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The frequency and severity of extinction after stroke affecting different vascular territories

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ABSTRACT

We examined the frequency and severity of visual versus tactile extinction based on data from a large group of sub-acute patients ($n=454$) with strokes affecting different vascular territories. After right hemisphere damage visual and tactile extinction were equally common. However, after left hemisphere damage tactile extinction was more common than visual. The frequency of extinction was significantly higher in patients with right compared to left hemisphere damage in both visual and tactile modalities but this held only for strokes affecting the MCA and PCA territories and not for strokes affecting other vascular territories. Furthermore, the severity of extinction did not differ as a function of either the stimulus modality (visual versus tactile), the affected hemisphere (left versus right) or the stroke territory (MCA, PCA or other vascular territories). We conclude that the frequency but not severity of extinction in both modalities relates to the side of damage (i.e. left versus right hemisphere) and the vascular territories affected by the stroke, and that left hemisphere dominance for motor control may link to the greater incidence of tactile than visual extinction after left hemisphere stroke. We discuss the implications of our findings for understanding hemispheric lateralization within visuospatial attention networks.

1. Introduction

The ability to attend symmetrically across both sides of space is essential for daily activities, as illustrated by the behavioural problems experienced by patients with attentional problems following stroke (for a review see Kerkhoff, 2001). While such problems have been predominantly investigated in relation to the syndrome of unilateral neglect (when patients ignore the side of space contralateral to lesion; Heilman & Valenstein, 1979), impairments in attention can also be found in patients showing extinction. Extinction is a common spatial disorder diagnosed in patients who can detect a single stimulus on the contralesional side but who fail to detect the same stimulus when presented concurrently with an ipsilesional item (Bender & Teuber, 1946; Critchley, 1953; Wortis, Bender, & Teuber, 1948). The deficit has typically been attributed to differential competition for attention to stimuli on the ipsi- and contralesional sides of space (Duncan, Humphreys, & Ward, 1997), though there may also be contributions from impaired perceptual processing on the contralesional side (Gorea & Sagi, 2000, 2002). Functional imaging studies show that extinction is associated with reduced activation to contralesional stimuli in early visual cortex (primary visual cortex/V1 and early extrastriate cortex including part of V2 and V3), consistent with biased attentional competition modulating perception (e.g., Driver & Vuilleumier, 2001; Rees et al., 2000, 2002).

As for unilateral neglect there are reports that extinction is asymmetrically associated with the damage to the right hemisphere. For example, Becker and Karnath (2007) reported that 24.3% of patients with lesions within the right hemisphere showed visual extinction as compared to only 4.9% of patients with damage to the left hemisphere (although see Ogden, 1985 for a contrary account). The higher incidence of extinction following right hemisphere strokes is consistent with there being an asymmetrical right hemisphere dominance of visuospatial attention (Corbetta & Shulman, 2002; Kinsbourne, 1977, 1987; Weintraub & Mesulam, 1988).

While the frequency of extinction and neglect may be greater after right (RHD) than left hemisphere damage (LHD), there are inconsistent results concerning the severity of the symptoms (e.g., Albert, 1973; Arrigoni & De Renzi, 1964; Chedru, 1976; Costa, Vaughan, Horwitz, & Ritter, 1969; Ringman, Saver, Woolson, Clarke, & Adams, 2004; Stone et al., 1991; Suchan, Rorden, & Karnath, 2012). For example, most studies comparing the severity of neglect have found that the symptoms are more severe after RHD compared to LHD damage (Albert, 1973; Chedru, 1976; Gainotti, Messerli, & Tissot, 1972; Ogden, 1987; Ringman et al., 2004; Stone et al., 1991) – though other reports have found that neglect symptoms can be equally severe in LHD and RHD patients

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(Costa et al., 1969; Suchan et al., 2012). In contrast to neglect symptoms, the severity of extinction after left versus right hemisphere damage has not been examined systematically.

The severity of visuospatial deficits following left versus right strokes has implications for how we view the nature of right hemisphere dominance in these spatial disorders. One account is that the right hemisphere has attentional receptive fields covering both sides of space, while the left hemisphere has attentional receptive fields only for the right side (Kinsbourne, 1987). The consequence of this is that right hemisphere lesions impair attention to both sides of space while left hemisphere lesions have less effect because the right hemisphere can still respond to stimuli in the right field. A somewhat different account is based on the right hemisphere dominance for disengaging attention so that items in unattended areas of field can be detected. It follows from this argument that right hemisphere lesions should lead to a deficit in disengaging attention from right side stimuli to detect those falling on the left and, given right hemisphere dominance for attentional disengagement, this problem should be worse after right than left hemisphere lesions (Corbetta & Shulman, 2002; Posner, Walker, Friedrich, & Rafal, 1984). We examined whether this was the case in a large group of subacute stroke patients with extinction symptoms.

