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Registered Report

Burning houses revisited: Unconscious preferences not specifically associated with semantic content or visuospatial neglect

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ARTICLE INFO

Article history:
Received 24 October 2024
Revised 19 May 2025
Accepted 20 May 2025
Action editor Robert McIntosh
Published online 29 May 2025

Keywords:
Visual neglect
Stroke
Pre-attentive processing
Neuropsychology
Cognitive impairment

ABSTRACT

Marshall and Halligan's (1988) pioneering study of unconscious processing in visuospatial neglect is one of the most influential neuropsychological single case studies of the last 40 years. Here we report a pre-registered conceptual replication of this study in a large group of patients. Fifty-four stroke survivors (21 with neglect), unselected for lesion location, completed a computerised and extended variation of the Burning House Task. Patients were asked to report whether pairs of pictures were the same or different, and then asked to indicate which image they preferred. On critical trials, one image was normal (intact), and the other had a lateralised addition of either fire (burning) or shading (shaded). In pre-registered analyses, one patient reliably preferred the intact images despite reporting the two to be identical. This replicates Marshall & Halligan's main finding, except that our patient did not have neglect. In exploratory analyses, with adjusted criteria, we identified five additional patients with this pattern, only one of whom showed signs of neglect. All six patients showed similar preferences for intact over burning and shaded pictures, suggesting that the preference was not due to unconscious processing of semantic content ('fire'). Overall, the results suggest that the preference bias preference reported by Marshall & Halligan is neither common in neglect nor exclusive to neglect, and may not be driven by semantic processing of the meaning of fire.

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https://doi.org/10.1016/j.cortex.2025.05.005

1. Introduction

The role of attention in modulating conscious visual perception has long been a subject of intense debate within the research community. Despite decades of targeted research on this topic, the extent to which attention is necessary for absorbing, processing, and consciously experiencing visual information from the world around us remains unclear. Previous research has demonstrated that some level of pre-attentive processing may occur for stimuli that are not consciously perceived, across a range of perceptual and attentional conditions. For example, patients with hemianopic blindsight have been found to be able to reliably identify the location of targets within the blind hemifield while remaining unable to consciously report viewing these stimuli (Cole et al., 1962; Leh et al., 2006; Sanders et al., 1974; Weiskrantz et al., 1974). Similarly, some patients with prosopagnosia exhibit elevated physiological responses when viewing familiar versus unfamiliar faces while remaining unable to consciously report this familiarity (Renault et al., 1989; Tranel & Damasio, 1985). However, pre-attentive processing has received the most attention in the context of visuospatial neglect.

Investigating pre-attentive processing in the context of visuospatial neglect provides a uniquely valuable opportunity to determine the extent to which visual stimuli are pre-attentively processed. Past studies have strongly suggested that pre-attentive processing may occur in patients exhibiting visuospatial neglect, leading to residual processing of some content even to the semantics level. Visuospatial neglect is a common neuropsychological syndrome characterised by consistently lateralised perceptual deficits (Heilman & Valenstein, 1979; Parton et al., 2004). Patients with visuospatial neglect have intact early visual processing, but are unable to consciously perceive stimuli presented in the neglected hemispace (Parton et al., 2004). Neglect is generally associated with damage to the right temporo-parietal or ventro-frontal cortex, but has also been found to result from lesions confined to subcortical structures or the cerebellum (Karnath et al., 2002; Kim et al., 2008; Mort et al., 2003; Ringman et al., 2004; Stone et al., 1993). The primary visual cortex and cortical areas associated with the occurrence of hemianopia blindsight frequently remain undamaged in patients with neglect (Ajina et al., 2015; Bridge et al., 2008; Driver & Vuilleumier, 2001; Leh et al., 2006), suggesting that pre-attentive processing of the nature of these neglected visual stimuli may still occur. This possibility is supported by evidence that the severity of neglect can be modulated by bottom-up perceptual cues presented within the neglected visual field (Daini et al., 2002; Driver & Vuilleumier, 2001; Robertson & North, 1992). Similarly, the severity of spatial bias in neglect patient line bisection performance has been found to be modulated by illusory length manipulations (e.g., Muller-Lyer, Judd illusions) presented within the unattended hemispace (Daini et al., 2002; Ro & Rafal, 1996). These findings suggest that neglected stimuli do in fact undergo early visual processing, but the exact level to which these stimuli are pre-attentively processed remains unclear.

