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Visuospatial neglect has been observed in the horizontal (left/right) and vertical (up/down) dimension and depends on the distance at which a task is presented (near/far). Previously, studies have mainly focused on investigating the overall severity of neglect in near and far space in a group of neglect patients instead of examining subgroups of neglect patients with different types of distance-specific neglect. We investigated the spatial specificity (near vs. far space), frequency, and severity of neglect in the horizontal and vertical dimensions in a large group of stroke patients. We used three tasks to assess neglect in near (30 cm) and far (120 cm) space: a shape cancellation, letter cancellation, and a line bisection task. Patients were divided into four groups based on their performance: a group without neglect (N–F–), a near only neglect (N+F–), a far only neglect (N–F+), and a near and far neglect group (N+F+). About 40% of our sample showed neglect. Depending on the task, N+F– was observed in 8 to 22% of the sample, whereas N–F+ varied between 8% and 11%, and N+F+ varied between 11% to 14% of the sample. The current findings indicate that horizontal and vertical biases in performance can be confined to one region of space and are task dependent. We recommend testing for far space neglect during neuropsychological assessments in clinical practice, because this cannot be diagnosed using standard paper-and-pencil tasks.

Keywords: Neglect; Stroke; Space; Attention; Cancellation; Line bisection.

Hemispatial neglect, also known as neglect, is a disabling disorder that frequently occurs after right-hemisphere stroke (Bowen, McKenna, & Tallis, 1999; Ringman, Saver, Woolson, Clarke, & Adams, 2004), suggesting a special role for the right hemisphere in spatial attention (Halligan, Fink, Marshall, & Vallar, 2003; Heilman, Watson, & Valenstein, 2003; Shulman et al., 2010). It refers to the failure to report, respond, or orient to stimuli on the contralesional side of space or body that cannot be accounted for by primary sensory or motor deficits (Halligan & Marshall, 1991; Heilman et al., 2003; Robertson, & Halligan 1999). Neglect has been observed in several sensory modalities (visual, auditory, and tactile, e.g., Barbieri & de Renzi, 1989) and is associated with poor functional recovery (Cherney, Halper, Kwasnica, Harvey, & Zhang, 2001; Jehkonen, Laihosalo, & Kettunen, 2006). Spontaneous recovery of neglect appears to occur mainly during the first 12 to 14 weeks after stroke (Nijboer, Kollen, & Kwakkel, in press), although 30% to 40% of the

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neglect patients did not fully recover and still had neglect a year after stroke (Cassidy, Lewis, & Gray, 1998; Jehkonen, Laihosalo, Koivisto, Dastidar, & Ahonen, 2007; Nijboer, Van de Port, Schepers, Post, & Visser-Meily, 2013). Clinical manifestations of neglect vary widely, which is consistent with the idea of neglect being a multicomponent syndrome (Vuilleumier et al., 2008): Patients can experience impairments in visual, auditory, tactile, and/or motor abilities (Bisiach, Cornacchia, Sterzi, & Vallar, 1984; Laplane & Degos, 1983; Pierson-Savage, Bradshaw, Bradshaw, & Nettleton, 1988) in perceptual as well as in representational space (Berti & Frassinetti, 2000; Bisiach & Luzzatti, 1978; Halligan & Marshall, 1991; Meador, Loring, Bowers, & Heilman, 1987; Mennemeier, Wertman, & Heilman, 1992). Perceptual neglect has been linked to lesions in the inferior parietal lobe, whereas lesions in the dorsolateral prefrontal cortex have been associated with visuomotor neglect (Verdon, Schwartz, Lovblad, Hauert, & Vuilleumier, 2010).

Although neglect may be characterized as a disorder in which patients show a spatial attentional bias in the horizontal dimension, this has also been found in the vertical dimension (Pitzalis, Di Russo, Spinelli, & Zoccolotti, 2001; Pitzalis, Spinelli, & Zoccolotti, 1997; Rapcsak, Cimino, & Heilman, 1988). Additionally, the presence and/or severity of (horizontal and vertical) neglect can depend on the distance at which visual information is presented: within reaching distance (i.e., near space) versus beyond reaching distance (i.e., far space; Aimola, Schindler, Simone, & Venneri, 2012; Pitzalis et al., 2001). Several group studies have reported that neglect was more severe in far than in near space, as measured with line bisection paradigms (Cowey, Small, & Ellis, 1994, 1999; Keller, Schindler, Kerkhoff, von Rosen, & Golz, 2005) and visual search paradigms (Butler, Eskes, & Vandorpe, 2004), but the opposite has been found as well, as measured with line bisection and target cancellation tasks (Aimola et al., 2012). The effect of distance on neglect is not always the same across different tasks in the same patient, as was illustrated by a study that showed an influence of distance on severity of neglect on a line bisection task, but not on a cancellation task (Keller et al., 2005). Previc (1998) suggested that different neuroanatomical structures are involved in processing sensory information from near compared to far space. More specifically, the inferior parietal cortex appears to be more involved in near space processing, whereas the superior and medial temporal cortex appear to be more involved in far space processing (for more candidate structures see Table 2 in Previc, 1998). Brain regions that are associated with near and far neglect by means of lesion analyses are in line with this idea of a dorsal (near)–ventral (far) stream distinction (Aimola et al., 2012; Butler et al., 2004).

All in all, these studies suggest that neglect can be present in horizontal (left/right) and vertical (up/down) space and that the presence and/or severity can be influenced by the distance from the observer at which a task is presented (near/far space). However, the influence of distance on the attentional biases in both of these dimensions has not yet been investigated simultaneously in stroke patients. Although previous studies have investigated neglect in near and far space (e.g., Aimola et al., 2012; Pitzalis et al., 2001), they did not measure biases in performance in horizontal and vertical space in the same task, they used relatively small sample sizes, and the samples in these studies consisted predominantly of patients with right-hemisphere lesions, who sometimes suffered from brain tumors. The sample included in the current study contains not only about the same number of patients with left- and right-hemisphere lesions, but also some patients with lesions in both hemispheres. This enables a broader view on the presence of distance-specific neglect in patients with left-sided, right-sided, or bilateral brain damage. Additionally, the presence of brain tumors was an exclusion criterion. The presence and severity of neglect appear to depend on several factors such as (a) the spatial location and orientation of the perceived stimuli, (b) the type of task used to assess neglect, (c) the type of visuospatial operation that is required to perform the test, and (d) the lesion location.