The severity and frequency of spatial disorders such as neglect and extinction has been studied mainly in the visual modality. However extinction occurs also in other sensory modalities (touch, audition, olfaction) and can be considered a multisensory phenomenon (e.g. Bellas, Novelly, Eskenazi, & Wasserstein, 1988a, b; Deouell & Soroker, 2000; De Renzi, Gentilini, & Pattacini, 1984; Hillis et al., 2006; Ladavas, Pavani, & Farne, 2001; Maravita, Spence, Clarke, Husain, & Driver, 2000; Vaishnavi, Calhoun, & Chatterjee, 2001). The asymmetrical association between damage to the right hemisphere and extinction symptoms in different modalities has not been studied thoroughly although De Renzi et al. (1984) demonstrated that, in the auditory modality, the prevalence of extinction symptoms was not significantly different following damage to the two hemispheres. These data suggest that the asymmetrical association between the frequency of spatial deficits and the hemisphere of damage may be either absent or weaker in modalities other than vision.

In the current study we examined the frequency and severity of extinction in the visual and tactile modalities in right versus left hemisphere strokes based on data from a large group of sub-acute patients ($n=454$). We also evaluated how these factors vary depending on the vascular territory affected by the stroke. Visual and tactile extinction were measured using matched procedures, minimizing the chances that non-specific task effects confounded the results.

Our results point to (i) the greater frequency of extinction after right relative to left hemisphere lesions for both the visual and tactile modalities, but no differences in the severity of the symptoms when they occur, (ii) a shift in the prevalence of tactile vs. visual extinction after left and right hemisphere damage, and that (iii) the frequency but not the severity of the extinction deficit depends on the vascular territory affected by the stroke.

2. Material and methods

2.1. Participants

Patients were recruited as a part of the BCoS project (Birmingham Cognitive Screen, http://www.bcos.bham.ac.uk), a large clinical study with several participating stroke units across the West Midlands area, UK. After excluding patients with incomplete behavioural data, we sampled data from a total of 454 sub-acute stroke patients (240 males and 214 females; average age of 69.9 years, range 30–93 years; see Table 1 for full demographic and clinical data) were included in the study. Within this group 215 patients had middle cerebral artery (MCA) stroke and 47 posterior cerebral artery (PCA) stroke. The remaining 192 patients had either strokes not visible on CT scans (131 patients; lesions may not be apparent on CT if the scan was conducted very early after the stroke, or if there was only a minor neurological change) or affecting other vascular territories (61 patients) such as anterior cerebral artery (ACA) stroke, basal ganglia and thalamus (LSA/lenticulostriate arteries and AChA/anterior choroideal artery territories strokes) as well as the cerebellum (PICA/posterior inferior cerebellar artery and SCA/superior cerebellar artery territories stroke). Clinical and demographic data for all patients were obtained from the clinical files. This included computed tomography (CT) scans acquired as part of routine clinical assessment following stroke and hospital admission. Clinical notes and CT scans (screened for visible presence of a lesion) were used to determine the type of stroke (ischemic or hemorrhagic/bleed or no clear abnormality/no visible lesion), vascular territory affected by stroke and the affected hemisphere. Specifically, for each patient the vascular territory affected by stroke was first defined based on clinical notes and further confirmed by examining CT scans by one of the experienced members of the research team. In the case of any uncertainty about stroke location further advice was sought from an experienced neuroradiologist. Patients were only included in the statistical analyses if they had well-defined unilateral lesions.

All study participants provided written informed consent in agreement with ethics protocols approved by the National NHS ethic committee and local NHS trusts.

2.2. Behavioural measures

Behavioural data were only collected from patients who were physically stable, willing to perform the task and had a concentration span of at least 60 min (judged clinically). The neuropsychological testing took place in the sub-acute phase

Table 1
Patient's details: clinical and demographic data ($n=454$, all recruited stroke patients).

	All patients ($n=454$) Mean (SD) or number	**MCA ($n=215$)** Mean (SD) or number	**PCA ($n-47$)** Mean (SD) or number	**Other[a] ($n=61$)** Mean (SD) or number	**NVL[a] ($n=131$)** Mean (SD) or number
Age in years	69.9 (13.7)	71.2 (13.1)	72.8 (10.7)	68.1 (14.2)	68.0 (15.0)
Sex: male/female	240/214	112/103	23/24	35/26	70/61
Aetiology: ISCH/BL	417/37	194/21	44/3	48/13	131/0
Affected hemisphere: right/left/NVL	161/162/131	103/112/0	21/26/0	37/24/0	0/0/131
Handedness: right/left	404/50	196/19	44/3	54/7	110/21
Stroke-BCoS in days[b]	23.0 (20.7)	24.6 (22.2)	24.7 (17.2)	24.2 (23.0)	18.8 (17.3)
Left VE index[c]	3.2 (2.5)	3.2 (2.5)	2.7 (2.7)	3 (1.4)	3.6 (2.9)
Right VE index[c]	2.3 (1.6)	2.7 (1.7)	N/A	2 (0)	1.3 (0.8)
Left TE index[c]	3.3 (2.3)	3.7 (2.3)	2.6 (2.1)	2.7 (2.7)	2.7 (1.8)
Right TE index[c]	2.6 (1.9)	3.0 (2.2)	2.5 (1.7)	1.5 (0.6)	2.2 (1.5)

