Neuropsychology
2011, Vol. 25, No. 5, 567–580

0894-4105/11/$12.00 DOI: 10.1037/a0023501

Separating Forms of Neglect Using the Apples Test: Validation and Functional Prediction in Chronic and Acute Stroke

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Objective: We report data on the validation and functional correlates of Apples Test, which attempts to differentiate between different forms of unilateral neglect. ***Method:*** Study 1 presents data from 25 participants with chronic brain lesions who completed the Apples Test and another standard measure of neglect (Star Cancellation). The patients' performance relative to 86 controls was assessed and their relative performance across the two tests compared. Study 2 recruited 115 acute hospital stroke patients who completed the Apples Test as part of the Birmingham University Cognitive Screen procedure. We assessed the relations between the different forms of neglect. Study 3 examined neglect type (as measured by the Apples Test) among the acute stroke group in relation to their activities of daily living abilities and affect. ***Results:*** In Study 1 Apples Test scores correlated with Star Cancellation performance, while also differentiating between neglect across the page and neglect of parts of objects. Study 2 confirmed the dissociation from Study 1. "Pure" forms of each type of neglect were equally prevalent after right and left hemisphere lesions, while the presence of both deficits was associated with right hemisphere damage. Study 3 showed that each form of neglect also correlated with other measures of cognition. When compared with pure page-based neglect, object-centered neglect was associated with a lower Barthel score ($p < .001$), while patients with both forms of neglect had higher level of depression ($p < .001$) than those with the pure forms. ***Conclusions:*** We conclude that the Apples test provides a clinically applicable measure of different forms of neglect. In addition it is a useful predictor of functional outcome. We discuss the nature of the two forms of neglect diagnosed by the test and the functional implications.

Keywords: unilateral visual neglect, Apples Test, functional outcome, Birmingham University Cognitive Screen

Patients with visuospatial neglect typically fail to respond to stimuli presented on the side of space contralateral to their lesion. Neglect is a relatively common consequence of stroke, occurring in up to 50% of the population in the acute phase, and it tends to be more prevalent and more severe in patients with right hemisphere damage (see Bowen, McKenna, & Tallis, 1999, for a systematic review, also Beis et al., 2004). Though often dealt with clinically as a single problem, there is mounting evidence that neglect is heterogeneous both in terms of its anatomy and the associated cognitive deficits (for reviews see Milner & McIntosh, 2005; Bartolomeo, 2007). For example, some patients may fail to orient their attention to the space on the left side of their body—a disorder we will refer to as egocentric neglect. On the other hand, other patients may neglect one side of each of a set of objects they try to copy, while still representing all of the items across a page (Gainotti, Messerli, & Tissot, 1972)—a disorder we will refer to as allocentric neglect (see Arguin & Bub, 1993; Driver & Halligan, 1991; Hillis & Caramazza, 1991; Olson, 2003; Walker & Young, 1996). The relation between different forms of neglect has been controversial. Thus while some patients experience both ego- and allocentric neglect, the two can also occur independently (Marsh & Hillis, 2008) and even be expressed on opposite sides in patients with bilateral lesions (Humphreys & Riddoch, 1994; Riddoch, Humphreys, Luckhurst, Burroughs, & Bateman, 1995).

Visual neglect has conventionally been assessed using tests of visual perception and spatial exploration where the interest focuses on the relations between the stimulus and the patient's body (Bowen, McKenna, & Tallis, 1999). Such assessments include line cancellation (Albert, 1973), star cancellation (Wilson, Cockburn & Halligan, 1987), line bisection (Halligan & Marshall, 1988), and figure copying (Gainotti, Messerli, & Tissot, 1972; Ogden, 1985), all of which vary where stimuli are positioned with respect to the patient but do not provide measures of allocentric neglect. Several tests of allocentric neglect have been described in the experimental literature (Driver & Halligan, 1991; Olson, 2003; Kleinman et al., 2007; Savazzi, Neppi-Mòdona, Zettin, Gindri, & Posteraro, 2004; Silvetti, Pessa, & Doricchi, 2007), but they are not incorporated into standard clinical tests of neglect. This holds true even for batteries where multiple measures of neglect are used (e.g., the Behavioral Inattention Test; Wilson et al., 1987).

This article was published Online First May 16, 2011.

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This work was supported by a programme grant from the Stroke Association and by adoption from the West Midlands Stroke Research Network.

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One promising test to assess allocentric neglect was first reported by Ota, Fujii, Suzuki, Fukatsu, & Yamadori (2001). They presented two patients with a page filled with drawings of either complete shapes or shapes with a gap on either their right or left side. The task was to circle all the complete shapes and to cancel incomplete shapes. They reported that one patient missed all stimuli on the contralesional side of space relative to their body, while the other patient marked stimuli across all areas of the page but circled items that were incomplete on the contralesional side. The same test has subsequently been exploited by Hillis and colleagues (e.g., Hillis et al., 2005; Marsh & Hillis, 2008; Medina et al., 2009). Marsh and Hillis, for example, reported 17 cases of "pure" egocentric (failing to mark on one side of the page), four of "pure" allocentric (wrong responses to items incomplete on one side), and two cases where patients showed both problems, in a consecutive series of 100 acute stroke patients. Both Ota et al. (2001) and Marsh and Hillis (2008) argued that their test revealed dissociations between egocentric and allocentric neglect within a single administration. Medina et al. (2009) also went on to examine the neural correlates of egocentric and allocentric neglect using perfusion imaging (see also Chechlacz et al., 2010; Verdon, Schwartz, Lovblad, Hauert, & Vuilleumier, 2009). Medina et al. (2009) argued that egocentric neglect is associated with abnormal function within the supramarginal and superior temporal gyri, while allocentric neglect is associated with dysfunction of middle-superior occipital regions and posterior temporal cortices. The study of Chechlacz et al. (2010) is of particular interest because it used the Apples test as administered here. Using data from chronic cases it was found that egocentric neglect was linked to relatively anterior lesions including the superior temporal sulcus, while allocentric neglect occurred after more posterior lesions including the angular and middle occipital gyri. Both analyses suggest that ego- and allocentric neglect can have distinct neural markers, consistent with the disorders being functionally distinct. In addition, Chechlacz et al. (2010) note that lesions of the right temporoparietal junction were associated with both forms of neglect, a point to which we return in the General Discussion here.

However, despite the promise of the above results, the clinical applicability and reliability of allocentric neglect tests in relation to standardized measurements of neglect in the literature have yet to be established. It also remains unclear whether egocentric and allocentric neglect could be distinguished in chronic as well as acute patients, because nearly all tests of allocentric neglect have focused on acute cases to date (though see Chechlacz et al., 2010). Finally, visual spatial neglect, if unresolved in the earlier days post stroke, has long been associated with poor functional recovery and rehabilitation outcome (Denes, Semenza, Stoppa, & Lis, 1982; Giaquinto et al., 1999; Halligan & Cockburn, 1993; Kalra, Perez, Gupta, & Wittink, 1997; Katz, Hartman-Macir, Ring, & Soroker, 1999; Paolucci, Antonucci, Grasso, & Pizzamiglio, 2001). Such important clinical implications call for an early and effective screening for neglect after stroke, to monitor progress and inform treatments. Yet, we know little about the functional effects of allocentric neglect (e.g., its relation to activities of everyday living), either when it occurs in isolation or combination with egocentric neglect.

In the present study, we report the first data on the relations between egocentric and allocentric neglect within a single test (the "Apples test") in both chronic (Study 1) and acute stroke patients (Studies 2 and 3). We also provide an assessment of our measures against standard tests in the field and against measures of functional outcome and affect (Study 3). The results highlight the distinction between these two forms of neglect, the utility of the Apples test as an efficient clinical evaluation of different forms of neglect, and the relations between the different forms of neglect and important clinical outcomes.