The aim of the current study was to investigate the frequency, spatial specificity (near vs. far space), and severity of neglect in two spatial dimensions (horizontal and vertical space in the cancellation tasks and horizontal space in the line bisection task) in a large sample of stroke patients. In addition, we investigated the relation between the various visuospatial operations in different regions of space and in what way neglect on a specific task was related to neglect on another task.

METHOD

Participants

The criteria for admission in a rehabilitation center in the Netherlands are: (a) the patient cannot be discharged home, but is expected to return home in view of the prognosis and availability of the caregivers; (b) the patient is able to learn and is sufficiently motivated; (c) the patient has sufficient vitality; (d) the rehabilitation goals are complex and need a multidisciplinary approach; (e) return to work may be possible; and (f) a relatively high rate of rehabilitation is possible. A group of 109 participants (61 without neglect, 48 with neglect on at least one task) were selected from stroke patients consecutively admitted for inpatient rehabilitation to Rehabilitation Center De Hoogstraat located in Utrecht in The Netherlands, according to the following inclusion criteria: (a) age between 18 and 85 years; (b) no severe deficits in communication and/or understanding; (c) normal or corrected-to-normal visual acuity; and (d) the ability to perform at least two tasks from our near/far neglect screening at both distances. An overview of the characteristics of the neglect and no neglect group is shown in Table 1. The groups did not differ in terms of time post stroke in weeks, $t(61.00) = -1.55$, $p = .13$, age, $t(107) = 0.35$, $p = .73$, sex, $\chi^2(1) = 0.60$, $p = .44$, the number of left- and right-hemisphere lesions, $\chi^2(1) = 2.66$, $p = .103$, Barthel Index score, $t(82) = 0.31$, $p = .76$, and Mini-Mental State Examination (MMSE) score, $t(61) = -0.29$, $p = .77$.

There are currently no normative data for our screening tasks. To be able to indicate whether the performance of patients deviated from healthy individuals, we needed to compare their performance with a sample of healthy control subjects. Therefore, we recruited 28 healthy individuals (16 male, mean age = 42.32 years, $SD = 20.31$) as a control group for performance on the shape cancellation, letter cancellation, and line bisection tasks in both near and far space.

TABLE 1
Characteristics per group

Clinical variables	*Results neglect (SE)*	*Results no neglect (SE)*
Group size	61	48
Time post stroke (weeks)	13.14 (5.49)	4.58 (0.50)
Age in years	58.25 (1.59)	59.06 (1.74)
Gender (% male)	66	58
Hemisphere of stroke		
Left hemisphere (*N*)	22	24
Right hemisphere (*N*)	37	21
Both (*N*)	2	2
Unknown (*N*)	0	1
Barthel index	14.69 (2.61)[a]	15.86 (2.53)[b]
MMSE	26.49 (0.60)[c]	26.19 (0.86)[d]

Note. Neglect versus no neglect. Patients in the no neglect group did not show neglect on any of the tasks. MMSE = Mini-Mental State Examination.
[a]Information on the Barthel index was available from 80% of the neglect group. [b]Information on the Barthel index was available from 73% of the no neglect group. [c]Information on the MMSE was available from 61% of the neglect group. [d]Information on the MMSE was available from 54% of the no neglect group.

Stimuli, task, and procedure

To test for the spatial specificity, frequency, and severity of neglect, a neglect screening was administered to all patients. Spatial specificity was defined in terms of whether a patient showed neglect in a single region of space (i.e., near or far only) or in both regions of space (i.e., near and far). The procedure that we used to indicate whether a patient showed neglect in a region of space is described in the *Data Preprocessing* section. The neglect screening included three tasks that are often used to test for the presence of neglect in the clinical practice: two target cancellation tasks (shape cancellation, letter cancellation) and a line bisection task. Each task was performed in two conditions. In the near space condition, stimuli were presented on a monitor at a distance of approximately 30 cm, whereas in the far space condition the stimuli were presented on a monitor at a distance of approximately 120 cm. Stimuli were enlarged in the far space condition to control for visual angle. The order of the tasks and the distance at which a task was first presented was randomized across patients. All subjects (i.e., patients and healthy control subjects) were tested individually in a quiet room, were seated in front of a monitor, and received specific instructions per task.

The shape cancellation task consisted of a field of 54 targets shapes (0.6° × 0.6°) among 75 distractor shapes of various sizes (with widths ranging from 0.95° to 2.1° and heights ranging from 0.45° to 0.95°). The stimulus presentation was corrected for visual angle and was approximately 18.5° wide and 11° high at both distances. Subjects were instructed to find all the target shapes presented on the screen and to click on them. A circle appeared on the screen around the location of each mouse click and remained on screen during the test.

The letter cancellation task consisted of five strings of 34 letters (0.6° × 0.6°). The stimulus presentation was controlled for visual angle and was approximately 19° wide and 5.7° high at both distances. Subjects were asked to cross out 40 target letters among the distractor letters, by moving the cursor with a mouse and clicking on the target letters. A circle appeared on the screen around the location of each mouse click and remained on screen during the task.

The line bisection task consisted of three horizontally oriented lines that were evenly distributed across the screen in vertical space. The middle line was presented in the horizontal and vertical center of the screen, the top line was presented above the vertical center of the screen and shifted to the right, whereas the bottom line was presented below the vertical center of the screen and shifted to the left. The amount of vertical shift was always 28% of the line length, and the amount of horizontal shift was always 15% of the line length in both near and far space. Lines were controlled for visual angle and were approximately 22° long and 0.2° thick. Subjects were asked to indicate the center of each line by moving the cursor with the mouse and clicking on the subjective midpoint of each line, starting at the topmost line and working their way down. This task was performed four times in a row, resulting in a total of 12 lines presented in each region of space.