[a] Patients with strokes affecting vascular territories other than MCA and PCA (only patients with lesions visible on CT scans) and NVL, patients with strokes not detected on CT scans.

[b] Interval between stroke onset and BCoS cognitive assessment.

[c] Mean extinction index score calculated based on data from patients with both contralesional and ipsilesional extinction deficits (not relevant for NVL patients; we have not calculated these separately due to very small number of patients with ipislesional deficits), please note that by contrast results section and Fig. 3 only present data for contralesional deficits; BL, bleed (hemorrhagic stroke); ISCH, ischemic stroke; MCA, patients with strokes affecting middle cerebral artery; N/A, not applicable, no patients with this type of deficits; PCA, patients with stroke affecting posterior cerebral artery; SD, standard deviation; TE and VE index; tactile and visual extinction index, both tests consists of 4 unilateral left, 4 unilateral right and 8 bilateral trials, extinction index was calculated to assess extinction severity by measuring selective drop in response to two stimuli relative to the response to one stimulus.

following stroke onset (<3 months) and the average stroke-to-test interval was 23 days (±20.7; with 93% of patients being tested within 2 months and 76% of patients being tested within 1 month). The cognitive assessment of each patient was based on the BCoS, a test instrument developed to screen patients for a range of cognitive problems following stroke (Humphreys, Bickerton, Samson, & Riddoch, 2012). For the sub-acute tests, the BCoS was administered in hospital settings and at follow-up it was administered either in the hospital, a rehabilitation clinic, the School of Psychology, Birmingham University or during a home visit. All examiners were blind to the location of the stroke and the patient's condition. In this study we were interested in extinction deficits and based our analysis on 2 BCoS tests: the Visual Extinction and Tactile Extinction tasks.

2.2.1. Visual and tactile extinction

The examiner sat approximately 1 m opposite at the participant's midline. For the visual extinction task, the examiner raised his/her left and right index fingers on either side of his/her head, approximately 20 cm from the nose. The testing was administered by experienced examiners who tried to maintain a consistent distance between their fingers and each patient's eyes. The instructions then specified: "*Look at my nose. Don't move your eyes. I will move my finger either on my left hand, on my right hand or on both hands simultaneously. Please tell me or show me which side moved. Always keep looking at my nose*". For each trial the examiner moved one or two finger(s) with two brief bending movements. For the tactile extinction test following instructions were given: "*Put your hands on your knees (or on the table/bed cover). Now, close your eyes. I will touch your hand, either your left hand, your right hand or both your hands simultaneously. Please tell me or show me which hand I touched. Always keep your eyes closed*". The patient sat straight and symmetrically (no crossed arms or legs) and the examiner touched the patient's hand(s) by gently tapping twice on the dorsal surface. In both tests there was a maximum time allowance of 15 s for each trial and the testing was abandoned if the patient showed no response on the first three trials. Both extinction tasks consisted of 4 unilateral left, 4 unilateral right and 8 bilateral trials. For each patient we calculated left and right asymmetry scores (the difference in report on left- versus right-side items) on two item trials and on unilateral trials. The asymmetry scores indicate whether a patient missed more items on the left or right. If the patient missed more items on the right, the difference between number of detected left and detected right items would generate a right asymmetry score and a left asymmetry score of 0 (and vice versa if the patient missed more items on the left). We also calculated the left and right extinction index for both tactile and visual extinction.

2.2.1.1. Extinction index. The difference in the asymmetry scores on bilateral vs. unilateral trials was assessed, to index any spatially selective drop in response to two stimuli relative to the response to one stimulus. This was done separately for both left- and right-side items. To do this we calculated an extinction index i.e. the unilateral asymmetry score multiplied by two minus the bilateral asymmetry score, taking into account the difference in the number of trials. The unilateral trials provide an indication of sensory deficits (e.g., a visual field defect or tactile sensory loss). The extinction index takes this loss into account when assessing any further drop in performance on two-item trials and thus extracts out effects of attentional competition (on two item trials) from the effects of sensory loss (unilateral trials). The extinction index was used in all statistical analysis.