Many previous investigations have aimed to determine whether this pre-attentive processing in neglect represents an early-selection process where only basic visual elements are processed or a late-selection where detailed semantic information is subconsciously processed (Deutsch & Deutsch, 1963; Driver & Vuilleumier, 2001; Norman & Bobrow, 1975; Treisman, 1969). According to the early-selection theory, focal attention is a necessary prerequisite for high-level perceptual processing (e.g., object recognition), implying that only the most basic perceptual features can be processed within unattended space (Halligan et al., 2003; Treisman, 1969). Conversely, late-selection theories of attention posit that some high-level categorical or semantic processing of visual stimuli can be completed in the absence of conscious perception (Deutsch & Deutsch, 1963; Driver & Vuilleumier, 2001). A series of neglect patients exhibiting high-level processing for unattended stimuli have provided tenuous support for a late-selection model of visual attention (Driver & Vuilleumier, 2001; Marshall & Halligan, 1988). For example, patients with visuospatial neglect have been found to exhibit significant priming effects when categorically similar words or picture stimuli are presented within unattended hemispace prior to lexical decision tasks (Làdavas et al., 1993; McGlinchey-berroth et al., 1993). Similarly, Rafal et al. (2002) found that the probability of stimulus extinction in neglect is higher when competing stimuli are semantically similar, regardless of visual similarity. These findings suggest that substantial high-level visual analysis, including reading and semantic categorisation, may be completed pre-attentively. However, it remains unclear exactly what type of higher-level visual information can be processed and to what extent these processes remain intact in patients with visuospatial neglect.

Perhaps one of the most famous studies investigating higher-level pre-attentive processing in neglect, is the Marshall and Halligan (1988) single case study involving PS, a patient with visuospatial neglect who exhibited blindsight-like pre-attentive processing within her neglected hemifield. PS was a 49-year-old woman presenting with a subarachnoid haemorrhage, left hemiparesis, and left hemianopia. When PS's visuospatial function was assessed using object cancellation, line bisection, figure drawing, and reading tasks she was found to demonstrate severe left egocentric (i.e., self-centred) neglect (Marshall & Halligan, 1988). Patient PS was then shown pairs of house line drawings. In each pair, one house had red flames emerging from the left side while the other was intact. When asked whether the drawings were the same or different, PS did not notice the flames and reported that the houses were the same. However, when asked which house she would prefer to live in, patient PS chose the intact house rather than the house without the flames in 14/17 trials ($p = .006$) (Marshall & Halligan, 1988). These findings implied that stimuli's semantic content can be pre-attentively processed and can influence perception in neglect even in the absence of conscious awareness.

However, although these findings are undeniably theoretically significant, there are several potentially serious limitations present within Marshall and Halligan's (1988) original experimental design and interpretation. First, it is not clear whether PS preference responses were influenced by the

semantic content of the images (e.g., the fire) or low-level physical differences lacking in semantic content (e.g., the presence of the colour red). Berti and Rizzolatti (1992) investigated this possibility by asking a series of neglect patients to make categorical judgements about stimuli presented in the attended hemispace. Reaction times were found to be significantly faster when the target stimuli was preceded by a categorical congruent prime stimuli compared to an unrelated stimulus presented in the neglected hemifield (Berti & Rizzolatti, 1992). When patients were primed using semantically meaningless but physically similar shapes, reaction times were found to be significantly faster than in non-congruent semantic conditions but significantly slower than within semantically congruent conditions (Berti & Rizzolatti, 1992). These results suggest that both semantic content and physical similarity can be pre-attentively processed in patients with neglect, but it is unclear whether these influences are different enough to be behaviourally dissociable. This investigation only included a very small sample of neglect patients ($n = 5$, $n = 2$ respectively) and pre-attentive processing was considered significant if it resulted in comparatively small reaction time differences. It remains unclear whether this small reaction time impact is analogous in magnitude to the behavioural preference biases observed by Marshall and Halligan (1998) and whether the impact of pre-attentive processing of semantic and physical differences remains strong enough to result in qualitative behavioural differences.

Second, it is not yet clear whether the findings of this original case study can be generalised to a wider sample of neglect patients. Neglect is a highly heterogenous condition with some patients exhibiting egocentric (i.e., self-centred) impairment and others exhibiting allocentric (i.e., object-centred) deficits (Caramazza & Hillis, 1990; Cubelli, Nichelli, Bonito, De Tanti, & Inzaghi, 1991; Demeyere & Gillebert, 2019; Demeyere, Sun, Milosevich, & Vancleef, 2019). Although egocentric and allocentric neglect do commonly co-occur, these conditions represent doubly dissociated impairments which can range greatly in severity and can occur following right or left hemisphere lesions (Beis et al., 2004; Demeyere & Gillebert, 2019; Moore et al., 2019). Previous studies of pre-attentive processing in neglect have exclusively investigated these effects in a comparatively homogenous sample of patients with severe left egocentric deficits. This means that it remains unclear whether pre-attentive processing is a feature of a specific type of neglect, whether the severity of neglect impairment acts as a predictor of the occurrence of pre-attentive processing, and whether this effect can be identified within a more representative sample of neglect patients. Notably, no previous studies have used Marshall and Halligan's (1988) paradigm in lesioned patients without neglect.