When a patient could not use the dominant hand (e.g., due to hemiplegia, hemiparesis, etc.), the nondominant hand was used. This was feasible as they were accustomed to work with their nondominant hand during other rehabilitation programs (e.g., physical therapy, occupational therapy, etc.).

Data preprocessing

For the cancellation tasks we used a difference score of the amount of omissions between the left and the right part of the stimulus field of at least two as a rough indication of neglect. We based this difference score on the average difference score of the healthy control subjects plus three standard deviations. On the shape cancellation task the average difference score of the control group was 0.107 (SD = 0.32) in near space and 0.04 (SD = 0.19) in far space. The three-standard-deviation cut-off was 1.05 in near and 0.60 in far space on the shape cancellation task. On the letter cancellation task, the average difference score of the control group was 0.25 (SD = 0.52) in near space and 0.21 (SD = 0.50) in far space. This resulted in a three-standard-deviation cut-off of 1.81 in near space and 1.71 in far space on the letter cancellation task. A difference score of at least two omissions falls outside of the normal range of our healthy control group on both the shape and the letter cancellation, and we therefore used this as an indication of neglect. This method of establishing a normal range for each task has also been reported in other studies (e.g., Stone et al., 1991). Our specific cut-off is also in line with other studies in which a difference score of at least two was used to provide an indication of neglect (e.g., Nijboer, Kollen, et al., in press; Nijboer, Van de Port, et al., 2013). We divided patients into four groups based on whether their difference score indicated neglect or not: no neglect (N–F–), neglect in near space only (N+F–), neglect in far space only (N–F+), or neglect at both distances (N+F+).

The horizontal and vertical normalized center of cancellation (respectively, CoC-x and CoC-y) was calculated for both cancellation tasks based on all the targets in a task (Rorden & Karnath, 2010). The CoC takes both the *amount* and the *location* of cancelled targets into account. It is therefore more indicative than the number of omissions in each half of the stimulus field. CoC-x and CoC-y scores could range from –1 to 1. When targets are missed in the upper left corner of the stimulus field, the CoC-x shifts to the right (closer to 1), and the CoC-y shifts down (closer to –1). In contrast, when targets are missed in the lower right part of the stimulus field, the CoC-x shifts to the left (closer to –1), and the CoC-y shifts up (closer to 1). A CoC-x or y score of zero indicated that there was no spatial bias in the number of missed targets. To analyze the CoC-x and y, we used the absolute value of the normalized CoC, because our sample contained both patients with left-sided neglect and those with right-sided neglect. Left-sided neglect would result in positive CoC-x values, and right-sided neglect would result in negative CoC-x values. Analyzing the CoC on a group level without using absolute values would distort the results, because positive values will cancel out negative values, and this would not show the overall effect of spatial bias in patients with neglect. Analyzing both the CoC-x and y allowed to us to investigate biases in both horizontal and vertical space. We presented the task in both near and far space, and this allowed us to analyze performance in three dimensions for each cancellation task.

To analyze performance on the line bisection, we calculated the deviation between the actual center and the subjective midpoint of each line in degrees of visual angle. Next, we calculated the average deviation on all 12 lines in each region of space and compared this to the control group of 28 healthy control subjects. Negative deviation values indicated a shift of the subjective midpoint to the left of the actual center, whereas positive deviation values indicated a shift to the right of the actual center. As on the cancellation tasks, performance indicated neglect when the average score of a patient was outside the normal range of the control group (mean ± 3 SDs) in a region of space. In the control group the average deviation from the actual center was –0.13 degrees of visual angle (SD = 0.20°) in near space and –0.15 degrees of visual angle (SD = 0.24°) in far space. The normal range (mean ± 3 SDs) was between –0.74 and 0.48 degrees of visual angle in near space and between –0.86 and 0.56 degrees of visual angle in far space. Patients were divided into neglect groups based on whether their average deviation score fell outside the normal range in a region of space. This again resulted in four groups: patients without neglect (N–F–), with neglect in near space only (N+F–), with neglect in far space only (N–F+), or with neglect at both distances (N+F+). To further analyze the results of the line bisection task we then used the absolute values of the average deviation from the center, because of the same reasons that were mentioned before (i.e., the sample contained patients with left- and right-sided neglect). We included the line bisection task in the current study to investigate the influence of distance on neglect using a more perceptual task and to be able to compare performance of patients in near and far space between cancellation and bisection tasks.

Statistical analyses

For each task, a 2×4 mixed repeated measures analysis of variance (ANOVA) was done with space (near/far) as within-subjects factor and neglect type (N–F–/N+F–/N–F+/N+F+) as between-subject factor. In order to gain power for the analyses, we analyzed both patients with left-sided neglect and those with right-sided neglect together. Thus we used the *absolute* values of the CoC-x and CoC-y as dependent variables in the analyses of the cancellation tasks. Although the relation between neglect type and CoC-x may appear circular because the groups are based on a difference score of missed targets in the left and right part of the task, this is not the case. A difference score of, for example, two can lead to totally different CoC-x values, depending on the location of the missed targets. We also used the absolute value of the average deviation in degrees of visual angle from the center of the line in the analysis of the line bisection test for the same reasons as on the cancellation tasks. It is important to note that the absolute values now only reflect the severity of imbalance in performance on the cancellation tasks and only the amount of deviation from the center of the line, not its direction (to the left or the right). Whenever a main effect of space or the interaction between space and neglect type was significant, three independent t tests were done for each region of space to compare the performance of each neglect group to the N–F– group in that region. For each of the tasks, we also compared the performance of the N–F– group (brain damage, but no neglect) with that of the healthy control group using independent-samples t tests to investigate whether their performance on each of the tasks was within the normal range.