Each patient's behavioural performance was classified based on cut-offs drawn from the BCoS (Humphreys et al., 2012). Patients were classed as having a clinical deficit on measures of visual and tactile extinction if their scores on the task fell outside the control norms taken from 70 healthy controls without history of brain lesion or any neurological disorders. The cut off scores for the visual extinction task were as follows: unilateral trials (both left and right) <4 impaired for all age groups; left bilateral trials <7 impaired for all age groups; right bilateral participants younger than 74 years old <8 impaired and participants older than 75 years old <7 impaired.

The reliability of differences in the frequency and severity of extinction (based on the extinction index) between groups defined on type of vascular territory affected by the stroke, left vs. right brain damage as well the reliability of differences in the severity of visual vs. tactile extinction was computed using when appropriate either chi-square test or two-sample *t*-test or mixed-design two way ANOVA (see Section 3). We used IBM SPSS 20 (IBM SPSS Statistics, NY, USA) or Matlab 7.14/R2012a (The MathWorks, Natick, MA, USA) for the statistical analyses. All statistical analyses were based only on the group of patients with lesion visible on CT scans i.e. excluding 131 patients with no detectable lesions.

3. Results

Table 1 presents a summary of the demographic and clinical data for all 454 patients sampled as well as patients grouped based on affected stroke territory. In this group, 161 (35.5%) patients had right hemisphere damage (average stroke-to-test interval of 23.8 days ± 21.3 days) and 162 (35.7%) left hemisphere damage (average stroke-to-test interval of 25.3 days ± 22.0 days) clearly visible on CT scans, while 131 (28.8%) patients had no lesions detectable on CT scans. Fig. 1 illustrates the frequency of visual and tactile extinction for the entire group of all 454 patients (this includes the incidence of extinction in both modalities among patients without lesions detectable on CT scans; 9.1% of left visual versus 7.6% left tactile extinction and 4.6% of right visual versus 6.9% right tactile extinction).

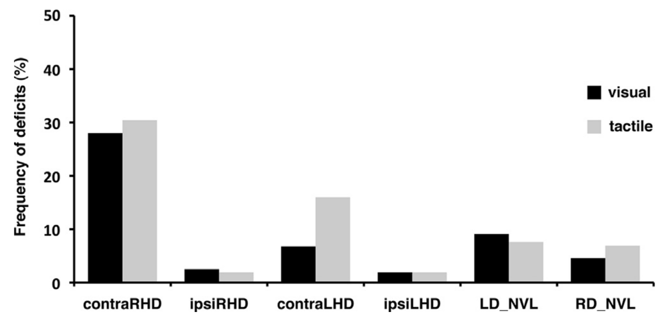

Fig. 1. The frequency of visual and tactile extinction deficits in the entire group of patients ($n=454$). contraRHD=contralesional (left) deficits following right hemisphere damage; contraLHD=contralesional (right) deficits following left hemisphere damage; ipsiRHD=ipsilesional (right) deficits following right hemisphere damage; ipsiLHD=ipsilesional (left) deficits following left hemisphere damage; LD_NVL=left deficits in patients without lesion visible on CT scans; RD_NVL=right deficits in patients without lesion visible on CT scans.

Among patients with visible lesions the frequency of extinction was significantly greater after right than left hemisphere damage for both visual ($\chi^2_{df=1}=24.10$; $p<0.00001$; specifically 28.0% of the patients with damage to right hemisphere showed left visual extinction and only 6.8.3% of the patients with left hemisphere damage showed right visual extinction) and tactile modalities ($\chi^2_{df=1}=8.85$; $p<0.005$; specifically 30.4% of the patients with damage to the right hemisphere showed left tactile extinction and only 16.0% of the patients with left hemisphere damage showed right tactile extinction). Furthermore, the frequency of left visual versus tactile deficits was comparable following contralateral lesions within the right hemisphere (RHD; $\chi^2_{df=1}=0.24$; $p=0.62$). In contrast there was a greater frequency of right tactile versus visual extinction in LHD patients ($\chi^2_{df=1}=6.57$; $p<0.01$). Finally, small number of patients showed ipsilesional deficits in both visual and tactile modalities (<2.5%).

3.1. The frequency of extinction in different patient groups

We next examined the frequency of extinction in patients with either MCA or PCA stroke (a total of 262; 215 patients had MCA stroke and 47 patients had PCA stroke), and then we report the frequency of extinction in the group of 61 patients with strokes affecting other vascular territories (e.g. anterior cerebral artery, basal ganglia, cerebellum). Fig. 2 illustrates the frequency of visual and tactile extinction respectively in each group.

