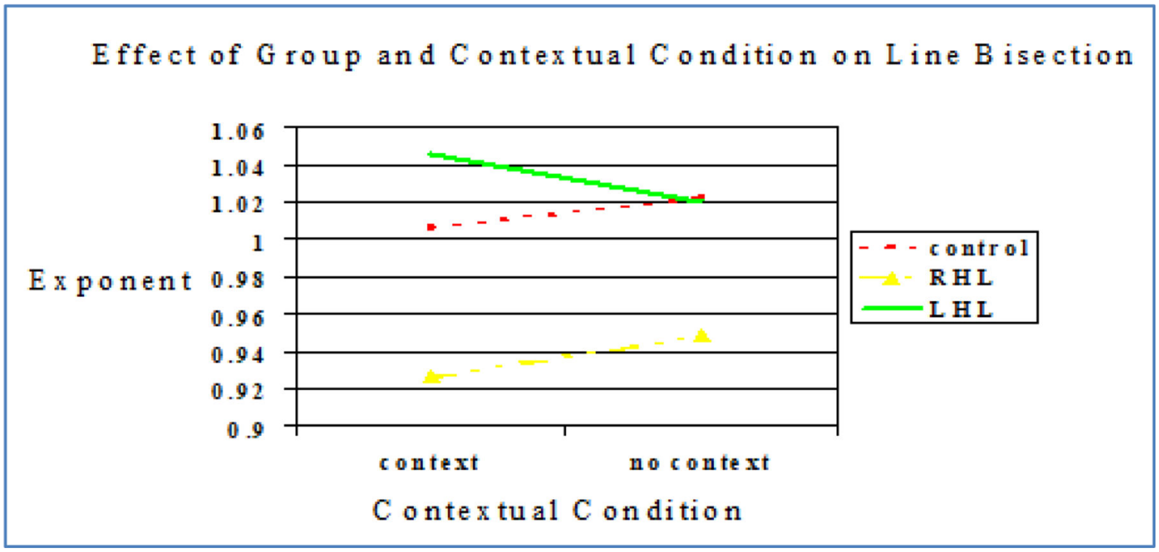

Figure 3.

Effect of Group and Contextual Condition on line Bisections. Control: Non-patient Controls, LHL: Left Hemisphere Lesions and RHL: Right Hemisphere Lesion