To investigate whether the allocation of patients to different neglect types differed across tasks, we performed a Pearson chi-squared test on the frequencies of neglect in each group on each of the three tasks post hoc. There are conflicting findings on the influence of lesion location (left vs. right hemisphere) on the severity of neglect for cancellation tasks with either verbal (i.e., letters) or nonverbal stimuli (i.e., shapes). Some researchers observed more severe neglect for nonverbal stimuli after right-sided lesions than for verbal stimuli (e.g., Leicester, Sidman, Stoddard, & Mohr, 1969; Weintraub & Mesulam, 1988), whereas others found no differences (e.g., Caplan, 1985). To investigate the relation between the hemisphere of stroke and the presence of neglect on the shape and the letter cancellation, we performed a post hoc Pearson chi-squared test on the neglect frequency after left- and right-hemisphere lesions.

All reported p values of the follow-up tests are two-tailed and Bonferroni corrected for the number of comparisons with the formula described in Motulsky (1995): $p = 1 - (1 - p)^n$.

RESULTS AND DISCUSSION

Frequency of neglect types

In total, 107 patients were tested with the shape cancellation test, whereas 81 patients were tested with the letter cancellation test, and 82 patients were tested with the line bisection test. Based on their difference score on the shape cancellation task, 30% of the patients were diagnosed with neglect, whereas this was 47% on the letter cancellation test, and 30% on the line bisection test. Note that the total number of patients that was assessed differs for each of the tasks, and that neglect type could differ across tasks (see the *Neglect Consistency* section). Overall, approximately 72% of the patients that showed neglect on the shape cancellation task had an impaired performance in far space (the percentage of patients with N–F+ and N+F+), whereas this was approximately 53% on the letter cancellation task, and 64% on the line bisection task. The percentage of patients that had neglect in near space (the percentage of patients with N+F– and N+F+) was 72% on the shape cancellation task, 76% on the letter cancellation task, and 72% on the line bisection task. The percentages of patients in each of the groups on each of the tasks are shown in Table 2. The results of the Pearson chi-squared test on the frequencies of distance-specific neglect diagnoses (N–F–, N+F–, N–F+, N+F+) on each of the tasks indicated

TABLE 2
Percentage of patients in each group on the three tasks

Group	*Shape cancellation (N = 107)*	*Letter cancellation (N = 81)*	*Line bisection (N = 82)*
N–F–	70	53	70
N+F–	8	22	11
N–F+	8	11	9
N+F+	14	14	11

Note. N–F– = without neglect, N+F– = near only neglect, N–F+ = far only neglect, N+F+ = near and far neglect.

TABLE 3
Percentage of patients with left- and right-sided neglect in each neglect group on the three tasks

Task	*Side*	*N+F–*	*N–F+*	*N+F+*
Shape cancellation	Left	56	38	87
	Right	44	63	13
Letter cancellation	Left	50	44	55
	Right	50	57	37
Line bisection	Left	22	86	89
	Right	78	14	11

Note. N+F– = near only neglect, N–F+ = far only neglect, N+F+ = near and far neglect. One patient showed an inconsistent pattern on the letter cancellation task: right-sided neglect in near space, and left-sided neglect in far space.

that the distribution of frequencies across neglect types did not differ across tasks, $\chi^2(1) = 10.61$, $p = .10$.

Table 3 shows the percentage of patients with left- and right-sided neglect based on difference scores and the nonabsolute values on the three tasks. As can be seen from this table, predominantly left-sided neglect was observed in the N+F+ group, whereas no clear pattern was observed in the region-specific groups (N+F–, N–F+). To be able to analyze the performance of both left- and right-sided neglect patients, absolute performance measures were used.

Spatial specificity and severity of neglect

As mentioned above, spatial specificity is defined by the presence of neglect in a region. We used difference scores on the cancellation tasks to create distance-specific neglect groups and analyzed the horizontal and vertical CoC of these groups to investigate whether the performance between groups was significantly different on this more subtle measure. Severity of neglect is reflected by the CoC value, with numbers closer to 1 or –1 indicating that performance is more lateralized.

Shape cancellation

The characteristics of each of the four groups based on the performance on the shape cancellation task are shown in Table 4. The groups did not differ in terms of time post stroke in weeks, $F(3, 103) = 0.07$, $p = .97$, age, $F(3, 103) = 0.15$, $p = .93$, sex, $\chi^2(1) = 0.76$, $df = 3$, $p = .89$, and the number of left- and right-hemisphere lesions, $\chi^2(1) = 4.95$, $p = .184$. A repeated measures ANOVA for the absolute CoC-x showed a significant main effect of space, $F(1, 103) = 4.21$, $p = .04$, indicating that patients deviated more from the horizontal center in near space (mean absolute CoC-x = .05, SE = .01) than in far space (mean absolute CoC-x = .04, SE = .01) by missing targets either on the left or on the right part of the stimulus field. The results also revealed a significant main effect of neglect type, $F(3, 103) = 26.52$, $p < .001$, showing that the neglect groups differed in their performance on the test. The N+F+ group showed the largest average deviation from the horizontal center (mean absolute CoC-x = .137, SE = .01) compared to the other three groups. The performance of the N–F– group did not differ from the healthy control group on the absolute CoC-x in near, $t(101) = 0.89$, $p = .38$,

TABLE 4
Characteristics of each of the groups that are based on the performance on the shape cancellation task

	Results			
Clinical variables	*N–F– (SE)*	*N+F– (SE)*	*N–F+ (SE)*	*N+F+ (SE)*
Group size	75	9	8	15
Time post stroke in weeks	10.41 (3.82)	7.29 (11.02)	6.09 (11.69)	7.87 (8.53)
Age in years	58.61 (1.43)	60.22 (4.12)	56.25 (4.37)	58.27 (3.19)
Gender (*N* male)	48	5	5	8
Hemisphere of stroke				
Left hemisphere (*N*)	33	2	5	4
Right hemisphere (*N*)	37	7	3	11
Both (*N*)	4	—	—	—
Unknown (*N*)	1	—	—	—

Note. N–F– = without neglect, N+F– = near only neglect, N–F+ = far only neglect, N+F+ = near and far neglect.