We first contrasted the frequency of extinction deficits between the MCA and PCA strokes. The frequency of both visual and tactile extinction was slightly higher in the MCA patients compared to the PCA group (Fig. 2A and B). Following RHD 34.6% of the MCA patients showed left visual and 32.7% left tactile extinction. For PCA patients 23.8% of the RHD patients had visual extinction and the same proportion had tactile extinction. After LHD 9% of the MCA group showed right visual and 18% right tactile extinction. None of the LHD patients with PCA stroke showed right visual extinction but 11.5% showed right tactile extinction. Interestingly, as indicated above, for both MCA and PCA patients visual and tactile deficits were equally frequent following right hemisphere

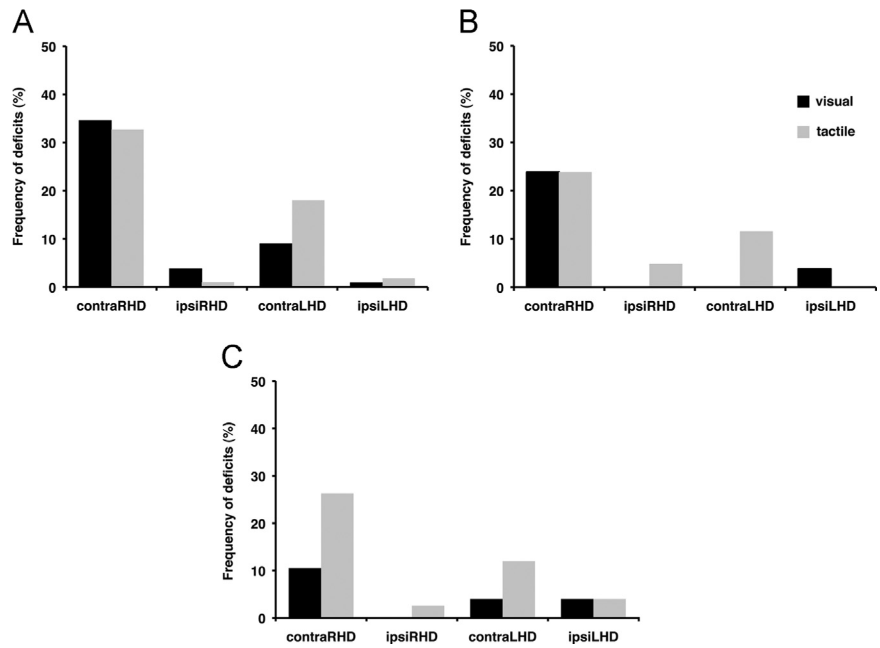

Fig. 2. The frequency of visual and tactile extinction deficits in (A) the MCA territory stroke only group, (B) the PCA territory stroke only group and (C) other strokes group i.e., stroke affecting regions neither linked to the MCA nor PCA territory. contraRHD=contralesional (left) deficits following right hemisphere damage; contraLHD=contralesional (right) deficits following left hemisphere damage; ipsiRHD=ipsilesional (right) deficits following right hemisphere damage; ipsiLHD=ipsilesional (left) deficits following left hemisphere damage.

lesions ($\chi^2_{df=1}=0.07$; $p=0.79$ and $\chi^2_{df=1}=0.17$; $p=0.68$ respectively). However, the greater frequency of tactile than visual extinction following left hemisphere damage held for MCA ($\chi^2_{df=1}=4.5$; $p<0.05$) but not PCA strokes (see Fig. 2A and B; please note that due to the small number of extinction patients in the PCA group, the lack of significance was determined based on Fisher′s exact test, $p=0.235$).

For consistency with previous studies where visuospatial deficits are often reported together from patients following MCA plus PCA strokes we also contrasted the frequency of left versus right and visual versus tactile extinction in MCA plus PCA stroke cases as a single group, these results are included in the Supplementary data files (for further discussion on MCA versus PCA strokes in visuospatial disorders see for example Chechlacz, Terry et al., 2013;Mort et al., 2003).

In the group of patients with strokes affecting territories other than regions linked to the MCA plus PCA, 10.5% of the RHD group showed left visual extinction and 26.3% had left tactile extinction. Within the LHD patients 4% showed right visual extinction while 12% had right tactile extinction (Fig. 2C). In addition small number of patients showed ipsilesional deficits in both visual and tactile modalities (see Fig. 2C for details). Interestingly, the frequency of extinction was not significantly greater after right than left hemisphere damage in patients with stroke affecting other (than MCA&PCA) vascular territories, and this was the case for both visual ($\chi^2_{df=1}=0.36$; $p=0.55$) and tactile ($\chi^2_{df=1}=1.28$; $p=0.26$) modalities. In general, the frequency of both visual and tactile extinction was lower in the group of patients with strokes affecting other vascular territories compared to MCA&PCA patients, although the difference in the frequency of extinction between MC&PCA versus other strokes was only significant in the visual modality following right hemisphere damage ($\chi^2_{df=1}=4.9$; $p<0.05$). Specifically, there was no significant difference in the frequency of visual extinction between the territory-defined groups (MCA&PCA versus other strokes) for LHD cases ($\chi^2_{df=1}=0.06$; $p=0.81$), and there were no differences in the frequency of tactile extinction for either RHD cases ($\chi^2_{df=1}=0.005$; $p=0.94$) or LHD cases ($\chi^2_{df=1}=0.005$; $p=0.94$).