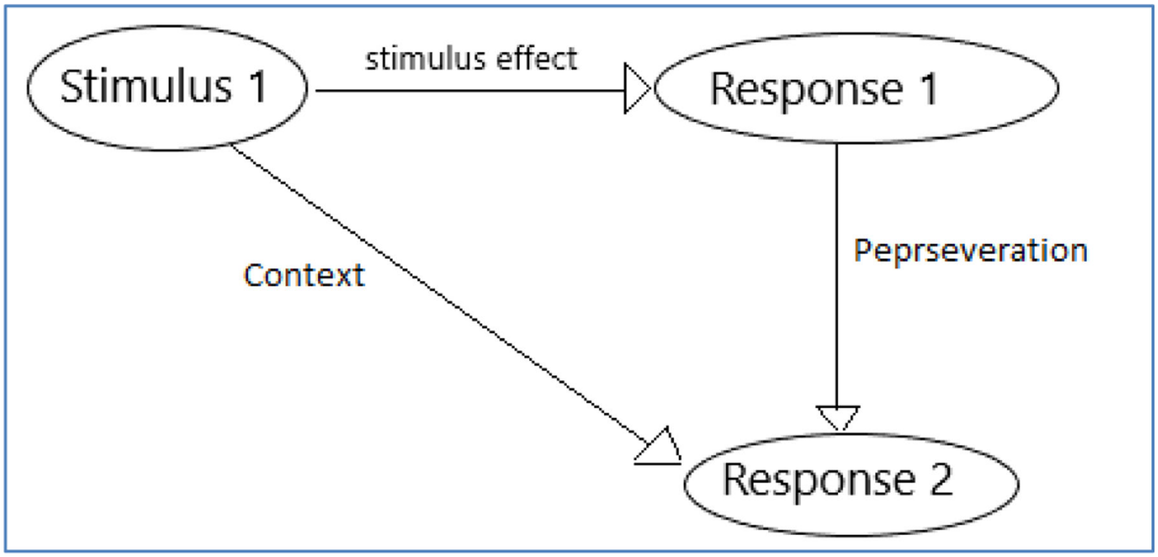

Figure 4.
Corelation Analysis

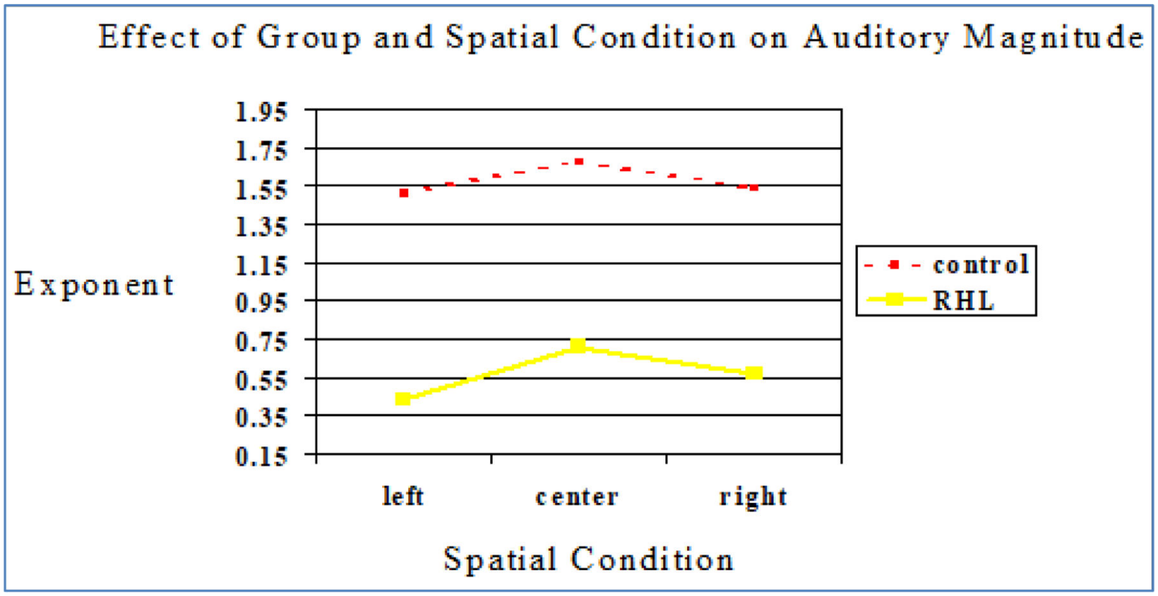

Figure 5.

Effect of group and spatial condition on auditory magnitude estimation. Control: Non-patient Controls and RHL: Right Hemisphere Lesion

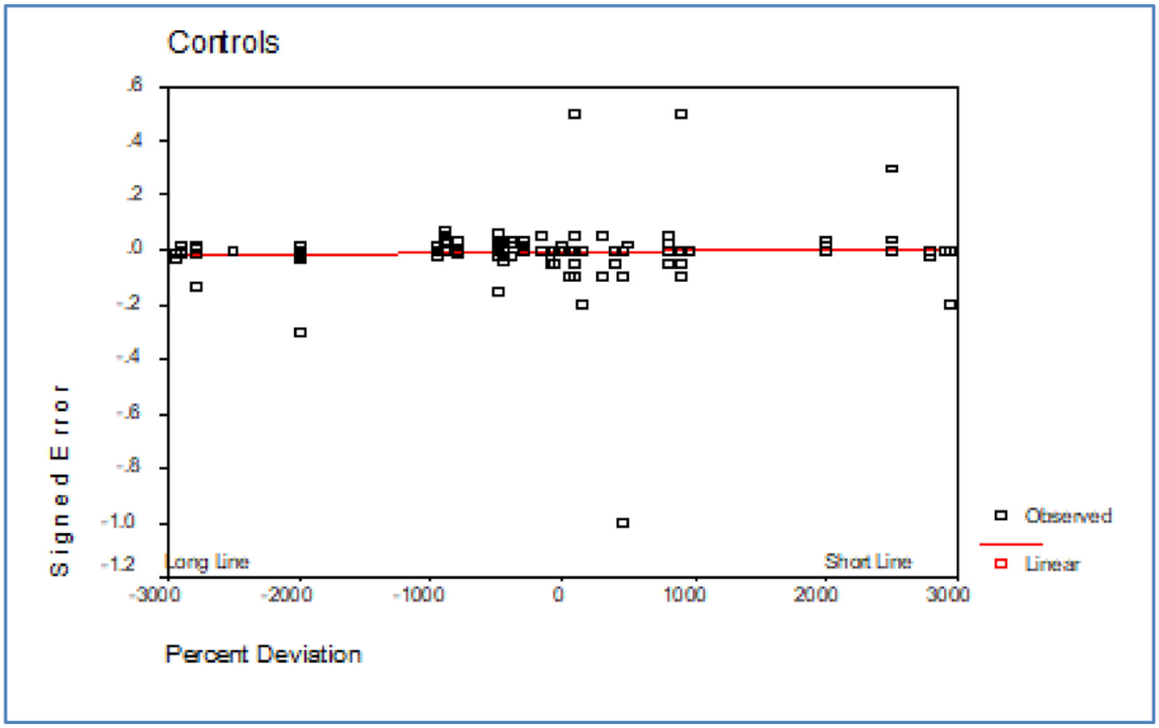

Figure 6.