Development of the Apples Test

Cancellation tasks are the most commonly used assessment for neglect (Bowen, McKenna, & Tallis, 1999) and can be more sensitive in detecting neglect than other tests such as reading (Halligan, Cockburn, & Wilson, 1991). Cancellation is used as the response mode in Ota et al.'s (2001) figurative discrimination task, and we followed this procedure in setting up the Apples Test. However, in most clinical tests (e.g., Star Cancellation Test from the BIT), patients are only asked to cancel a minority of items on the page and they should make no response to other (distractor) items. In the procedure originally used by Ota et al. (2001; also Marsh & Hillis, 2008; Medina et al., 2009; Verdon et al., 2009), patients were required to make a response to all the items present (circling complete items and canceling incomplete stimuli). This requirement to respond to all items may encourage patients to explore all parts of space, compared with when they only have to respond to a minority of targets. Having to respond to all items also reduces the direct relations between the test and the standardized forms of measurement (e.g., Star Cancellation Test). Accordingly we adapted the figure discrimination task of Ota et al. so that participants only had to respond to the complete items presented to them, and no response had to be made to the incomplete distractors. In addition, the stimulus array was made more dense, to increase the difficulty of the detection task and to increase sensitivity to neglect. We defined egocentric neglect on the basis of the differences in target omissions on the two sides of the page, while allocentric neglect was defined by the presence of false positive responses to distractors with gaps on one side of the shape. The use of distractors as well as targets, and of displays with relatively dense arrays of stimuli, resulted in a cancellation task with a relatively high attentional load, which ought to induce visual neglect (Azouvi et al., 2002). We also made the stimuli into apples (see Figure 1), to make the test slightly more interesting and easier to explain relative to when abstract shapes are used.

Study 1: The Apples Test Versus Star Cancellation Test With Chronic Patients

Study 1 validates the Apples Test against a standardized test of neglect from the Behavioral Inattention test (BIT, Wilson et al., 1987). The Star Cancellation Test is one of the six conventional subtests in the BIT (line crossing, letter cancellation, figure and shape copying, line bisection, and representational drawing) and it is most comparable to the Apple Test in terms of the nature of the targets and the type of response required.

Method

Participants

Healthy control participants. For the Apples Test, 86 control participants (51 female) with no history of neurological dis-

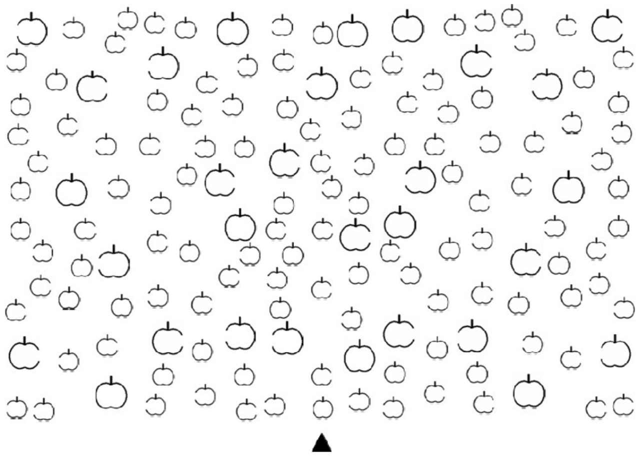

Figure 1. Apple Cancellation sheet.

ease were recruited through patients' relatives, personal contact, and poster advertisement in public notice boards around areas of Birmingham. The mean (*SD*) age of the controls was 67.1 (8.4) years (range 47–88). The mean (*SD*) years of education was 12.07 (3.26). Twelve participants were left-handed and one ambidextrous.

Brain-damaged participants. All patients participating in the study were recruited from the panel of neuropsychological volunteers established in the Behavioral Brain Sciences Centre at the School of Psychology, University of Birmingham. All patients provided written informed consent according to the ethics protocols of the UK National Research Ethics Committee and Birmingham University Imaging Centre (BUIC). The patient group consisted of 25 individuals [mean age (*SD*) = 64.5 (8.12) years, range = 36–74, mean years of education (*SD*) = 12.10 (3.25)] with chronic acquired brain lesions. All but one patient had had a stroke, and one suffered an arterial venus malformation. Time after lesion ranged from 9 months to 16 years. Lesion information was obtained from either hospital CT scans or MRI scans from either the admitting hospital or from BUIC. Seven of the patients had a left hemisphere lesion, and 18 had a right hemisphere lesion. All patients were right-handed. All patients were assessed by the Birmingham University Cognitive Screen (BUCS) (www.bucs.bham.ac.uk).

Procedures and Materials

The Apple test consisted of 150 apples pseudorandomly scattered on an A4 page presented in landscape orientation (see Figure 1). All the apples were presented in an upright orientation. Two thirds of the apples were distractor items (half with an opening on the left side and half with an opening on the right side), the remaining were targets (full apples). The page was divided into a grid with two rows and five columns (see Figure 2) to ensure that the probability for omissions showing left versus right or upper versus lower space neglect was balanced. The grid was not visible to participants but was designed to ensure an equal distribution of each type of apple across the page. Each cell of the grid contained 15 apples: three large ones (one without opening, one with an opening on the right side, and one with an opening on the left side) and 12 small apples (four without openings, four with an opening on the right side, and four with an opening on the left side). The large apples were 50% bigger than the small apples. The midline of the page (indicated by a black triangle, see Figure 1) was positioned at the midline of the patient.

Each participant was asked to cross out all the complete apples while ignoring all the incomplete apples. To ensure that patients understood the task instructions, at least one practice trial was presented before the test. In the practice trial, stimuli (a mixture of target and distractor items) were displayed along the midline of the page only. This enables even patients with spatial neglect to learn the task. Up to two practices were allowed, with feedback given after the first practice when required. If the patient failed to understand the task after two practices, the test was discontinued. A maximum of five minutes was allowed for the completion of the test.

The accuracy score corresponded to the total number of targets selected (max. = 50). The asymmetry score for egocentric neglect corresponded to the difference between the number of targets selected on the right side and the number of targets selected on the left side (excluding the middle column) (max. = 20). Positive values indicate that more targets were selected on the right than the left side (left neglect) and negative values indicate the opposite (right neglect). The asymmetry score for allocentric neglect corresponded to the difference between the total number of distractor apples cancelled with a left opening and the number cancelled with a right opening (total left opening *minus* total right opening). Again, positive values indicated left neglect, and negative values right neglect. The cut offs, based on scores from the 86 control participants, were as follows: overall accuracy on targets (5th percentile cut off) $<42/50$; asymmetry across the page (based on $<$5th percentile or $>$95th percentile) = <-2 or >2; asymmetry for detecting incomplete apples (based on $<$5th percentile or $>$95th percentile) = <-1 or >1).[1]

For the Star Cancellation Test (Wilson et al., 1987), we followed the standard administration procedure. Patients were asked to select the small stars (54 in total) from among the 75 distractors of large stars, letters, and words. No time limit was given. The original normative data were obtained from 50 control subjects [mean age (*SD*) = 58.2 (13.5), range 22–82]. Though cut offs were given for each of the subtests in BIT (including the Star Cancellation Test), explicit diagnosis of neglect is only given with the *aggregated* total score from the six subtests being lower than any control subject (Wilson et al., 1987). However, the authors later suggested that visuospatial neglect was considered present in patients if they made more omissions on *any one test* than the age-matched controls (Stone et al., 1991). In the BIT, the original cut off for the total Star Cancellation score was $<52/54$. A substantially different cut off for older adults ($<39/54$, omission of 16 stars or more) was later established from a group of 47 controls with a mean age of 71.6 (*SD* = 12.77, range 34–93) (Stone et al.,

[1] We have reviewed a variety of other scoring methods, including scaling any asymmetry score by the number of items completed. However, this "normalization" procedure inflates a small asymmetry score of patients who make few completions, even if the absolute asymmetry score falls within the normal range. For this reason, this procedure was not used.