Finally, we also examined the co-occurrence of the deficits in both modalities across different groups of patients. Across the entire group, 13.04% of RHD patients had both left visual and left tactile extinction. In the MCA group 18.3% of RHD patients had extinction in both modalities, while none of the PCA patients exhibited both types of deficit. In the group of patients with strokes affecting other than MCA &PCA vascular territories, 5.6% of RHD patients had both left visual and left tactile extinction. In contrast to the RHD patients, only LHD patients in the MCA group had extinction in both modalities (3.6%), while neither the LHD PCA patients nor the LHD patients with strokes affecting vascular territories other than MCA &PCA exhibited both types of deficit.

3.2. *The severity of extinction in different patient groups*

As well as examining the incidence of extinction we also evaluated the severity of extinction (based on extinction index scores) in both modalities for the different types of stroke (including only RHD versus LHD patients classified as having extinction). Fig. 3 contrasts the severity of visual and tactile extinction deficits (mean extinction index scores plus standard deviation) in RHD versus LHD patients with strokes affecting different vascular territories. In the MCA & PCA group, the mean scores for visual extinction were 3.21 (SD=2.55) and 2.6 (SD=1.58) for RHD and LHD patients respectively and the mean scores for tactile extinction were 3.71 (SD=2.29) and 3.04 (SD=2.16) for RHD and LHD patients respectively. However, these differences in the severity of the symptoms between RHD an LHD patients were not reliable in either of the examined modalities (visual extinction, $t(49)=0.73$, $p=0.4$; tactile extinction, $t(60)=1.14$, $p=0.26$). In the group of patients with strokes affecting other vascular territories the mean scores for visual extinction were 3.0 (SD=1.4) and 1.5 (SD=0.71) for RHD and LHD patients respectively and the scores for tactile extinction were 2.73 (SD=2.69) and 2.25 (SD=1.90) for RHD and LBD patients respectively. Again these differences in the severity of the symptoms, occurring after right versus left brain damage, were not reliable for either modality

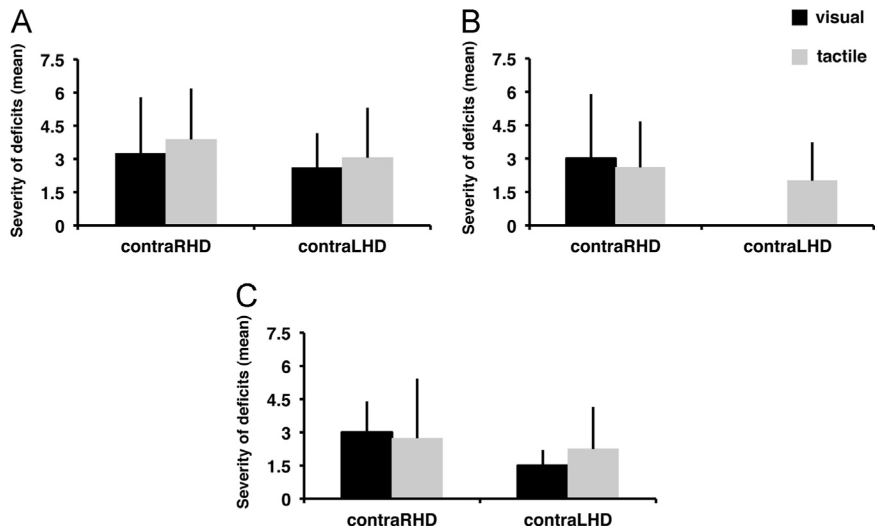

Fig. 3. The severity of visual and tactile extinction deficits (mean extinction index scores plus standard deviation) in (A) the MCA territory stroke only group, (B) the PCA territory stroke only group and (C) other strokes group i.e., stroke affecting regions neither linked to the MCA nor PCA territory. contraRHD=contralesional (left) deficits following right hemisphere damage; contraLHD=contralesional (right) deficits following left hemisphere damage.

(visual extinction, $t(5)=1.37$, $p=0.23$; tactile extinction, $t(13)=0.32$; $p=0.75$).