Association of the signed percent index of context (i.e., percent deviation: x-axis) with the signed percent error score (i.e., signed error: y-axis) on line bisection for NCS

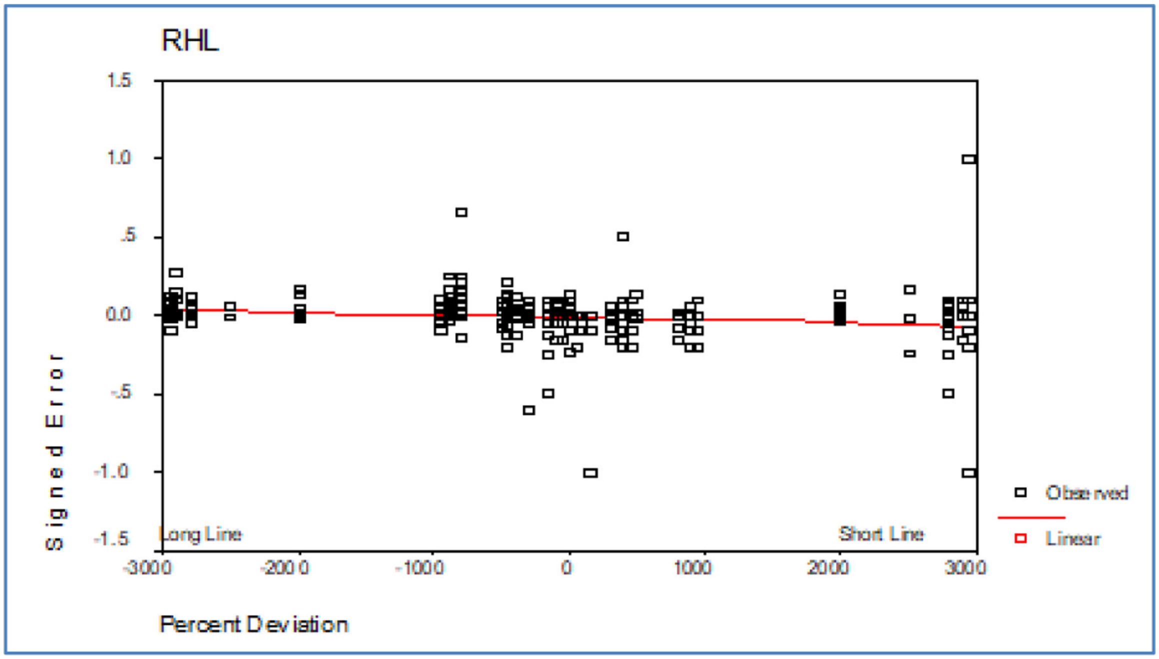

Figure 7.

Association of the signed percent index of context (i.e., percent deviation: (x-axis) with the signed percent error score (i.e., signed error: y-axis) on line bisection for RHL subjects