Finally, the small number of trials used to assess PS's preference bias would give very limited statistical power to detect anything other than very large effects (Cohen, 1990, 1992; Faul et al., 2009). Previously attempted replications of Marshall and Halligan's (1998) study have employed similarly underpowered experimental designs (e.g., Bisiach & Rusconi, 1990) and have only assessed a very small, homogenous sample of neglect patients (Berti & Rizzolatti, 1992). Given this limited statistical power present in conjunction with the theoretical significance of Marshall and Halligan's (1988) findings, it remains critically important to verify whether this pre-attentive processing effect can be reliably identified in a wider sample of visuospatial neglect patients.

The purpose of the present study is to replicate the pre-attentive semantic processing effect first documented by Marshall and Halligan (1988) under more stringent experimental conditions and in a broad, representative sample, and to investigate which factors modulate the occurrence of pre-attentive processing in neglect patients. The topic of attention's role in conscious visual perception has long been heavily debated within the research community. This investigation offers a novel opportunity to validate the seminal findings of Marshall and Halligan (1988) while extending these findings to clarify the extent to which visual processing can occur in the absence of conscious perception. The results of this study promise to substantially extend understanding of attention's role in facilitating conscious visual perception.

2. Hypotheses

1) Neglect Patient(s) exhibiting a significant preference for normal over fire stimuli will be identified.
2) Not all patients exhibiting a preference for normal over fire stimuli will also exhibit a significant preference for normal over shaded stimuli.
3) The strength of patient preference bias will be significantly correlated with the severity of egocentric and allocentric neglect.

See Supplementary Table 1 for a summary of each hypothesis' relevant statistical tests, requirements for sufficient power, potential outcomes, and corresponding interpretations.

The Registered Report Stage 1 manuscript associated with this project is available at https://osf.io/x2emr/. Parts of the Methods section have been modified from the Stage 1 document (https://osf.io/x2emr/), to improve the clarity of reporting of the intended study plan, in consultation with the Action Editor at Stage 2.

3. Patients

Stroke survivors both with and without neglect were recruited to take part in this study from Oxford's John Radcliffe Hospital's Hyper Acute Stroke Unit and a community rehabilitation setting (Oxfordshire Stroke Rehabilitation Unit at Abingdon Community Hospital) as a follow-up component of the OCS-Recovery study (national REC reference: 18/SC/0550, see also Milosevich et al., 2023). To be included in this investigation each patient had to: be at least 18 years old, have a confirmed stroke diagnosis, be able to remain alert for 20 min, be able to reliably respond to questions (verbally or via pointing), have completed the OCS Cancellation task with at least 5 targets marked (Demeyere et al., 2015). As this investigation aimed to include a representative sample, patients were not pre-selected based on stroke type, location, or co-occurring cognitive impairments. All planned within-patient analyses were performed on data from patients both with and without

neglect to evaluate whether the pre-attentive processing effect documented by Marshall and Halligan (1988) is specifically associated with the neglect syndrome.

Patients exhibiting hemianopia were excluded in a multi-step process. First, all patients in this investigation completed a basic visual field confrontation task as a component of their standardised post-stroke cognitive assessment (e.g., Demeyere et al., 2015). In this task, the examiner faces the patient and raises both hands. The patient is instructed to maintain central fixation (on the examiner's nose) and report whenever the examiner wiggles their fingers. The examiner sequentailly wiggles fingers placed in the left upper, right upper, left lower, and right lower visual quadrants (four presentations total, maximum possible score = 4) (Demeyere et al., 2015). Patients are awarded one point for each hand wiggle correctly reported, with scores of <4 representing significant visual field impairment relative to normative data (Demeyere et al., 2015).

If a patient exhibited significant impairment on this task, their clinical neuroimaging notes and CT scans were considered. If a patient had a visible lesion which clearly impacts the primary visual cortex, they were excluded from pre-registered analyses. However, as the CT scans being considered are often taken within 24 h of admission, some lesions will not have fully developed at this time. Similarly, hemianopia can result from damage to the optic tract at any point in the brain, not just in the occipital lobe (Pollen, 1999; Zhang et al., 2006). This exclusion process is therefore imperfect, but the authors believe it is the most effective possible, given the limitations of working with this acute stroke population.