TABLE 5
Average values for each condition and each group of the absolute CoC-x and y on the shape cancellation task in near and far space

Group	*Near abs. CoC-x*	*Far abs. CoC-x*	*Near abs. CoC-y*	*Far abs. CoC-y*
N–F–	.004 (.007)	.001 (.004)	.006 (.011)	.003 (.005)
N+F–	.046 (.056)	.006 (.012)	.038 (.021)	.003 (.005)
N–F+	.004 (.007)	.030 (.016)	.005 (.005)	.017 (.012)
N+F+	.159 (.164)	.115 (.151)	.038 (.036)	.040 (.033)

Note. N–F– = without neglect, N+F– = near only neglect, N–F+ = far only neglect, N+F+ = near and far neglect. CoC-x and CoC-y = horizontal and vertical normalized center of cancellation, respectively. abs. = absolute. Standard errors in parentheses.

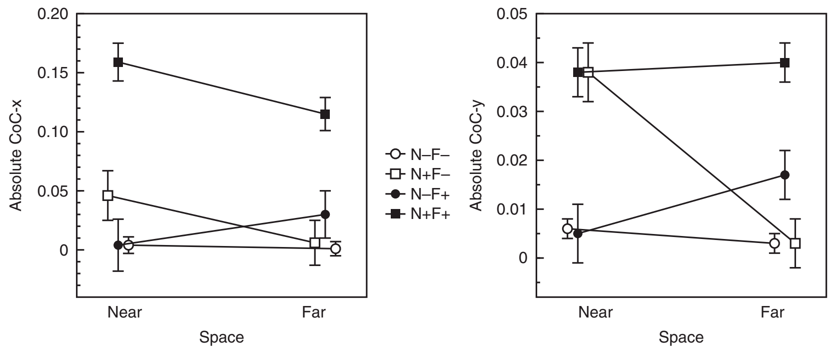

Figure 1. Average absolute CoC-x (left panel) and CoC-y (right panel) for each group at both distances for the shape cancellation task. CoC-x and CoC-y = horizontal and vertical normalized center of cancellation, respectively. N–F– = without neglect, N+F– = near only neglect, N–F+ = far only neglect, N+F+ = near and far neglect. Error bars depict standard error of the mean.

and in far space, $t(74) = 0.71$, $p = .48$. The average values for the absolute CoC-x and -y for each neglect group and each region of space are shown in Table 5.

More importantly, we found a significant interaction between space and neglect type, $F(3, 103) = 4.74$, $p < .01$. The mean absolute CoC-x for each group in each region of space on the shape cancellation task is shown in Figure 1 (left panel). We used planned comparisons to compare the performance of each of the neglect groups with the N–F– group in each region of space (because of the main effect of space and the interaction between space and neglect type). Surprisingly, the N+F– group did not significantly deviate from the N–F– group, $t(8.03) = –2.28$, $p = .15$, uncorrected $p = .05$. As expected, the performance of the N–F+ group did not significantly differ from that of the N–F– group in near space, $t(8.28) = –0.27$, $p = .99$, and performance of the N+F+ group did significantly differ from that of the N–F– group, $t(14.01) = –3.66$, $p < .01$. The N+F– group did not differ from the N–F– group in far space, $t(8.18) = –1.22$, $p = .53$, whereas the N–F+ and the N+F+ group did: respectively, $t(7.08) = –5.00$, $p < .01$, and $t(14.00) = –2.92$, $p = .03$.

For the absolute CoC-y, we found a main effect of space, $F(1, 103) = 5.73$, $p = .02$, and neglect type, $F(3, 103) = 29.70$, $p < .01$, driven by an interaction between space and neglect type, $F(3, 103) = 12.11$, $p < .01$. Patients' absolute CoC-y deviated slightly more from the vertical center in near (mean absolute CoC-y = 0.02, SE = 0.002, than in far space (mean absolute CoC-y = 0.02, SE = 0.002). The N+F+ group showed the largest deviation from the vertical center (mean absolute CoC-y = 0.04, SE = 0.003) followed by the N+F– group (mean absolute CoC-y = 0.02, SE = 0.004), the N–F+ group (mean absolute CoC-y = 0.01, SE = 0.005), and the N–F– group (mean absolute CoC-y = 0.004, SE = 0.002). The performance of the N–F– group did not differ from that of the healthy control group on CoC-y in near, $t(101) = –0.58$, $p = .56$, and in far space, $t(28.81) = 0.76$, $p = .45$. The average absolute CoC-y for each group in each region of space on the shape cancellation task is shown in Figure 1 (right panel, note the difference in scale of the y-axis compared to the left panel).

To further investigate the interaction between space and neglect type, we used planned comparisons to compare performance between each of the neglect groups and the N–F– group in each region of space. In near space, the N+F– group deviated from the N–F– group, $t(8.54) = –4.33$, $p < .01$, as did the N+F+ group, $t(14.54) = –3.34$, $p = .02$, but not the N–F+ group, $t(81) = 0.35$, $p = .98$. In far space, the N–F+ group and the N+F+ group deviated significantly from the N–F– group, $t(7.49) = –3.24$, $p = .04$, and $t(14.25) = –4.34$, $p < .01$, respectively, but the N+F– group did not, $t(11.48) = –0.22$, $p = .86$.

In sum, we observed that performance of patients with neglect could be impaired in the horizontal and in the vertical dimension, and that this impairment could be present in both regions of space (near and far), or in only one region of space (near or far). In addition, when performance was impaired in both regions of space, the horizontal bias was more severe than when performance was impaired in only one region of space.

Letter cancellation

A repeated measures ANOVA on the absolute CoC-x showed no significant effect of space, $F(1, 77) = 0.02$, $p = .89$, and no significant interaction between space and neglect type, $F(3, 77) = 2.59$, $p = .06$. A significant main effect of neglect type, $F(3, 77) = 18.17$, $p < .01$, was obtained. In line with the SC, the N+F+ group showed the largest deviation from the horizontal center (mean absolute CoC-x = .12, SE = .01) followed by the N–F+ group (mean absolute CoC-x = .03, SE = .02), the N+F– group (mean absolute CoC-x = .03, SE = .01), and the N–F– group (mean absolute CoC-x = .01, SE = .01). All three neglect groups performed significantly different from the N–F– group (all $p < .05$). The performance of the N–F– group did not differ from the healthy control group on CoC-x in near, $t(69) = –0.92$, $p = .36$, and in far space, $t(69) = –0.19$, $p = .85$. Although the interaction between space and neglect type was not significant, the means of each group showed the same interaction pattern as that on the shape cancellation task and are shown in Figure 2 (left panel; note that the groups do not consist of the same patients as those on the shape cancellation test, see section *Neglect Consistency*). The average values of the absolute CoC-x and y for near and far space and for each region of space are shown in Table 6.