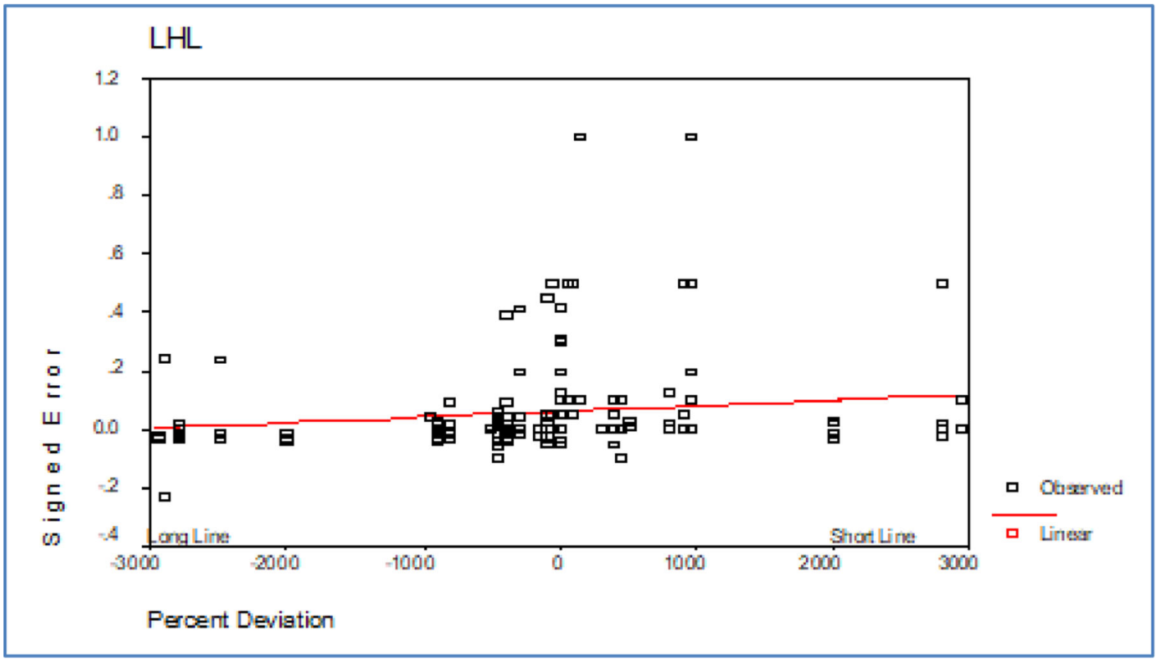

Figure 8.

Association of the signed percent index of context (i.e., percent deviation: (x axis) with the signed percent error score (i.e., signed error: y-axis) on line bisection for LHL subjects

Table 1.

Subject characteristics

Id#	Group	Gender	MMSE	Age	Defect	Hemiparesis	Bisect	Cancel	Clock	DSS	Lesion Location
1	LHL	M	22	66	−	+	−	−	−	+	bg
2	LHL	M	21	36	−	+	+	−	−	+	TP
3	LHL©	F	28	69	−	+	−	−	−	+	
6	LHL	F	26	50	−	+	−	−	−	+	FTP
7	LHL	M	1	66	−	+	+	+	−	−	FTP
10	LHL	F	8	70	−	+	−	−	−	−	FOP
11	LHL©	M	25	56	−	+	−	−	−	−	
12	LHL©	M	10	79	−	+	−	−	−	−	
13	LHL©	M	18	68	−	+	−	+	−	−	
15	LHL	F	?	39	−	−	−	−	−	+	F
16	LHL©	F	24	36	+	−	+	+	−	+	
23	LHL©	F	27	94	−	+	−	−	−	−	
26	LHL	M	?	60	−	+	−	−	−	+	FTOP
31	LHL	M	28	40	−	+	−	−	−	−	FP
32	LHL®	M	13	57	−	+	+	−	−	+	MCA distribution
36	LHL	F	16	89	−	+	+	+	−	+	F
37	LHL©	F	30	50	−	+	−	−	−	−	
38	LHL©	F	19	40	−	+	+	−	−	+	
4	RHL	F	16	62	−	+	+	+	−	+	FTOP
5	RHL	M	26	71	−	+	−	−	+	−	
8	RHL	F	10	82	−	+	−	−	−	−	P
9	RHL	F	17	44	−	+	+	+	+	−	FTOP
14	RHL	M	29	38	−	+	+	−	−	+	FTP
17	RHL	F	21	73	+	−	+	+	−	+	FTOP
18	RHL©	F	24	63	−	+	+	+	+	+	
19	RHL	M	21	57	+	+	−	−	−	−	F
20	RHL	M	19	64	−	+	−	−	−	−	

Id#	Group	Gender	MMSE	Age	Defect	Hemiparesis	Bisect	Cancel	Clock	DSS	Lesion Location
24	RHL	F	26	48	−	+	−	−	−	+	
25	RHL®	M	20	67	−	−	−	−	+	+	MCA distribution
27	RHL	M	23	59	+	+	−	+	+	+	FTOP
28	RHL©	M	21	67	−	+	−	+	−	+	
29	RHL	F	23	56	−	+	+	−	−	−	
30	RHL	F	27	80	−	+	+	+	−	+	bg
33	RHL	F	20	84	−	+	+	+	+	+	
34	RHL	M	17	67	+	+	+	+	−	+	O
35	RHL	M	18	85	−	+	+	+	−	+	bg

® lesion location based on radiology report only

© lesion laterality based on clinical signs only

F: Frontal Lobe; T: Temporal Lobe; O: Occipital Lobe; P: Parietal Lobe; bg: Basal Ganglia

Table 2.

Correlational analysis for line bisection

Group	Stimulus Effect	Context	Perseveration
RHL Patients	r=0.965 *p*<0.001	r=0.18 *p*<0.001	r=0.48 *p*<0.001
Control Subjects	r=0.997 *p*<0.001	r=0.02 *p*>0.05	r=0.01 *p*>0.05

Table 3.

Correlational analysis for loudness estimation

Group	Stimulus Effect	Context	Perseveration
RHL Patients	r=0.419 $p<0.001$	r=0.5 $p<0.001$	r=0.61 $p<0.001$
Control Subjects	r=0.769 $p<0.001$	r=0.01 $p>0.05$	r=0.006 $p>0.05$