4. Materials

4.1. *Cancellation task*

Data from the OCS Cancellation Task was employed to identify patients exhibiting significant visuospatial neglect impairment. This task has been demonstrated to be highly sensitive (94.12%, versus the Behavioural Inattention Test Star Cancellation) and is able to reliably differentiate between allocentric and egocentric visuospatial neglect deficits (Demeyere et al., 2015).

The OCS Cancellation Task consists of a search matrix of 150 heart line drawings pseudo-randomly scattered across a landscape orientation A4 page (Fig. 1). One third of these drawings have left-lateralised gaps, one third have right gaps and the remaining third are complete drawings. These drawings are arranged in grid pattern to ensure that the probability for omissions in each quadrant of the matrix is equal. This grid is not visible when completing the task but is used to assign quantitative neglect severity scores. To complete this test, patients are asked to cross out all complete drawings while ignoring the incomplete, distractor stimuli.

4.2. *Computerised burning house task*

A computerised variation of the original burning house task employed by Marshall and Halligan (1988) was used to detect pre-attentive processing in visuospatial neglect patients and to determine which factors modulate the strength of this effect. In this task, two stimuli were displayed on a tablet computer screen, one in the top half of the screen, and one in the bottom. Five different stimulus types were employed in this investigation: house, car, book, pizza, and television. Each stimulus had three different variations: a normal, intact drawing (intact); a drawing with semantically irrelevant shading; and a version with added flames (burning) (Fig. 2). Before each pair is displayed, a fixation cross remains on screen until the assessor taps to start each trial. Each image was presented in a 10 cm × 12 cm window and remained onscreen for the allocated exposure time. Following each stimulus presentation, patients were prompted to report whether the presented stimuli were the same or different (discrimination task) and to report which one (top image or bottom image) they would prefer to have (preference task) (Fig. 3). Patients were allowed to respond verbally or via touchscreen response (see Fig. 4).

In line with Rafal et al. (2002), we adapted exposure time to match patient performance across the sample in a simplified staircasing procedure. This means that as wide a range of patients as possible were able to complete the task at an appropriate difficulty level. Stimulus exposure time was adjusted based on patient performance and comfort levels. First, practice block stimuli were presented for 500 msec. If patients reported that they were comfortable with the task, the main experiment began. However, if they reported that they found the task too fast, too hard, stressful, or otherwise uncomfortable to complete, the practice block was repeated using a longer exposure time (1500 msec). This longer exposure practice block was required in 29 cases.

Once patients completed the practice block, the exposure time of subsequent stimuli was adjusted based on practice block performance. This adjustment was repeated after every 10 trials involving non-identical image pairs. Specifically, accuracy within the last 10 (practice or experimental) trials involving stimuli with differences was calculated. If accuracy was >70%, exposure time was reduced by half; if accuracy was <20%, exposure time was doubled. Exposure time was not decreased if the current exposure time was ≤250 msec and was not increased if the current exposure time was ≥1000 msec. Overall, this procedure results in exposure times between 187.5 and 1500 msec.

This investigation included 15 blocks of 17 stimuli pairs presented in a randomised order with 255 stimuli presentations total. These stimulus pairs always included stimuli of the same type (e.g., house versus house; pizza versus pizza). Each block contained five intact/intact, five shaded/intact, and five burning/intact trials as well as 2 catch trials. In total, each condition therefore consisted of 75 experimental trials (and 30 catch trials). The location of intact, shaded, and burning stimuli (top or bottom) was counterbalanced. For the catch trials, one burning/intact and one shaded/intact stimuli pair were reflected across the y axis so that the difference appears in the opposite hemifield. These catch trials aim to ensure some stimuli pairs will look different to patients with severe inattention to one side. Neglect patients who respond at chance levels (as tested by a chi-squared analysis) in these catch trials were excluded from this investigation. Patients without neglect were not excluded based on catch trial