We next examined the severity of visual and tactile extinction (based on the extinction index) following strokes to different vascular territories. The severity of extinction symptoms was examined only across patients classified as having either visual or tactile extinction and the analysis was restricted to RHD patients with left-side deficits due to the small number of LHD patients with right deficits. A mixed-design ANOVA was computed with patient groups (either MCA&PCA versus other strokes or MCA versus PCA) as between-participant factor and severity of symptoms (visual versus tactile modality) as the within-participants factor. We found no reliable difference in severity between MCA&PCA and other strokes ($F(1,71)=1.18$; $p=0.28$) as well as no effect of modality ($F(1,71)=1.50$; $p=0.22$) and no interaction between patient group and severity of symptoms ($F(1,71)=0.70$; $p=0.41$). Similarly, we found no reliable difference in severity when comparing MCA versus PCA strokes ($F(1,58)=1.90$; $p=0.17$). There was no effect of modality ($F(1,58)=0.03$; $p=0.96$) and no interaction between patient group and severity of symptoms ($F(1,58)=0.15$; $p=0.70$).

4. Discussion

The current study examined the relative incidence of visual and tactile extinction after left and right hemisphere lesions, and whether the vascular origin of the stroke has an effect on the prevalence and severity of these disorders. The study demonstrated several important findings. We found clear evidence that both tactile and visual extinction were more frequent after right than left hemisphere lesion, but the severity of the deficits did not vary with the lesioned hemisphere. In addition, while visual and tactile extinction were equally frequent after right hemisphere damage, tactile extinction was more frequent than visual extinction for left hemisphere cases. There was also an important link between the frequency of extinction and the territory of the stroke. The greater frequency of extinction after right than left hemisphere damage was found only in MCA and PCA cases, while this was not the case for patients with strokes affecting other vascular territories. The implications of these findings are discussed below.

4.1. Lesion laterality: the frequency and severity of extinction

Our findings confirm previous reports showing that extinction is more frequent after right compared with left hemisphere damage (Becker & Karnath, 2007; Stone, Halligan, & Greenwood, 1993). Here we extend previous studies by demonstrating that this is the case not only for vision but also for touch, though the relative frequency of visual and tactile extinction varied according to the laterality of the lesion.

The asymmetrical representation of extinction deficits (i.e., the greater frequency following right hemisphere damage) is similar to the reported higher incidence of neglect after lesions within right hemisphere (e.g., Bowen, McKenna, & Tallis, 1999; Gainotti et al., 1972; Ringman et al., 2004; Stone et al., 1993). The finding is consistent with arguments that attentional receptive fields in the right hemisphere are bilateral while those in the left hemisphere are unilateral (Kinsbourne, 1987). According to this account, after lesioning the left hemisphere, the right hemisphere can still allocate attentional resources to right side items, reducing right-side extinction effects; after a right hemisphere lesion there is no similar compensation and left-side extinction results. Alternatively, the increased frequency of extinction after right hemisphere lesions may reflect right hemisphere dominance for disengaging attention, to enable items in the contralesional field to be detected (Corbetta & Shulman, 2002; Posner et al., 1984). Again across a population, the right hemisphere may be more likely to house a disengagement process compared with the left hemisphere, and so extinction is more prevalent after right hemisphere damage. Interestingly, however, once extinction occurred, the strength of the effect (i.e. the severity of the deficit) did not differ as a function of lesion laterality. This suggests that the right and left hemispheres may differ in the likelihood of representing a given function (bilateral vs. unilateral attentional representation; the likelihood of a disengagement process being lateralised), but not the strength of the function itself. It should be noted though that we examined the severity of symptoms at a sub-acute phase following stroke and it is plausible that the recovery of extinction following left and right hemisphere damage is different and thus the severity of symptoms varies as a function of lesion laterality at a chronic phase. An interesting research question would be to understand the progress of extinction following left or right hemisphere damage relative to changes in the balance of brain activity in the ipsi- and contralesional hemispheres (Corbetta, Kincade, Lewis, Snyder, & Sapir, 2005; He et al., 2007).

The data on the differential frequency of extinction after right and left hemisphere lesions is difficult to explain if extinction simply reflected the impact of a general brain lesion on a natural tendency to suffer in perceptual report when multiple rather than single stimuli are presented. For example, several authors (for review see Farnè, Brozzoli, Làdavas, & Ro, 2007, chap. 9; see also Pollmann, 1996, 2000) have pointed to the existence of extinction-like phenomena in neurologically healthy participants. These findings suggest that extinction might arise because of an intrinsic limitation of the sensory system that might be exacerbated by the brain lesion. However in this case we might expect the frequency of the problem to be similar across left and right hemisphere cases.