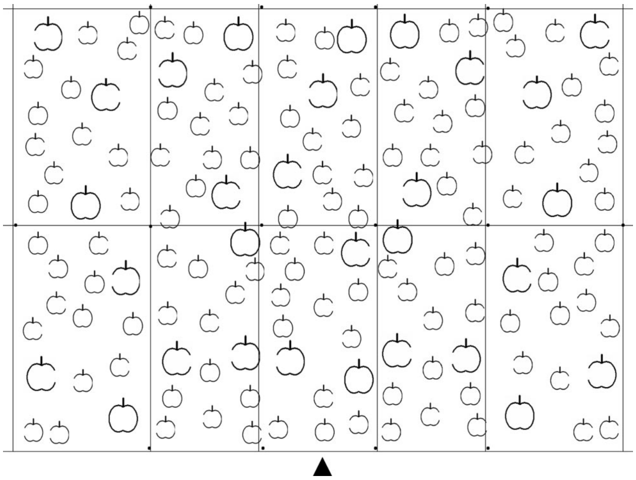

Figure 2. An overlaying grid dividing the Apple Cancellation sheet into areas with equal number of target apples and each type of distractor apples (with left opening or right opening).

1991). The latter cut-off was adopted in this study as the age of that control group was more comparable to the age of our patient group.

On a subset of patients we were also able to administer the Apples Test twice, to provide a measure of test/retest reliability.

Control participants were tested on the Apples Test only; patients were assessed on both the Apples Test and the Star Cancellation Test. The order of the tests was randomized for the patients.

Results

Patients' Performance

Overall accuracy has frequently been used as indicator of neglect (Wilson, Cockburn, & Halligan, 1987), and, if not an indicator of neglect, it does indicate the general (nonlateralized) ability to direct attention to targets and to ignore distractors. We correlated patients' *overall accuracy scores* between the Star Cancellation Test [mean (SD) = 47.64 (6.12), range = 30–54] and the Apples Test [mean (SD) = 45.52 (6.12), range = 30–50]. There was a reliable correlation [$r(25) = 0.919$, $p < .01$, with age taken into account].[2]

Using the Star Cancellation Test (cut off 39/54) as the "gold standard," the Apples Test demonstrated good sensitivity (100%) and fair specificity (59%) (please see Greenhalgh, 1997, for details of calculation). This indicated that, for detecting general impairments in visual attention, the two tasks were comparable. Interestingly, the Apples Test appeared to be more sensitive than the Star Cancellation Test in identifying patients with milder signs of inattention. All patients who were impaired in the Star Cancellation accuracy score (3/25, 12%) were also impaired in the overall accuracy index for the Apples Test, but there were 9/25 (36%) patients who were impaired on the Apples accuracy score but not on the Star Cancellation accuracy score.

Page-Based Asymmetry Scores

The overall accuracy score alone does not take into account the extent of left versus right asymmetry in performance. For the Star Cancellation Test, Stone et al. (1991) suggested that neglect was present if individuals omitted more than 15 stars (accuracy cut off); or for those who omitted between 6 and 15 stars (performance above cut off but below ceiling), "if there were at least twice as many omissions on one side of the page as the other" (p. 347). We term this a page-base asymmetry. The present study also adopted this criterion for the Star Cancellation Test to diagnose an asymmetrical page-based deficit for a given patient. For the Apples Test, a page-based asymmetry of more than 2 (more omissions on the left than on the right or vice versa) was defined as impaired based on the 5th percentile level of the age-matched controls' performance as described above.

There was a significant correlation ($p < .001$) between the page-based asymmetry scores (the difference between the number of targets detected on the right side and those on the left of the page) for the Star and Apples tests, partialing out effects of age [$r(22) = 0.90$]. There was a somewhat weaker correlation between the measure of allocentric neglect on the Apples test and the page-based asymmetry in the Star Cancellation task [$r(22) = .41$, $p < .05$, with age partialed out].

There was substantial agreement between the two tasks on the diagnosis of a page-based asymmetry ($\kappa = 0.87$, $p = .001$) (Muñoz & Bangdiwala, 1997). Good agreements were achieved for patients who did not show neglect according to the Star Cancellation "gold standard" [i.e., specificity: Apples Test (page-based asymmetry) = 88%] and for those who showed neglect [i.e., sensitivity: Apples Test (page-based asymmetry) = 100%]. Table 1 shows details of the distribution of the diagnoses according to the two tasks.

The data also showed that the diagnostic profile varied with the type of neglect and the lesion side. Of the patients who showed abnormal page-based asymmetry in *both* tasks ($n = 7$), all showed neglect consistently on one side (six with left neglect after a right hemisphere lesion and one with consistent right neglect after a left hemisphere lesion). These results were not strongly related to the presence of visual field defects, measured via confrontation testing. Two patients, who both showed left-sided page-asymmetries in both the Star Cancellation and Apples Tests, had a left field defect, but the other patients did not.

Judging by the absolute value of their asymmetry scores, the severity of neglect for patients who failed only one task (Group 1, $n = 3$) was less than that of patients who failed both tasks (Group 2, $n = 7$) (Kruskal-Wallis test, $p = .029$).

Item-based asymmetry scores (false positives). False positives on the Apples Test can indicate a deficit in spatially attending to the features within objects (given the task to detect a target on the left or right side) or a more general failure in selective attention (responding to a distractor rather than the target irrespective of where the distractor differs from the target). General failures in selective attention are revealed in Star Cancellation when patients respond to distracters, and in the Apples Test (possibly) when they respond to distractors with an ipsilesional gap or when they responded equally often to distractors with a contralesional gap. A problem in allocentric attention will be most clearly indi-

[2] For all the current results, omitting the nonstroke patient made little difference to the results. This also held true for the matching neuroanatomical analyses reported by Chechlacz et al. (2010).

Table 1
Distribution of the 25 Patients According to the Page-Based Asymmetry Diagnosis Profile Between the Star Cancellation and Apples Tests (%)

Diagnosis	%
Impaired in both	28
Spared in both	60
Impaired in Star Cancellation Test only	0
Impaired in Apple Test only	12
Total agreement	*88*
Kappa	0.87 (p = .001)

cated by an asymmetry score with more false positive responses expected to distractors with a contralesional gap in the Apples Test.

False positives rarely occurred in Star Cancellation (1/72 by one patient) even for patients with severe neglect. However, false positive responses occurred more generally in the Apples Test (for 13 of the 25 patients), perhaps because of target-distractor similarity being higher in this task than in the Star Cancellation Test and the items being more densely packed. For the Apples test false positive scores ranged from 1/100 to 21/100.[3]

Relative to the controls, seven patients performed at an impaired level in terms of item-based asymmetries (more false positives when the gap was on one side rather than the other). Five patients showed left allocentric neglect and two right allocentric neglect. One patient with left allocentric neglect had a left visual field deficit; the other patients had no field deficits.

Test/Retest Reliability

On a subset of 20 patients we were able to give the Apples Test a second time to provide a measure of the reliability of classification. There was a concordance rate of 88% on a classification of patients having (or not having) egocentric neglect and a concordance rate of 94% on classifying patients as having (or not having) allocentric neglect.

Relations Between Egocentric and Allocentric Neglect

To assess the relations between egocentric neglect (indicated by the page-level asymmetry) and allocentric neglect (indexed by asymmetrical false positive errors), we correlated the two asymmetry scores for the Apples Test. There was a modest but reliable correlation across the measures [$r(22) = 0.53$, $p < .01$, with age partialed out]. There were, however, some dissociations across patients. Using cut-off scores from our norms (see above), two patients had allocentric neglect only (a significant asymmetry, compared with controls, on false positive errors) and five had egocentric neglect only (a significant page-based asymmetry, compared with controls). Five patients presented with significant impairments for both our allocentric and egocentric measures.