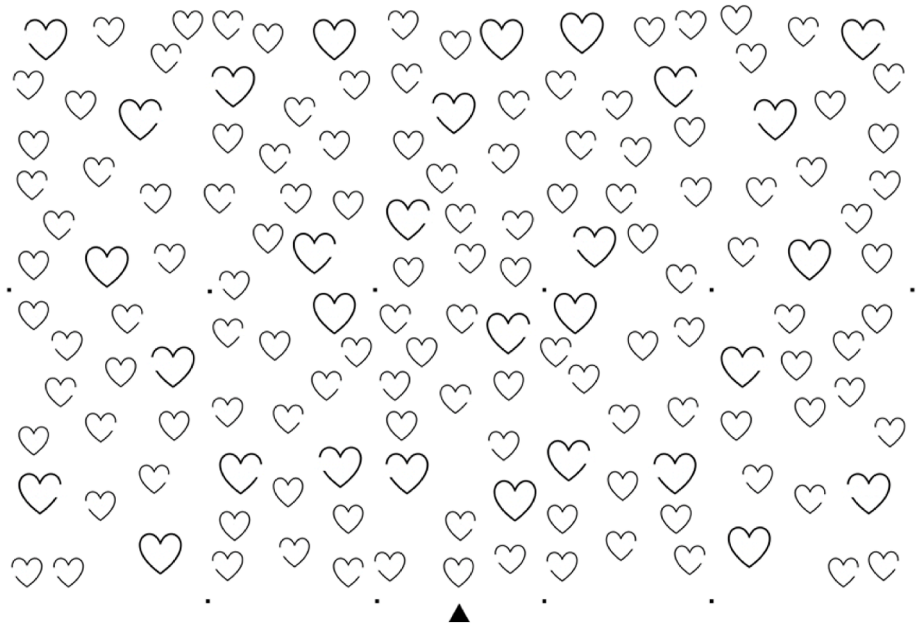


Fig. 1 – The OCS' cancellation task.

performance, as no lateralised performance differences were expected in these patients. Short pauses were taken between blocks, and longer self-timed breaks were allowed after ever five experimental bocks.

This experiment was programmed in MATLAB, employing functions from the Psychtoolbox package (Brainard, 1997) and run on a Microsoft platform tablet computer with touch screen responding. All data, scripts, and study materials associated with this project are openly available at https://osf.io/x2emr/.

5. Procedure

Patients first completed the OCS Cancellation task and then the computerised task within the same testing session. Before beginning the cancellation task, each patient was shown examples of distractor and target drawings and was given two practice trials before proceeding to the full task. Each patient was allowed 5 min to complete the Cancellation Task. Patients who were unable to hold a pen responded by pointing to each stimulus which was then marked by the examiner. Patients who were unable to complete this task reliably (i.e., fewer than five target hearts identified) were excluded from this investigation. In any case where the diagnosis of neglect was not clear (e.g., if a patient was exceptionally slow in completing the cancellation task), the cancellation task was re-administered at a later time to confirm the presence of neglect before the computerised task was completed.

According to the Oxford Cognitive Screen's scoring guidelines, egocentric neglect impairment is scored by subtracting the number of correctly identified targets on the left side of the page from those correctly identified on the right side of the page with scores of less than −3 or greater than 3 represents significant neglect impairment. Allocentric neglect impairment is calculated by subtracting the number of right-gap false positive responses from the number of left-gap false positives with scores less than −1 or greater than 1 representing significant allocentric impairment. These neglect impairment thresholds are based on the Oxford Cognitive Screen's standardised cut-offs which have been established based on normative data (Demeyere et al., 2015).

While these raw behavioural scores provide an effective method for distinguishing between patients with and without neglect impairment, it is possible for the same raw scores to be assigned to two patients exhibiting qualitatively different impairment patterns. For this reason, additional centre of cancellation and allocentric error proportion scores were used to quantify the severity of egocentric and allocentric impairment in this investigation's planned group-level analyses. Egocentric neglect severity was quantified using a centre of cancellation score (e.g., Binder et al., 1992; Rorden & Karnath, 2010). This score is calculated by assigning each target a numerical weight according to its horizontal position in the search matrix and averaging these values to calculate the "centre of mass" of patient responses. Similarly, the proportion of allocentric errors to correct target cancellations was used to quantify allocentric neglect severity in the planned group-level analyses.

All patients (both with and without neglect) completed a version of the computerised burning house task in which 80% of stimuli differences appeared in the neglected side of space. Patients without neglect completed the left-lateralised version (80% of differences on the left), unless the examiner had reason to believe the patient may exhibit mild right neglect ($n = 4$). These patients each exhibited mild rightward biases on acute OCS testing but exhibited normal cancellation scores at the time of testing. Before beginning the computerised task, the experimenter read each patient instructions about the task. These instructions