Previous reports have primarily examined the severity of visuospatial deficits after right versus left hemisphere damage in patients with neglect (e.g., Albert, 1973; Arrigoni & De Renzi, 1964; Chedru, 1976; Costa et al., 1969; Ringman et al., 2004; Stone et al., 1991; Suchan et al., 2012), with neglect typically being more severe after RHD compared to LHD stroke (Albert, 1973; Chedru, 1976; Gainotti et al., 1972; Odgen, 1987; Ringman et al., 2004; Stone et al., 1991) – although this has not been the case in all studies (Costa et al., 1969; Suchan et al., 2012). In contrast, the severity of extinction after left versus right hemisphere damage has not been examined systematically. We present here data demonstrating that, at least at a sub-acute phase following stroke, the severity of extinction in both visual and tactile modality does not differ following left and right hemisphere damage. We also found that, while visual and tactile extinction was equally likely after RHD, for LHD patients tactile extinction was more frequent. To the best of our knowledge, this is the first time this has been shown. The data suggest that there may be some shift in the likelihood with which patients have a more dominant representation of space in the left hemisphere, for tactile relative to visual stimuli. This may reflect right hand dominance for tactile exploration on the ipsilateral side of space, which may result in (e.g.) a more even distribution of spatial coding in the left and right hemispheres, increasing the prevalence of right tactile extinction after LHD (more patients coding right tactile space only in the left hemisphere). Indeed in the examined group of sub-acute stroke patients, a total of 26 LHD patients showed right tactile deficits and among these 25 patients were right handed and only 1 left handed.

To account for our data, we propose here a probabilistic account of functional lateralisation. The majority of patients have dominant right hemisphere attentional functions, so that extinction occurs most frequently after right hemisphere damage in accordance with previous functional accounts of asymmetrical organization of spatial attention (Corbetta & Shulman, 2002; Kinsbourne, 1987; Posner et al., 1984). However, it is likely that a proportion of the patients have left hemisphere dominance, and in those patients extinction can occur after left hemisphere damage. Once the dominant hemisphere is lesioned, then the severity of the observed deficits does not differ – even though the asymmetry in which hemisphere is more dominant means that the frequency will be higher in patients with right hemisphere lesions. The evidence to support this account can be drawn from recent data indicating a direct correlation between the behavioural and anatomical (in terms of organization of brain networks) lateralization across individuals (Thiebaut de Schotten et al., 2011).

4.2. Vascular territory of stroke: the frequency and severity of extinction

One of the striking findings of the current study is that the dominance of extinction after right hemisphere damage held only for patients with MCA and PCA strokes. Our 'non MCA–PCA' group included a large number of patients with no visible lesions and a mixture of strokes affecting different vascular territories (such as ACA, PICA, LSA and AChA), and hence we cannot link the extinction symptoms in this group to any specific neuronal substrates. Nevertheless, these findings suggest that (i) extinction might occur following lesions in regions outside the dorsal and ventral fronto-parietal networks predominantly affected by MCA and PCA strokes (inferior and middle frontal gyrus, inferior parietal lobule, insula and superior temporal cortex) and traditionally linked to visuospatial deficits (e.g., Chechlacz et al., 2010; Chechlacz, Rotshtein et al., 2013; Chechlacz, Rotshtein, & Humphreys, 2012; Chechlacz, Terry et al., 2013; Corbetta et al., 2005; Corbetta & Shulman, 2002, 2011; Karnath, 2001; Mort et al., 2003; Vallar, Bottini, & Paulesu, 2003; Vallar & Perani, 1986) and (ii) that right hemisphere dominance in some of the cognitive processes underlying visuospatial attention deficits does not arise outside dorsal frontoparietal network. These points are of a particular interest, as we have previously shown in lesion-symptom mapping analyses that both visual and tactile extinction after lesions in the vicinity of different vascular territories may be indeed associated with contrasting anatomical–functional factors (Chechlacz, Terry et al., 2013).

4.3. Methodological considerations

One caveat of the current analyses is that as the behavioural results were derived from a large-scale clinical trial, only a limited amount of data could be collected on the extinction tests, i.e. we used here a somewhat crude measure of extinction, with a relatively low number of event repetitions. Certainly it would be useful to conduct more extensive tests, but this was not possible across the group of patients recruited as a part of a large-scale post-stroke cognitive screen trial (Bickerton, Samson, Williamson, & Humphreys, 2011; Humphreys et al., 2012).

Finally, we would like to note that the effect of handedness on frequency of left versus right extinction is an interesting issue as hand dominance may have an impact on both visual and tactile exploration. Unfortunately, the number of left-handed patients in our group prevented us from any tangible statistical analyses to systematically address this point. As illustrated in Table 1 only 50 of our group of 454 patients were left-handed and among these only 29 had lesions visible on CT scans (13 RHD and 16 LHD patients). Furthermore among these 29 patients, only 10 had any type of extinction deficit, while 19 had no problems. The question of the effects of handedness can only be examined in an even larger group study than the one we report.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at: http://dx.doi.org/10.1016/j.neuropsychologia.2013.12.016.

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