Discussion

These data, on patients with chronic brain lesions, indicate that the Apples Test is at least as sensitive as the Star Cancellation task. In addition, the Apples Test offers the possibility of distinguishing between different forms of neglect within the same task. Although there was an overall correlation between the measures of egocentric and allocentric neglect, we found evidence for dissociations between the symptoms, with some patients presenting only with egocentric neglect and others presenting with allocentric but not egocentric neglect. These behavioral results support previous behavioral (e.g., Beis et al., 2004; Humphreys & Heinke, 1998; Marsh & Hillis, 2008; Kleinman et al., 2007; Ota et al., 2001) and neuroimaging data (Chechlacz et al., submitted; Hillis et al., 2005; Medina et al., 2009) in demonstrating a dissociation between allocentric and egocentric neglect. In addition to differentiating between the two forms of neglect, the data also indicate that the Apples Test is able to give a reliable classification of patients as having each form of neglect, with there being strong concordance between the classifications given on two test occasions. In these data with chronic patients there were no clear relations between the presence of neglect and the presence of a visual field defect on confrontation testing.

Aside from these results with the Apples Test, Study 1 revealed that there as a bias in the lateralization of egocentric neglect (page-based asymmetries; 9/10 with left egocentric neglect). However, conclusions from the study should be cautious because the analyses were based on small groups of patients. In Study 2 we sought to extend the first study in two ways: (1) by collecting data across a larger group of patients, and (2) by testing patients at an acute stage (within 3 months of their lesion). It is conceivable that the dissociation between egocentric and allocentric neglect in Study 1 reflected the reorganization of attentional functions over the longer term (given that the patients all had chronic lesions). In Study 2 we tested 115 patients with all the data recorded within 100 days post lesion. We also assessed how egocentric and allocentric neglect, measured by means of the Apple Test, related to wider measures of cognition obtained through a broader cognitive screen (the Birmingham University Cognitive Screen, BUCS). The BUCS provides measures across five "cognitive domains": language, memory, attention and executive function (including sustained attention and working memory), praxis, and number processing, while additional measures are taken of activities in everyday living (Barthel index, Mahoney & Barthel, 1965) and of affect, particularly anxiety and depression (using the HADs; Snaith & Zigmond, 1994). The data from Study 1 indicate that egocentric and allocentric neglect may dissociate. If this pattern is replicated with a larger group of patients here, we may be able to pull apart subgroups with relatively "pure" allocentric and egocentric deficits. Following this, we can then test whether patients with the apparently contrasting forms of neglect differ in terms of ancillary cognitive and affective deficits, and also in terms of their activities of everyday living. This is important both in terms of predicting which patients may have problems in affect and which have impairments in everyday life. In addition, neglect has been associated with a range of nonspatial as well as spatial deficits including problems in working memory (Malhotra, Coulthard & Husain, 2009), sustained attention, and arousal (Robertson & Manly, 1998). Here we test whether such deficits are more apparent in patients with pure egocentric or allocentric neglect or a combined

[3] There were no differences in the relative proportions of large or small apple distractors that were responded to, either in this study or in Study 2.

form of neglect, as well as evaluating whether the severity of either form of neglect is related to the degree of impairment in working memory, sustained attention, or arousal.

Study 2: Contrasting Two Forms of Neglect in Acute Stroke Patients

Method

Participants

One hundred fifteen right-handed patients with unilateral brain lesion [mean age (*SD*) = 70.28 (13.87], with an age range between 18 and 93 years; female = 49/115; mean years of education (*SD*) = 11.15 (3.03) were tested within 100 days post stroke (mean days post stroke = 27.42, *SD* = 25.61). The patients were consecutively recruited on a Cognitive Screen Project from two local hospital wards. CT scans revealed that 56 (48.7%) had left hemisphere lesions, 59 (51.3%) right hemisphere lesions. All participants provided written informed consent according to the UK National Research Ethics Committee approved procedures.

Neglect, Cognitive and Functional Assessments

The patients were assessed on the Birmingham University Cognitive Screen (BUCS, *www.bucs.bham.ac.uk*) of which the Apples Test is an integral part. Apart from measuring spatial attention (assessed by the Apples Test plus also tests of visual and tactile extinction), the areas covered by the BUCS include language, attention and executive functions, memory, praxis, and number processing. A brief description of the tests is provided in the Appendix. The daily living ability was assessed by the Barthel Activity of Daily Living (ADL) index (Mahoney & Barthel, 1965), and the emotional well being was assessed by the Hospital Anxiety and Depression Scale (HADS, Snaith & Zigmond, 1994).

Testing took place as bedside examinations or by examining patients in a room on the stroke ward.

Results

Frequency of Deficits

According to the cut off scores from our norms (Study 1) for the Apple Test, 47 (40.9%) patients failed on the overall accuracy score. Using the asymmetry scores as more specific measures of neglect, 35 (30.4%) patients showed egocentric neglect (26 on the left side and nine on the right). A similar number of patients (37, 32.1%) showed allocentric neglect, with the majority showing a deficit on the left side (25 patients showed poor detection of distractors with a left gap and 12 had impaired detection of distractors with a right gap).

Effects of Lesioned Hemisphere

We next analyzed whether there were differences in the degree of the different forms of neglect in left and right hemisphere lesioned patients. Table 2 gives the number of left and right hemisphere lesioned patients who were clinically impaired for each neglect score.

Overall accuracy. In terms of overall accuracy, patients with RHD had lower mean scores (34.31, *SD* = 14.73) than patients with LHD (41.96, *SD* = 11.08) [$t(113) = 3.14$, $p = .002$]. RHD patients also had a higher incidence of impairment in overall accuracy (32/59), compared with LHD patients (15/56), $\chi^2(1) = 8.96$, $p = .003$. This indicates that, relative to LHD patients, RHD patients may have a generally worse ability to select targets and not distractors.

Page-based asymmetry. Compared with the LHD patients, the RHD patients showed a more severe page-based asymmetry in detecting full apples [4.98, *SD* = 6.22, compared with LHD: 1.76, *SD* = 2.82, $t(113) = -3.62$, $p < .001$] and RHD patients were more likely to be classified as having egocentric neglect [RHD: 24/59; LHD:11/56, $\chi^2(1) = 9.15$, $p = .002$].

Item-based asymmetry. For allocentric neglect, the RHD patients had significantly greater spatial asymmetries in detecting distractors [RHD: 3.10, *SD* = 5.22; LHD: 1.25, *SD* = (2.33), $t(113) = -2.44$, $p = .016$] and there was a trend for a greater incidence of the impairment in RHD patients, but this was not reliable [RHD:23/59; LHD:14/56, $\chi^2(1) = 2.57$, $p = .109$]. Nevertheless, lesion side predicted the "sign" of the asymmetry (contralateral to lesion side). This was true for egocentric neglect, $\chi^2(1) = 6.98$, $p = .008$ and for allocentric neglect, $\chi^2(1) = 15.63$, $p < .001$.

ANCOVAs. ANCOVAs were conducted to ensure that our results were not contaminated by factors known to covary with neglect, namely working memory and selective and sustained attention (measures of these covarying nonspatial factors were derived from the BUCS; see the Appendix).

Overall accuracy. The effect of lesion side remained, $F(1, 80) = 7.35$, $p = .008$.

Table 2
Distribution of Patients With Impairments in the Apples Test Separated by Type of Neglect (Egocentric and Allocentric) and Lesion Side (Study 2)

	% (*n*) Impaired		
	LHD (*n* = 56)	RHD (*n* = 59)	Total (*n* = 115)
Accuracy	26.8 (15)	54.2 (32)	40.9 (47)
L egocentric/page-based Apple asymmetry	8.9 (5)	35.6 (21)	22.6 (26)
R egocentric/page-based Apple asymmetry	10.7 (6)	5.1 (3)	7.8 (9)
L allocentric/false positive Apple asymmetry	7.1 (4)	35.6 (21)	21.7 (25)
R allocentric/false positive Apple asymmetry	17.9 (10)	3.4 (2)	10.4 (12)

Note. LHD = left hemisphere damage; RHD = right hemisphere damage.