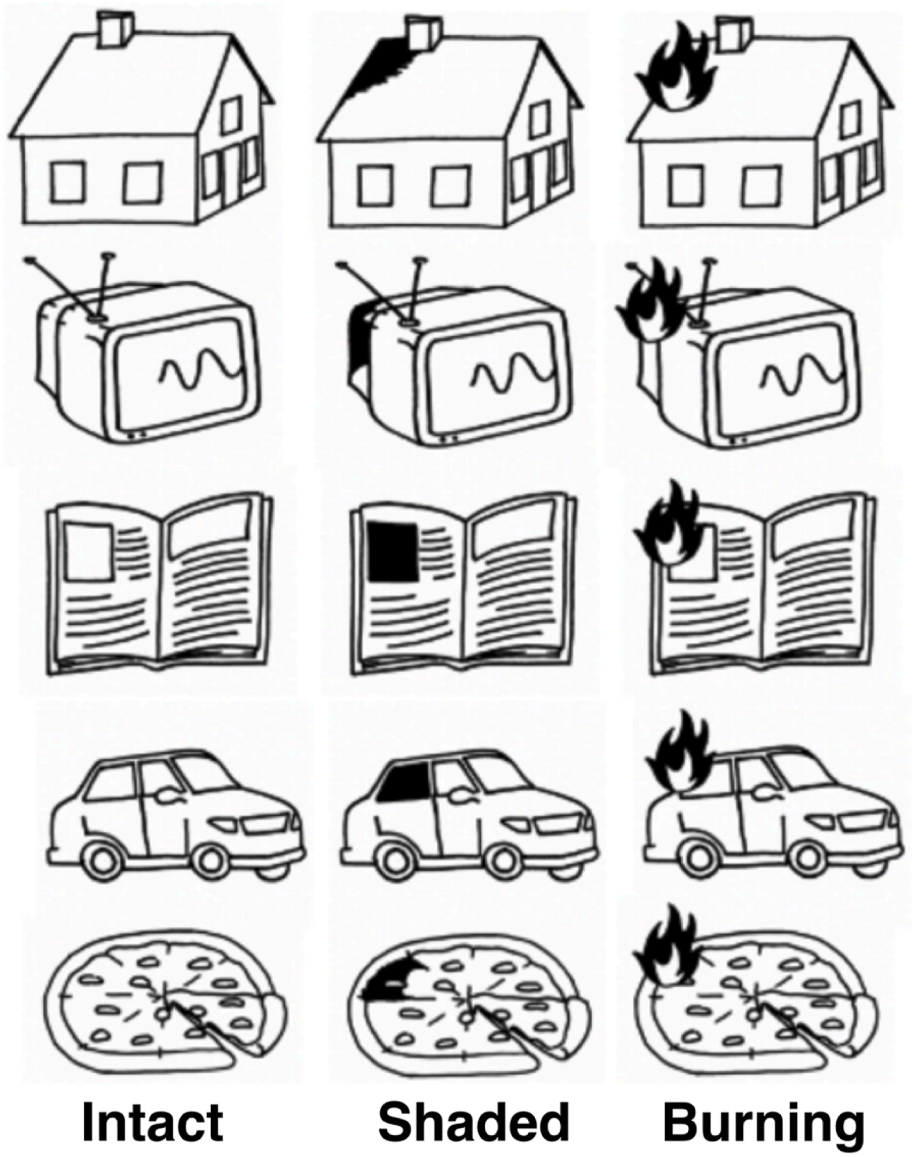


Fig. 2 – The experimental stimuli employed in the computerised task. For cases in which patients exhibit right-lateralised impairments, stimuli are mirror reflected so differences fall in the right visual field.

tell patients that they will be shown a series of items, asked whether they are the same or different, and asked which item they would prefer to have. Patients were told that some items will be different because they are damaged and other items are different because of the way they are drawn. The experimenter made it explicit that damaged items should affect which item they choose to have, while it does not matter which of the items with extra shading they prefer. Patients were told that it is ok to be unsure about which item they would prefer to have, especially since many of the items shown will be the same. Patients were encouraged to guess or pick at random when unsure. Patients were seated approximately 50 cm from this centrally presented tablet screen, with an approximate visual angle of 13.6° for each stimulus. Pilot testing of this procedure has revealed that this experiment takes approximately 25 min to complete.

As a hospital-based study of acute and subacute stroke survivors, several allowances were made to minimise the impact of fatigue on performance. Patients were allowed to take breaks while completing the task and, if necessary, the full number of trials was completed on two separate testing sessions. The planned number of experimental trials (255) was a standard set to ensure that as many patients as possible were able to complete the tablet-based assessment. Patients who were not able to complete this full number of trials were included in analysis if they committed the required number of critical errors in the discrimination task.