On the absolute CoC-y, a significant main effect of space, $F(1, 77) = 15.49$, $p < .01$, and neglect type, $F(3, 77) = 23.17$, $p < .01$, was obtained, as well as a significant interaction between space and neglect type, $F(3, 77) = 4.55$, $p < .01$. On average, patients deviated more from the vertical center in near space (mean absolute CoC-y = 0.06, SE = 0.007) than in far space (mean absolute CoC-y = 0.03, SE = 0.003). The largest deviation from the vertical center of the stimulus field was found in the N+F+ group (absolute CoC-y = 0.10, SE = 0.009), followed by the N–F+ group (absolute CoC-y = 0.04, SE = 0.010), the N+F–

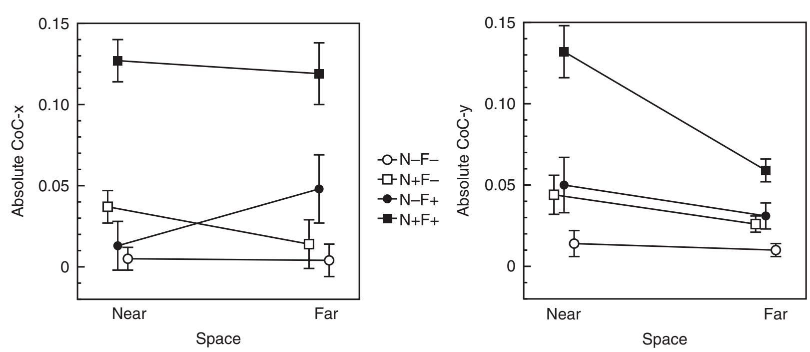

Figure 2. Average absolute CoC-x (left panel) and CoC-y (right panel) for each group at both distances for the letter cancellation task. CoC-x and CoC-y = horizontal and vertical normalized center of cancellation, respectively. N–F– = without neglect, N+F– = near only neglect, N–F+ = far only neglect, N+F+ = near and far neglect. Error bars depict standard error of the mean.

TABLE 6
Average values for each condition and each group on the absolute CoC-x and y on the letter cancellation task in near and far space

Group	*Near abs. CoC-x*	*Far abs. CoC-x*	*Near abs. CoC-y*	*Far abs. CoC-y*
N–F–	.005 (.007)	.004 (.010)	.014 (.008)	.010 (.004)
N+F–	.037 (.010)	.014 (.015)	.044 (.012)	.026 (.005)
N–F+	.013 (.015)	.048 (.021)	.050 (.017)	.031 (.008)
N+F+	.127 (.013)	.119 (.019)	.132 (.016)	.059 (.007)

Note. N+F– = near only neglect, N–F+ = far only neglect, N+F+ = near and far neglect. CoC-x and CoC-y = horizontal and vertical normalized center of cancellation, respectively. abs. = absolute. Standard errors in parentheses.

group (absolute CoC-y = 0.04, *SE* = 0.007), and the N–F– group (absolute CoC-y = 0.01, *SE* = 0.005). The performance of the N–F– group did not differ from that of the healthy control group on CoC-y in near, $t(67.93) = 0.35$, $p = .73$, and in far space, $t(69) = -1.00$, $p = .32$.

The interaction between space and neglect type indicated that the amount of deviation from the vertical center depended both on the region of space in which the task was performed and on the group in which the patient was placed based on the difference score of at least two omissions between the left and the right part of the stimulus field. The mean absolute CoC-y for each group in near and far space is shown in Figure 2 (right panel).

Planned comparisons in each region of space were done to compare the absolute CoC-y between each of the neglect groups and the N–F– group. In near space the N+F– group deviated significantly from the N–F– group, $t(21.85) = -3.17$, $p = 0.01$, as did the N+F+ group, $t(10.17) = -3.29$, $p = .02$, but not the N–F+ group, $t(8.45) = -1.80$, $p = .29$.[1] In far space the N+F– group did not deviate from the N–F– group, $t(21.81) = -2.16$, $p = .12$ (see Footnote 1), whereas the N–F+ group, $t(11.36) = -3.34$, $p = .02$, and the N+F+ group, $t(11.10) = -4.39$, $p < .01$, did.

To summarize, the results of the letter cancellation indicate that the horizontal spatial bias in near and far space did not differ between groups. However, the pattern of horizontal bias in near and far space for each of the groups was similar to what we observed on the shape cancellation task. The performance of patients with neglect in both regions of space was more impaired than that of patients with neglect in one region of space. Despite the lack of differences in horizontal bias, we did find differences in vertical spatial bias in near and far space between groups. Interestingly, the group with neglect in both regions of space showed a more severe bias in the vertical dimension in near space than in far space, whereas the groups with neglect in one region only showed approximately the same amount of vertical bias in near and far space.

Hemisphere of lesion and cancellation content

The frequency of neglect after left- and right-sided lesions was not related to the content of the cancellation task (verbal vs. nonverbal) that was used to measure neglect, $\chi^2(1) = 0.72$, $p = .40$. The percentages of neglect after left- and right-sided brain lesions were about the same across the two cancellation tasks: shape cancellation, left 34% versus right 66%; letter cancellation, left 25% versus right 75%. These differences in occurrence of neglect between left- and right-sided lesions are in line with the literature (see Bowen et al., 1999).