Page-based asymmetry. There remained an effect of lesion side, $F(1, 80) = 8.66$, $p = .004$.

Item-based asymmetry. The effect of lesion side was not significant when the covariates were taken into account, $F(1, 80) = 2.71$, $p = .104$.

No significant effect was shown by any of the three covariates on the dependent variables.

Relations Between Egocentric and Allocentric Neglect

There were 18 patients who were classified with both egocentric and allocentric neglect (page-based and false positive asymmetries). Of these patients the majority (15/18) had unilateral RHD and three had LHD. All (15/15) of the RHD patients showed both egocentric and allocentric neglect on the left side. In contrast, two of the three LHD patients were inconsistent across the two measures on the side where neglect was expressed; one showed left egocentric neglect but right allocentric neglect and the other showed the opposite pattern. One LHD patient had consistent right neglect.

Strikingly, a larger number of patients classified with some form of neglect demonstrated differential impairment [i.e., they showed a reliable page-based or false positive asymmetry, but not both; for 36/54 (67%) of the patients with neglect] (see Table 3). There were no marked differences in the prevalence of "pure" egocentric or allocentric neglect in left and right hemisphere patients.

Relations to Field Deficits

We also investigated the relations between performance on the Apples test and hemianopia among the acute patients. Of 115 participants tested on Apple, 113 were also given a simple visual field test (detecting confrontation finger movements) as part of the BUCS. Five patients had a left field deficit on this task and six a right field deficit. Of these individuals who failed on the field test, three presented with a pure allocentric neglect, one showed pure egocentric neglect, three showed combined allocentric and egocentric neglect, all on the affected side. There is some suggestion here that a field deficit could contribute to allocentric neglect, but there are also cases (5/11) who had a hemianopia and did not show allocentric neglect. The results do not suggest that allocentric neglect is necessarily linked to a field defect, while the presence of a field defect does necessarily produce neglect symptoms.

Table 3
Number (Percentage) of Dissociations Between Patients Classified With Egocentric and/or Allocentric Neglect (Study 2)

Neglect diagnosis	LHD (n = 56) n (%)	RHD (n = 59) n (%)
Allocentric only		
L	3 (5.4)	6 (10.2)
R	8 (14.3)	2 (3.4)
Egocentric only		
L	4 (7.1)	6 (10.2)
R	4 (7.1)	3 (5.1)
Both		
L	—	15 (25.4)
R	1 (1.8)	—
LE & RA[a]	1 (1.8)	—
RE & LA[a]	1 (1.8)	—
Neither	34 (60.7)	27 (45.8)

[a] E = egocentric; A = allocentric.

Discussion

The data from Study 2 concur with prior trials in showing that visual neglect is relatively prevalent among the acute stroke population, with egocentric and allocentric both being found in around 30% of our acute population. Interestingly, the two forms of neglect detected by the Apples test were equally common. Previously allocentric neglect has tended to be reported in relatively small-scale studies and not covering a consecutive sample of acute stroke patients. In addition, the test of neglect has not been as sensitive as the Apples test (particularly to allocentric neglect; see Study 1). Our data indicate that, given a sensitive test, allocentric neglect is not uncommon. However, there was also evidence indicating that egocentric and allocentric neglect can dissociate. While the performance of a third of the neglect patients showed both the egocentric and allocentric deficits, two thirds of patients with neglect presented with a clinically apparent form of one deficit without demonstrating the other. This pattern of double dissociation across the patients supports other smaller-scale group and single case study reports (Humphreys & Riddoch, 1994, 1995; Marsh & Hillis, 2008; Ota et al., 2001).

Although hemisphere of lesion was not strongly tied to the single forms of the disorders, right hemisphere patients were more likely than left hemisphere patients to show more severe egocentric neglect, and patients with both sets of neglect symptoms also tended to have right hemisphere damage. These data are consistent with there being an underlying functional distinction between the processes that contribute to our measures of egocentric and allocentric neglect but also greater lateralization (predominantly right hemisphere) in patients showing both sets of problems. We consider these points in more detail in the General Discussion.

Study 3: The Relations to Tests of Other Cognitive Processes, Everyday Activities, and Affect

Method

The method was as set out for Study 2.

Results

Functional Correlations of Egocentric and Allocentric Neglect

We examined the correlations between egocentric and allocentric neglect and 1) more general aspects of cognitive performance, 2) patients' activities of daily living function, and 3) affect (anxiety and depression).

Cognitive Performance

A priori we would expect the neglect measures to correlate with tasks requiring visual spatial attention (e.g., reading, copying a figure) but not tasks requiring little spatial attention (e.g., verbal memory, auditory attention) (Tables 4 and 5).

Table 4
Correlations With BUCS Tasks (Controlling for Lesion Side L, R, & B)

Domain	Controlling for lesion side			Controlling for lesion side, nonspatial attention, and working memory		
	df from 91 to 112			*df* from 85 to 100		
	Overall accuracy	Egocentric asymmetry	Allocentric asymmetry	Overall accuracy	Egocentric asymmetry	Allocentric asymmetry
Language						
Instruction comprehension	0.27	−0.14	−0.15	0.20	−0.04	−0.09
Picture naming	0.28	−0.05	−0.05	0.19	0.09	0.04
Sentence construction	0.45**	−0.05	−0.05	0.40**	0.05	0.01
Sentence reading (accuracy)	0.41**	−0.25	−0.17	0.35**	−0.15	−0.09
Sentence reading (time)	−0.26	0.13	0.02	−0.27	0.10	−0.02
Nonword reading (accuracy)	0.29	−0.10	−0.07	0.22	0.00	0.00
Nonword reading (time)	−0.26	0.08	0.07	−0.27	0.06	0.06
Word writing	0.38**	−0.21	−0.22	0.30	−0.05	−0.12
Memory						
Time & space orientation (mc)	0.41**	−0.12	−0.05	0.36**	−0.07	−0.02
Story free recall (immediate)	0.01	0.04	0.04	−0.12	0.19	0.14
Story recognition (immediate)	0.19	−0.14	−0.03	0.08	0.02	0.11
Story free recall (delayed)	0.12	−0.02	−0.02	−0.01	0.15	0.09
Story recognition (delayed)	0.20	−0.16	−0.05	0.11	−0.02	0.07
Task recognition	0.26	−0.14	0.01	0.17	0.00	0.13
Extinction						
Left unilateral (visual)	0.46**	−0.39**	−0.34**	0.45**	−0.37**	−0.33**
Right unilateral (visual)	0.04	0.03	−0.06	0.02	0.06	−0.04
Left bilateral (visual)	0.58**	−0.55**	−0.49**	0.55**	−0.51**	−0.47**
Right bilateral (visual)	0.06	0.00	−0.07	0.04	0.03	−0.05
Left unilateral (tactile)	0.08	−0.11	−0.21	0.09	−0.12	−0.22
Right unilateral (tactile)	0.17	−0.07	−0.05	0.17	−0.06	−0.05
Left bilateral (tactile)	0.43**	−0.34**	−0.41**	0.40**	−0.29	−0.37**
Right bilateral (tactile)	0.10	0.05	−0.04	0.07	0.11	0.00
Controlled attention						
Rule finding accuracy	0.45**	−0.33**	−0.27	0.42**	−0.25	−0.21
Rule finding (number of rules detected)	0.43**	−0.31**	−0.24	0.39**	−0.23	−0.18
Auditory attention accuracy	0.24	−0.30	−0.21			
Auditory working memory index	0.04	−0.18	−0.16			
Praxis						
Figure copy	0.73**	−0.46**	−0.36**	0.70**	−0.39**	−0.31
Multiple object use	0.42**	−0.37**	−0.18	0.35**	−0.30	−0.12
Gesture production	0.28	−0.15	−0.05	0.16	0.02	0.07
Gesture recognition	0.26	−0.14	0.00	0.20	−0.01	0.12
Imitation	0.43**	−0.35**	−0.39**	0.36**	−0.2	−0.35**
Number						
Number reading	0.48**	−0.22	−0.12	0.41**	−0.10	−0.02
Number writing	0.39**	−0.23	−0.15	0.30	−0.04	−0.02
Calculation	0.24	−0.23	−0.15	0.15	−0.08	−0.03

** Significant at 0.001. The degrees of freedom varied because not all sub-tests of the BUCS could be completed with all patients.