This procedure follows a protocol approved by the National Research Ethics Service (REC reference: 18/SC/0550). All

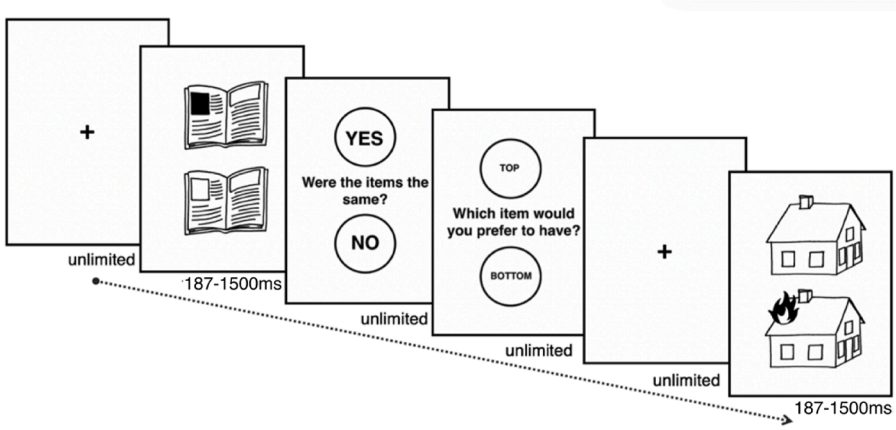
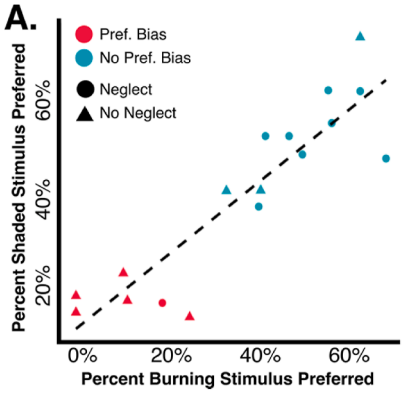


Fig. 3 – A visualisation of the experimental loop design. Two figures were displayed, patients were asked whether or not they were the same (discrimination task), and were then asked to report which item they would prefer to have (preference task). Actual exposure time varied based same/different judgement accuracy. After every 10 trials involving non-identical stimuli pairs, patient performance was evaluated and exposure time adjusted to different difficulty levels based on same/different judgement accuracy.



B. Preference Bias Results

	Burning	Shaded
Pilot 10	15/74*	12/74*
Pliot 7	0/16*	3/17*
P01	7/58*	7/42*
P02	2/18*	6/27*
P03	0/9*	2/14*
P04	4/15	2/15*

Fig. 4 – Relationship between preference biases in shaded and burning trials for patients who were impaired on the discrimination task. (A) Relationship between the percentage of each stimulus type reported as preferred in trials in which the patients reported that different stimuli were the same. This plot shows only patients who were impaired on the discrimination task. Point colour denotes whether each individual met criteria for exhibiting significant preference biases. The dotted line is the line of identity, along which the preference bias is the same for burning and shaded stimuli. (B) Preference bias results for all patients exhibiting significant preference biases. The number of each stimulus type (burning or shaded) chosen as "preferred" is reported over the number of trials in which different stimuli were reported to be the same. Starred proportions are statistically significant. IDs which are starred indicate pilot patients (excluded from main sample) all other patients met criteria for inclusion in the registered analyses.

experimental materials, code, and raw data are openly available on the Open Science Framework webpage.

6. Planned analysis

6.1. *Individual patient performance analysis*

The power requirements, possible outcomes and interpretations of all pre-registered analyses are summarised in Table 1. First, data was analysed to determine whether the pre-attentive processing effect documented by Marshall and Halligan (1988) can be replicated. To address this question, the strength of patient stimuli preferences in intact/burning trials in which stimuli were reported to be the same was analysed. In the original investigation, patient PS was found to prefer the intact stimuli to the burning stimuli in 14/17 (82.40%) of trials in which she reported the stimuli to be identical. This proportional bias yields a Cohen's w effect size of .648 when compared to a hypothetical chance-level preference proportion

(.50). This value was used to inform an a priori power calculation, indicating that a minimum of 31 trials are needed to detect this estimated effect with a power level of .90 in a one-way X^2 goodness of fit test (alpha = .02, df = 1). This analysis revealed that patients must have at least 31 trials in which they report fire and normal stimuli to be the same for their preference bias to be analysed with sufficient power. This analysis was performed for all patients (regardless of neglect occurrence) to evaluate whether Marshall and Halligan's (1988) reported preference bias effect is specifically associated with the neglect syndrome. If at least one patient exhibiting a significant preference for intact/burning stimuli which were reported to be the same was successfully identified, this investigation replicates the preference bias behavioural pattern documented by Marshall and Halligan (1988).