Line bisection

The repeated measures ANOVA revealed a significant main effect of space, $F(1, 78) = 39.23$, $p < .01$, and neglect type, $F(3, 78) = 21.30$, $p < .01$. On average, patients deviated more from the center of the lines in far space (mean absolute deviation = 1.19°, *SE* = 0.12°) than in near space (mean absolute deviation = 0.88°, *SE* = 0.12°). The N+F+ group showed the largest deviation (mean absolute deviation = 2.45°, *SE* = 0.26°), followed by the N–F+ group (mean absolute deviation = 0.74°, *SE* = 0.29°), the N+F– group (mean absolute deviation = 0.69°, *SE* = 0.26°), and the N–F– group (mean absolute deviation = 0.26°, *SE* = 0.10°). The absolute average deviation in degrees from the center of the line in each region of space and for each group is shown in Table 7. The average absolute deviation from the center in the healthy control group was 0.23° (*SE* = 0.03°) in near space and 0.21 (*SE* = 0.05°) in far space. The performance of the N–F– group did not differ from that of the healthy control group in near, $t(83) = -0.04$, $p = .97$, and in far space, $t(83) = 0.31$, $p = .76$.

More importantly, we found a significant interaction between space and neglect type, $F(3, 78) = 38.79$, $p < .01$. To examine the interaction more closely, several planned independent *t* tests for near space and far space were done. In near space, the N+F– group performed significantly worse than the N–F– group, $t(64) = -11.08$, $p < .01$, but not

TABLE 7
Average values for each condition and each group for the absolute deviation from the center in degrees of visual angle on the line bisection task in near and far space

Group	*Near abs. deviation from center (degrees)*	*Far abs. deviation from center (degrees)*
N–F–	0.247 (0.102)	0.278 (0.105)
N+F–	0.926 (0.258)	0.451 (0.264)
N–F+	0.225 (0.292)	1.250 (0.300)
N+F+	2.120 (0.258)	2.785 (0.264)

Note. N–F– = without neglect, N+F– = near only neglect, N–F+ = far only neglect, N+F+ = near and far neglect. abs. = absolute. Standard errors in parentheses.

[1] Levene's Test for Equality of Variances indicated that the variance between the respective groups was not equal. We therefore used the adjusted *t*-value and degrees of freedom in this *t* test, resulting in a less significant *p*-value, which was then also Bonferroni corrected.

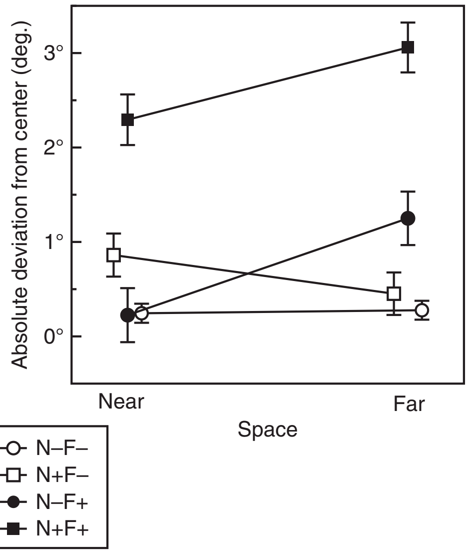

Figure 3. Average absolute deviation from the center of the line in degrees of visual angle for each group for both distances on the line bisection task. N–F– = without neglect, N+F– = near only neglect, N–F+ = far only neglect, N+F+ = near and far neglect. Error bars depict standard error of the mean.

the N–F+ group, $t(62) = 0.34$, $p = .98$, and the N+F+ group, $t(8.01) = -2.37$, $p = .13$. In far space, the performance of the N+F– group did not differ from that of the N–F– group, $t(64) = -2.35$, $p = .07$, whereas the N–F+ and the N+F+ group did, $t(6.46) = -6.80$, $p < .01$, and $t(8.02) = -3.15$, $p = .04$, respectively. The mean line bisection performance of each group in each region of space is shown in Figure 3 and shows again the same interaction pattern as that seen on the shape and letter cancellation tasks (note that the groups do not consist of the same patients; see the next section).

Neglect consistency

To investigate whether neglect was consistent across tasks, we examined how many patients consistently showed neglect on each of the tasks. In order to do so, we selected those patients that performed all neglect tasks (shape cancellation, letter cancellation, line bisection) in each region of space ($N = 65$). Of these 65 patients that performed each task of the screening (shape cancellation, letter cancellation, line bisection), 37% did not show neglect on any of the tasks, 32% showed neglect on only one task, 15% of these patients showed neglect on two tasks, and another 15% of these patients showed neglect on three tasks. Of the patients that showed neglect on one task, 90% had neglect in one region of space (N+F– or N–F+). Of the patients that showed neglect on three tasks, 50% had neglect in both regions of space (N+F+), whereas the other 50% had a different type of neglect on at least one of the tasks (e.g., N+F+ on the shape cancellation and line bisection, yet N+F– on the letter cancellation). The results indicate that neglect for one region of space is often found on one specific task, whereas neglect for both regions of space is often found on several tasks. The latter might be due to more severe neglect in the N+F+ group (as shown by the results from each of the tasks), resulting in more consistent performance impairments.

GENERAL DISCUSSION

The aim of the current study was to investigate the frequency, spatial specificity (near vs. far space), and severity of neglect in two spatial dimensions in a large sample of stroke patients. We tested patients in two regions of space (near: 30 cm vs. far space: 120 cm) with three frequently used tasks for measuring neglect (a shape cancellation, a letter cancellation, and a line bisection task). We analyzed biases in both the horizontal and the vertical dimension for the cancellation tasks.

With respect to the frequency of neglect, approximately 40% of the patients were diagnosed with neglect, depending on the task that was used to assess neglect. Although there is a large variation in the reported frequency of neglect, our findings are in line with the percentage of neglect frequency as reported by Bowen and colleagues (1999) in their systematic review. The current results also indicate that the presence and the severity of neglect can depend on the distance at which a task is presented as well as on the type of task that is used to test for neglect. Patients could have neglect in only one region of space, or in both regions of space. This has also been observed in previous (small group) studies in which the influence of distance on neglect was investigated (e.g., Aimola et al., 2012; Halligan & Marshall, 1991; Vuilleumier, Valenza, Mayer, Reverdin, & Landis, 1997). Of the patients with neglect, the percentage of patients with neglect at one distance (N+F– or N–F+) varied between 8% and 22%, and the percentage of patients with near and far neglect (N+F+) varied between 11% and 14%, depending on the task that was used to assess neglect. A rather large part of the patients showed far neglect (25% N–F+ and 47% N+F+ based on the shape cancellation task). Far space neglect is often not assessed in clinical practice, and our results indicate that a large proportion of patients with neglect may have an attentional impairment for stimuli presented in far space. Even more important, about one fourth of the patients with neglect were impaired in far space only (N–F+), which we would not be able to identify when these patients were tested in near space only with paper-and-pencil tasks.