Relations to Overall Accuracy on the Apples Test

Using a p value of < 0.001 to correct for multiple correlations, we controlled for nonspatial attention (auditory attention, auditory working memory) using a generalized linear model approach. Significant correlations were found between overall cancellation accuracy on the Apples test and tasks within the language, memory (orientation), and praxis domains (see Table 4). Many of these components of the BUCS require visual attention. For example, sentence reading in the language domain, the visual extinction task[4] (ability to detect stimuli on the left/right side when stimuli are presented bilaterally compared with when they are presented unilaterally), the rule finding task which required following and predicting the movement of a marker around a grid as well as gesture imitation and figure copy in the praxis domain (see Table 4).

Relations to Asymmetry Scored on the Apples Test

Relative to the wide spread of correlations of subtests in the BUCS with the measure of overall accuracy on the Apples, the two

[4] The neglect measure correlated with left but not right extinction scores could be attributable to the fact that right extinction was significantly less severe than left extinction in both the visual [L: mean(SD) = 7.0 (2.4), R: mean(SD) = 7.5 (1.7), $t(181) = -2.4$, $p = .017$], and tactile modalities [L: mean(SD) = 7.0 (2.2), R: mean(SD) = 7.5 (1.7), $t(178) = -2.4$, $p = .022$].

Table 5
Comparisons of Cognitive Performance Between Patients With Allocentric Neglect, Egocentric Neglect, or Both Types of Neglect

Domain	Cognitive tasks	Neglect type: Egocentric Est. mean (*SE*)	Allocentric Est. mean (*SE*)	Both Est. mean (*SE*)	Wald's χ^2 *p*	Post hoc LSD
	Max N	14	17	17		
Language	Picture naming	10.31 (0.89)	8.24 (0.67)	11.47 (0.82)	NS	
	Sentence construction	6.69 (0.72)	5.73 (0.62)	7.00 (0.64)	NS	
	Sentence reading accuracy	36.08 (1.67)	32.13 (1.42)	30.12 (1.33)	NS	
	Sentence reading time	56.77 (2.09)	33.08 (1.60)	34.13 (1.46)	< 0.001	E > B, E > A
	Nonword reading accuracy	3.92 (0.55)	3.50 (0.47)	4.24 (0.50)	NS	
	Nonword reading time	26.00 (1.41)	22.38 (1.31)	22.12 (1.18)	NS	
	Word writing	2.42 (0.45)	1.75 (0.33)	2.67 (0.42)	NS	
Memory	Orientation time & space	5.50 (0.63)	5.47 (0.57)	5.47 (0.57)	NS	
	Immediate story free recall	7.08 (0.28)	6.23 (0.26)	8.21 (0.24)	< 0.001	B > A, B > E
	Immediate story recognition	11.57 (0.91)	11.82 (0.83)	12.71 (0.87)	NS	
	Delayed story free recall	6.54 (0.28)	5.68 (0.27)	9.09 (0.24)	< 0.001	B > A, B > E
	Delayed story recognition	13.08 (1.00)	12.18 (0.85)	12.82 (0.87)	NS	
	Task recognition	8.33 (0.83)	8.83 (0.86)	9.17 (0.87)	NS	
Extinction	Left visual extinction	6.57 (0.69)	7.47 (0.66)	2.41 (0.38)	< 0.001	A > B, E > B
	Right visual extinction	7.93 (0.75)	6.41 (0.61)	8.00 (0.67)	NS	
	Left tactile extinction	6.29 (0.67)	6.94 (0.66)	4.06 (0.49)	= 0.001	A > B, E > B
	Right tactile extinction	8.00 (0.76)	6.94 (0.66)	7.88 (0.68)	NS	
Controlled attention	Rule finding accuracy	2.71 (0.44)	3.47 (0.45)	3.29 (0.44)	NS	
Praxis	Figure copy	28.15 (0.28)	30.67 (0.26)	25.00 (0.25)	< 0.001	A > E > B
	Multiple object use	8.77 (0.82)	8.88 (0.72)	8.27 (0.74)	NS	
	Gesture production	10.00 (0.88)	9.12 (0.73)	10.35 (0.78)	NS	
	Gesture recognition	4.54 (0.59)	4.44 (0.53)	5.00 (0.54)	NS	
	Gesture Imitation	8.54 (0.28)	6.87 (0.26)	8.00 (0.24)	< 0.001	E > A, B > A
Number	Number reading	7.17 (0.77)	6.50 (0.68)	6.20 (0.64)	NS	
	Number writing	3.42 (0.53)	2.31 (0.38)	3.69 (0.53)	NS	
	Calculation	1.83 (0.39)	2.60 (0.42)	2.31 (0.42)	NS	

Note. A = Patients with allocentric neglect; E = Patients with egocentric neglect; B = Patients with both neglect types.

asymmetry scores on the Apples test correlated with fewer subtests from the BUCS and these correlations were linked more specifically with visual spatial functioning. Interestingly, there were indications of differential relations between the two measures of neglect and praxis abilities. Having controlled for nonspatial attention, the egocentric asymmetry score showed a significant relationship with figure copy performance ($p < .001$) and with the multiple object use test ($p = .003$), while the allocentric asymmetry score alone correlated with gesture imitation ($p < .001$). This pattern suggests possible distinctions in the functional impact of the two types of neglect on the abilities of patients to perform everyday actions. We review this point in the General Discussion.

To investigate the potentially different relations to everyday function for egocentric and allocentric neglect directly, the measures of cognition were compared between the groups of patients showing only egocentric neglect, only allocentric neglect or both types of neglect (see Table 5). Overall, there was no difference in the percentage of BUCS tasks failed across the three groups.

Controlling for effects of lesion side as well as nonspatial attention and working memory, patients with pure allocentric neglect were faster in reading, better at figure copy, but worse in gesture imitation than those with pure egocentric neglect. Those with combined forms of neglect were worse than those with pure neglect (regardless of type) in left visual and tactile extinction scores and figure copy. The combined neglect groups were consistently better than the pure neglect groups in story recall (both immediate and delayed) where only auditory and verbal information was involved in task presentation and responses.

Activities of Daily Living

Using a similar Generalized Linear Modeling method to that described above, we compared the Barthel index (measuring abilities in everyday activities) for patients who showed only egocentric neglect, only allocentric neglect, or both types of neglect. As in the analysis of cognitive performance above, comparisons were made with the effect of lesion side, nonspatial attention, and working memory partialed out. Moreover, as motor impairment among patients with neglect (indexed by the ability to use both hands in multiple object use) had a significant impact on the Barthel score, $t(46) = 4.03$, $p < .001$, this factor was also entered as a covariate in the modeling. There was a significant main effect of neglect type [Wald $\chi^2(2) = 150.2$, $p < .001$]. Post hoc LSD pairwise comparisons showed that patients with "pure" allocentric neglect were significantly less able in their activities of daily living [mean (*SE*) = 8.88 (0.24)] than those with "pure" egocentric neglect [mean (*SE*) = 12.97 (0.28), $p < .001$]. Patients with the combined disorders [mean (*SE*) = 8.96 (0.27)] were disadvantaged when compared with the egocentric neglect group ($p < .001$) but not the allocentric group ($p = .82$).

Affect

A similar analysis to that for everyday living was carried out for the HADS measures. Having controlled for nonspatial attention, working memory, Barthel score (to rule out effects of higher functional impairment) and both asymmetry scores, significant main effects of neglect types were revealed on the level of depression [Wald $\chi^2(2) = 48.50$, $p < .001$] but not anxiety. Post hoc LSDs showed that individuals with the combined disorders were worse off [mean(*SE*) = 7.25 (0.29)] than both the allocentric group [mean(*SE*) = 5.13 (0.25)], and the egocentric group [mean(*SE*) = 4.55 (0.30), $p < .001$ in both pairwise comparisons]. There was no difference between the two pure forms of neglect in the level of anxiety or depression.

Discussion

The results from Study 3 highlighted the differential effects of the three patterns of neglect (allocentric, egocentric, or both) on functional performance, measured through the BUCS tasks and the Barthel index. Egocentric neglect was associated with slower reading time and reduced performance on the figure copy task, relative to allocentric neglect. The degree of egocentric neglect also correlated with performance on the multiobject use task. In all of these tasks, patients needs to continuously update representations of several visual elements/objects that have been attended (for reading, copying, or using objects, respectively) to integrate with the elements/objects still to be attended. Egocentric neglect may generate problems in using the separate element/objects to guide attention, or problems in keeping track of attended elements/objects (cf. Malhotra, Coulthard, & Husain, 2009), and either of these problems in turn will lead to difficulties on the reading, copying, and multiobject use task. In contrast, and surprisingly, allocentric neglect was associated with poorer imitation of gesture—even with the degree of motor deficit partialed out across patients. Gesture imitation requires a number of processes—assimilating separate parts of an actor's body, judging movement of the actor's hand in relation to the actor's body, and maintaining the representation of the whole image in working memory. The coding of parts to the whole, to integrate the gesture with the actor's body, may tap the same processes as those required to attend to the missing parts of the individual distractors in the Apples Test, so that patients have difficulties with both tasks after damage to these processes. Humphreys and Riddoch (1994; see also Humphreys, 1998) proposed that egocentric and allocentric neglect reflected, respectively, impaired attention to a 'between-object' representation of independent elements and a 'within-object' representations of parts in relation to a perceptual whole. The present data are consistent with this distinction, with a within-object deficit affecting the imitation of gestures as well as part detection within objects. In contrast, egocentric neglect may reflect a deficit in attending to and integrating separate elements in tasks such as reading, copying complex figures, and dealing with multiple objects.

The combined form of neglect was associated with all of the tasks affected in the pure forms of the disorders. In addition, patients with the combined disorder (primarily RHD patients) were significantly more likely to show left extinction in both visual and tactile modalities than those with either pure allocentric or egocentric neglect. We believe this is a telling point. In their neuroanatomical analysis of egocentric and allocentric neglect, Chechlacz et al. (2010) reported that egocentric neglect alone was associated with relatively more anterior lesions including the superior temporal sulcus. Allocentric neglect alone was associated with more posterior lesions including the angular gyrus and middle occipital and temporal gyri. However, a lesion to the right temporoparietal junction generated both forms of neglect. In a follow-up neuroanatomical analysis of extinction (using a completely different set of patients to those reported in Study 3 here), Chechlacz et al. (under review) report that extinction is also strongly associated with damage to the right temporoparietal junction, and this produces a multimodal deficit, affecting touch as well as vision. These results fit with the idea that the right temporoparietal junction serves as a supramodal relay station critical for the detection of stimuli under conditions of competition within the frame of what is currently being attended. Chechlacz et al. (2010) discuss their results in terms of the model of visual selection put forward by Heinke and Humphreys (2003) in which stimuli from different spatial positions are mapped through a common focus of attention, for subsequent detection (see below for further discussion). The right temporoparietal junction may be critical for reading activity out of this focus of attention, and it might be biased to favor the left side. Damage to this region then could lead to poor detection of the left of individual objects, of two objects (e.g., under conditions of extinction) or of the whole scene, depending on the span of the stimulus being attended. According to this argument, patients showing both egocentric and allocentric neglect actually have a different problem, supported by a distinct neuroanatomical substrate, than patients who present with "pure" forms of each type of neglect. Alternative accounts of these results are more difficult to sustain. One argument is that patients have both disorders because they have a larger lesion than patients with "pure" forms of the deficits. However, this fails to account for the differential prevalence of the combined disorder in right rather than left hemisphere patients—a result that fits our proposal that the right temporoparietal junction is particularly important for selecting stimuli within the focus of attention. Another account of why the combined disorder might be more prevalent in right hemisphere patients is that large left hemisphere lesions lead to patients being excluded as a result of an ancillary problem (such as aphasia). However, the BUCS is designed to be highly inclusive for aphasic patients, and the number of patients excluded because of severe comprehension problems was very small (<1%). So this too seems unlikely to be a critical factor.

We also found an unpredicted association between the presence of the combined disorder and superior performance in the verbal free-recall tasks (where no visual attention is required). One speculation here is that the presence of a more severe form of visual neglect may lead to patients allocating more resources to other modalities and to nonspatial (linguistic) information, with the result that patients are better with the combined relative to pure forms of neglect. This possibility requires further investigation.

Finally, patients with allocentric neglect or combined neglect were less able in their activities of daily living (as measured by the Barthel questionnaire) than patients with egocentric neglect (even with the presence of hemiplegia controlled). Individuals with the different types of neglect did not differ in terms of their levels of anxiety. However, the level of depression varied with the neglect symptoms, with patients with the combined form being most depressed. These last analyses were conducted using the degree of motor deficit as a covariate, so the differential results cannot reflect a contrast in the motor problems patients experience. Nevertheless, the patients with combined forms of neglect show greater across-the-board deficits in relation to their cognitive and functional abilities relative to the patients with "pure" egocentric or allocentric neglect, and it would not be surprising were their greater depression to reflect the decreased abilities in these patients.

General Discussion

We have reported data showing that the Apples Test 1) can be used to measure both egocentric and allocentric neglect, in both chronic and acute patients, 2) reveals dissociations between these two forms of neglect in different patients, 3) correlates with, and is at least as sensitive as, the clinically standard test of Star Cancellation (Wilson et al., 1987), and 4) can be linked to functional deficits in patients, including poor everyday action. The sensitivity of the Apples Test, alongside its ability to detect two forms of neglect in a single session, highlights that the test is clinically useful and it goes beyond other standardized assessments of neglect in the literature by dissociating different subcomponents of the neglect syndrome.

Theoretical accounts of the different types of neglect. The contrast between egocentric and allocentric neglect can be linked to the distinction between the representation and exploration of separate objects ('between-object coding') and the representation and encoding of parts within objects ('within-object coding') made by Humphreys (1998). Egocentric neglect can be considered a problem in representing multiple distinct object representations, in using these representations to guide attention, and/or in keeping a memory record of objects that have been inspected. Exactly which of these processes may be affected cannot be judged from the present results. Allocentric neglect can be viewed as a problem in assimilating parts into a representation of a single object. Our data, along with previous reports of dissociations across patients, indicate that the process of coding parts into objects is distinct from the representation and use of between-object representations in spatial exploration (see also Marsh & Hillis, 2008; Ota et al., 2001). A computational account of this distinction is that offered by Heinke and Humphreys (2003; see above). The Selective Attention and Identification Model (SAIM) is a connectionist framework in which stimuli are mapped from the retina through a spatial window (the 'focus of attention,' FOA) to translational-invariant 'templates' that recognize objects. When there are multiple objects present there is competition within a retinotopically organized selection network for objects to enter into the FOA. Within the FOA, visual elements are represented in their spatial locations in relation to the object and matched against the recognition templates. Spatial biases ("neglect") are generated after lesioning either at the retinal input into the selection network or the information passed from the selection network into one side of the FOA. The first lesion generates a form of neglect that varies with the positions of separate items in relation to the body (egocentric neglect). Lesions affecting input into the FOA, on the other hand, generate a form of neglect where elements on the affected side of an object are omitted (allocentric neglect). Recent studies (Chechlacz et al., 2010; Medina et al., 2009; Verdon et al., 2009) have examined the neural substrates of egocentric and allocentric neglect, and in each the results support the argument that the two disorders are linked to lesions in different brain regions—with more anterior parietotemporal damage characteristic of egocentric neglect and more posterior parietooccipital damage linked to allocentric neglect. In Chechlacz et al. (2010), patients with both forms of neglect tended to have damage to a further, distinct site, the right temporoparietal junction. Our results are consistent with this in that patients presenting with both forms of neglect tended to have right hemisphere lesions. We suggest that the right temporoparietal junction may be critical for reading out from the FOA, biasing processing to the left. Because this read-out process is common to information derived from egocentric and allocentric spatial representations, damage to it will generate both forms of neglect.