Interestingly, the patients with neglect showed not only a horizontal spatial bias (an imbalance in the number of missed targets between the left and right part of the visual field in the cancellation tasks), but also a vertical spatial bias (an imbalance in the number of missed targets between the upper and lower part of the task in the cancellation tasks). Vertical neglect has been found before (Butter, Evans, Kirsch, & Kewman, 1989; Halligan & Marshall, 1989; Pitzalis et al., 1997), but our results indicate that horizontal and vertical attentional biases can co-occur.

Concerning the severity of neglect, in general, patients with neglect at both distances (N+F+), showed more severe neglect than patients that showed neglect at one distance (N+F– or N–F+). The severity of neglect was approximately the same for the near and the far neglect groups. A correlation between the size of a brain lesion and the severity of neglect has been reported previously (Leibovitch et al., 1998). Leibovitch and colleagues suggested that this relation might be the result of damage to more areas that are involved in attentional processing. The dorsal and ventral streams have been associated with the processing of information coming from near and far space (Previc, 1998) and with action and perception (Milner & Goodale, 2008), respectively. On a speculative basis, we suggest that patients with neglect in both near and far space may have larger lesions that include both parietal (dorsal) and temporal (ventral) cortical regions that are involved in near and far space attentional processing (Previc, 1998). On the other hand, patients with neglect confined to one region of space may have smaller lesions that include only one of these areas (e.g., Aimola et al., 2012; Butler et al., 2004). Different neglect tasks may depend more heavily on either action or perception, and therefore more on one of the two streams. A brain lesion might affect either one or both of the streams, which may result in different performance impairments across tasks.

In line with this reasoning, patients in one of the neglect groups based on one task were often not found in the same neglect group on another task. This was especially true for the N+F– and the N–F+ group. There was a higher consistency of neglect type across tasks when patients had both near and far neglect, which might be because their performance was worse than that of the single space neglect groups. These findings are in agreement with a previous study in which it was shown that the correlation between performance on cancellation and line bisection tasks is generally low (Schubert & Spatt, 2001). This might be the result of different operations that are required to perform the task. Cancellation tasks might depend more on visual exploration and require a dominant motor response (hence the term cancellation), whereas line bisection tasks may depend more on a perceptual estimation with a less dominant motor component. This difference might explain why some patients showed neglect on one task, but not on another task, suggesting that their neglect is only present when certain operations are required. This was also reported by Keller and colleagues (2005), who found no influence of distance on severity of neglect on a cancellation task, whereas they did find an effect of distance on performance on a line bisection task in the same patients. We found that the severity of neglect depended on distance in both cancellation and line bisection tasks, but most often not within the same patient.

Although we did not test for the presence of hemianopia, we do not expect that patients with visual field deficits influenced the current results. We know that hemianopia (one of the common visual field defects, Suchoff et al., 2008) can cause a contralateral line bisection bias, and that performance on cancellation tasks is not lateralized in patients with hemianopia (Barton & Black, 1998; Doricchi, Onida, & Guariglia, 2002). Still, we would not expect a difference in the bisection bias between near and far space on a line bisection task, because we corrected the lines that needed to be bisected for visual angle. More importantly, the amount of deviation from the center in patients with hemianopia may be larger than that in healthy subjects but is smaller than that in patients with neglect (Barton & Black, 1998). In this study, we used the mean bisection bias ± 3 standard deviations of a healthy control group as a cut-off for neglect. In other studies, the performance of hemianopia patients fell within a 3-standard-deviation range from the mean of their control group (Barton & Black, 1998; Doricchi et al., 2002). We therefore assume that the performance on the line bisection of any patient with hemianopia in our sample was below the cut-off and was therefore not included in any of the neglect groups.

On the line bisection task, we observed that there were more patients with signs of right-sided than left-sided neglect in the near neglect group. This was mainly due to three right-hemisphere patients with ipsilesional deviations on this task (all other patients showed contralesional deviations). One possibility is that their performance reflects ipsilesional neglect, which is more commonly found on line bisection tasks than on cancellation tasks after frontal subcortical lesions (e.g., Kim et al., 1999). Another possible explanation for their pattern of performance may be the use of compensatory scan strategies. During their stay in the rehabilitation center, patients with signs of neglect are made more aware of their attentional bias and are trained to start scanning on their neglected side of space in order to learn to compensate for their neglect in everyday life. In several cases we observed that patients actually started to miss information that was presented in their non-neglected side of space after several training sessions. Although we have not systematically investigated the influence of this training on search behavior, the current results may in part be influenced by the effects of overcompensation due to this training in the rehabilitation center. Patients are trained in near space, and it is currently unknown whether the effects of the scan training in near space are transferred to far space. Strikingly, one of the patients in our sample showed an inconsistent neglect pattern on the letter cancellation task: right-sided neglect in near space, and left-sided neglect in far space. Although highly speculative, the deviating pattern of neglect in this patient would be in line with the fact that search strategies are not transferred from near to far space, as this would explain the presence of right-sided neglect in near space due to overcompensation and the presence of left-sided neglect in far space.

In sum, the current study adds to the growing body of research on distance-specific neglect by showing that both horizontal and vertical neglect can be distance specific in a large group of stroke patients and that the type of neglect depends on the type of task that is used to assess this disorder. Far neglect was present in a relatively large part of the patients with neglect, and this cannot be observed with the standard paper-and-pencil neglect tests that are widely used in clinical practice. Overall, our results suggest that it is important to take the three dimensions of space into account when testing for the presence of neglect.

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