Although we have discussed the Apples test almost exclusively in terms of the distinction between allocentric and egocentric neglect, an alternative conceptualization is that the page-centered neglect reflects a problem in global space perception and item-based neglect reflects a problem in local spatial representation. Halligan and Marshall (1994) proposed that left neglect after right hemisphere damage is brought about at least in part by patients being impaired at global space perception in addition to having a spatial bias in attention. This impaired global perception could be significant for egocentric neglect. In contrast, poor attention to local spatial areas is associated with left rather than right hemisphere damage (Delis, Robertson, & Balliet, 1983). If this is coupled to a spatial bias in selection, then patients may fail to detect missing parts on one side of individual objects—the pattern of allocentric neglect. Now, as we have discussed, there are aspects of this local-global account that overlap with our allocentric-egocentic proposal. For example, mapping an egocentric representation of all of the apples on the page into a FOA will be analogous to forming a global spatial representation; mapping single apples into the FOA would be akin to forming a local spatial representation. However, there are aspects of our data that challenge the local-global proposal as a complete account of performance. To begin with, we used large and small apples. In many studies, the global forms are larger than local forms (e.g., Navon, 1977), and hence we might expect a bias affecting global representations to emerge in the omission of large apples, while a bias affecting more local levels of representation may lead to small apples being omitted. We found no evidence for any bias based on the sizes of the stimuli. Against this it could be argued that the global or local forms reflect the level of a hierarchical representation rather than stimulus size per se, but then it is not clear whether detecting complete apples is a more global task than detecting a gap in the side of the stimulus, given that the gap was present on the outer rim of the shape. In addition, on a global-local account, we would expect that allocentric/local neglect would be associated with left hemisphere damage and egocentric/global neglect with right hemisphere lesion. However, the "pure" forms of both allocentric and egocentric neglect were not strongly lateralized, with lateralization primarily confined to patients with both forms of neglect. Further work is needed to distinguish the local-global and the allocentric-egocentric accounts definitively. One other theoretical argument is that allocentric neglect may reflect a gradient of attention across egocentric space (e.g., Pouget & Driver, 2000). On this gradient account, there would be a bias against elements on one side of objects, even when those objects fall in the spared visual field.

However, this should mean that allocentric neglect necessarily co-occurs with egocentric neglect. Our data do not agree with this, given that “pure” forms of allocentric deficit can be found in individuals not showing egocentric neglect (see Table 3). Also this gradient account fails to explain prior results where opposite egocentric and allocentric biases have occurred even in the same patient (Humphreys & Riddoch, 1994, 1995). We note that we too observed two patients who presented with egocentric and allocentric neglect on opposite sides. As with previous cases, we suggest that this might reflect undetected bilateral damage which affects the allocentric and egocentric spatial representations on opposite sides in these individuals. These results suggest that the two forms of representation are coded independently and, from lesion-based analyses, in different brain regions (Chechlacz et al., 2010).This proposal stands even if each representation can be fed into a common FOA which, when damaged, produces combined egocentric and allocentric neglect (cf. Heinke & Humphreys, 2003).

Patients showing ipsilesional neglect. In Study 2 we also reported some patients who showed ipsilesional rather than contralesional neglect (there were 12 patients who showed “pure” allocentric or egocentric neglect but on the ipsilesional side). It has been noted before that neglect patients can generate ipsilesional neglect if they allocate reduced resources to the contralesional side, leaving insufficient resources left for the ipsilesional stimuli (Robertson & Frasca, 1992). The patients who manifested ipsilesional problems did not differ from the other patients in terms of the time when they were tested or whether they had been introduced into a rehabilitation strategy of orienting to the bad side. Our results do indicate that this is not a particularly rare event and it was no more likely to occur in left (seven) than in right hemisphere patients (five). It would be interesting to examine whether such patients do have more awareness of their problems than patients showing “standard” contralesional neglect.

Functional deficits. Finally, previous studies showed that the presence of neglect is related to poor long-term outcome in patients (Suhr & Grace, 1999). Our results concur with this. The presence of either type of neglect was associated with impaired performance on a range of cognitive tasks, though allocentric problems linked to poorer activities of everyday living (as assessed by the Barthel questionnaire, Mahoney & Barthel, 1965) and the combined form of neglect was associated with higher levels of depression (as assessed by the HADS, Snaith & Zigmond, 1994). This highlights the overall importance of screening for neglect to predict outcome in patients, and, more particularly, the need to include a measure of allocentric as well as egocentric deficits within any screen.

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(*Appendix follows*)

Appendix

The Birmingham University Cognitive Screen (BUCS)

Table A1: Description of Tasks Included in the BUCS

Cognitive areas	Cognitive impairments	Tasks	Measures
Language[a]	Speech	Picture naming	Accuracy
		Sentence construction	Accuracy
	Reading	Sentence reading	Accuracy & time
		Nonword reading	Accuracy & time
	Writing	Word/nonword writing	Accuracy
Mathematical/number abilities	Number reading	Number reading	Accuracy
	Number writing	Number writing	Accuracy
	Calculation	Calculation	Accuracy
Praxis/control and planning of action	Visuo-constructive	Figure copy	Accuracy
	Gesture recognition	Transitive/intransitive gesture recognition	Accuracy
	Gesture production	Transitive/intransitive gesture production	Accuracy
	Gesture imitation	Meaningless gesture imitation	Accuracy
	Action planning & organization	Multi-object use	Accuracy
Memory	Orientation	Personal information	Free recall accuracy
		Orientation in time and space	Free recall accuracy
			Multiple choice accuracy
	Episodic memory	Story recall	Story free recall (immediate) accuracy
			Story recognition (immediate)accuracy
			Story free recall (delay) accuracy
			Story recognition (delay) accuracy
		Task recognition	Accuracy
Attention and executive functions	Spatial neglect	Apples cancellation	Accuracy
			Full apples asymmetry
			Incomplete apples asymmetry
	Extinction	Visual extinction	Left unilateral perception (visual)
			Left bilateral perception (visual)
			Right unilateral perception (visual)
			Right bilateral perception (visual)
		Tactile extinction	Left unilateral perception (tactile)
			Left bilateral perception (tactile)
			Right unilateral perception (tactile)
			Right bilateral perception (tactile)
	Auditory attention	Auditory attention test	Accuracy
			Sustained attention index
			Working memory
	Executive function	Birmingham rule finding and switching	Accuracy
			Number of rules detected

Note. The BUCS was designed to provide a set of "broad but shallow" measures of cognition. Table A1 summarizes the cognitive areas covered and lists the tasks that are part of the screen. The tests are laid out to be "neglect friendly" by, where possible, using vertical rather than horizontal arrangements of stimuli and cueing patients to attend to stimuli when the tests are administered. Furthermore, when tests do not target language, these are designed to be "aphasia friendly," through the use of high frequency and short words that aphasics are likely to be able to process and where possible by presenting stimuli both visually and verbally, and where possible we use forced-choice administrative procedures to minimize problems resulting from poor word finding.

[a] Instruction comprehension is assessed across four tasks: Orientation, Sentence construction, Auditory attention, and Birmingham rule finding and switching.

Received March 5, 2010
Revision received January 10, 2011
Accepted February 7, 2011 ■