While data from a single patient exhibiting significant preference bias is sufficient to replicate the findings of Marshall & Halligan (1998), the number of patients in which this behavioural pattern is replicated provides a measure of the strength and generalisability of Marshall and Halligan's (1988) original conclusions. If only a single neglect patient is identified, it implies that pre-attentive processing may not be a feature of the neglect syndrome as a whole. While not necessarily representing a strong replication, this finding facilitates a discussion of what behavioural factors might be related to the occurrence of this behavioural pattern and is therefore still theoretically meaningful.

Next, we investigated whether the semantic content of unreported stimulus differences significantly impacts patient preference responses. This analysis aims to determine whether patient preference biases are modulated by physical or semantic aspects of the stimuli, which will clarify the level to which unreported differences are pre-attentively processed. Patients were included in this investigation if they completed at least 31 shaded/intact trials in which a difference was presented, and they reported the stimuli to be the same. In patients with neglect, only stimuli in which differences were presented on the neglected side of space were considered in this analysis. In patients without neglect, all stimuli where differences were not detected were included. This is because, in neglect patients, catch trials were defined as trials in which stimuli were presented on the non-neglected side of space to account for lateralised performance differences. Lateralised performance differences were not expected in patients without neglect, meaning that stimuli presented on both sides of space were considered equivalent in analysis.

A one-way X^2 goodness of fit test was performed to determine whether each patient's preference bias in these trials was significantly different from chance. If patient preference bias for shaded/intact stimuli was significantly different from chance, this would suggest that meaningless differences in shaded stimuli were also pre-attentively processed. This result would indicate that meaningless physical, not just semantic, differences were influencing patient preferences, suggesting that the effect documented by Marshall and Halligan (1988) may be due to pre-attentive processing of physical differences, not semantic content. Alternatively, if this effect is not identified in patients who exhibit significant preference biases for burning/intact stimuli it would imply that semantic content alone is responsible for modulating preference biases.

If both semantic and meaningless physical differences were found to significantly modulate patient preference responses, an additional chi-square analysis was performed to compare the strength of patients' preferences in normal/fire versus normal/shaded conditions. Preference bias strength was quantified as the proportion of fire stimuli preferred in fire/normal and shaded stimuli preferred in shaded/normal presentations. A 2 × 2 X^2 analysis was performed to compare these proportions, meaning that patients must have completed 31 shaded and fire pairings in which they reported the stimuli to be the same to be included in this analysis. If there was no difference in the strength of these biases in a patient, it remained unclear whether semantic or meaningless physical differences were responsible for driving the effect. However, a significant difference in the proportions of fire/shaded stimuli preferred within a patient suggests that physical and semantic stimuli differences were differentially impacting preference biases.

7. Pilot data

The proposed experimental paradigm was pilot tested on 10 stroke survivors (see Table 1). Five of these patients were found to exhibit significant neglect and 5 exhibited no significant neglect impairment. See Table 2 for patient demographics, neglect scores, and a performance summary. One patient with neglect (Pilot 9) was found to respond at chance to catch trials [$X^2(1) = .692$, $p = .41$] and was therefore excluded. The patients with no neglect were found to be able to reliably complete the computerised assessment task while committing a comparatively low number of same/different judgement errors (mean accuracy = 83.0%, SD = 14.8).

Of the 5 neglect patients identified in pilot testing, 2 committed a sufficient number of critical errors (different stimuli reported as the same) to evaluate their preference response biases for both fire and shaded stimuli. Pilot 6 (left egocentric neglect) was not found to exhibit a significant preference bias for fire [$X^2(1) = .25$, $p = .62$] or neutral trials [$X^2(1) = .373$, $p = .54$]. However, the second neglect patient, Pilot10 (right egocentric neglect), was found to exhibit a significant preference bias for normal stimuli in both fire [$X^2(1) = 26.16$, $p < .001$] and neutral [$X^2(1) = 33.78$, $p < .001$] stimuli trials. There was not a significant difference in the strength of preference bias between fire and shaded stimuli conditions for this patient [$X^2(1) = .181$, $p = .67$]. These results suggest, that in this single case, the preference bias effect was driven by pre-attentive processing of physical differences rather than semantic content.

Cumulatively, this pilot data demonstrates that the planned experimental paradigm is feasible. While this pilot data suggests the pre-attentive processing effect documented by Marshall and Halligan (1988) can be replicated, data from additional patients is needed to confirm the factors which modulate the occurrence of this bias in neglect patients. All raw pilot data has been made available on the Open Science Framework and is reported in detail in Tables 2 and 3 (see Table 4).

Table 1 – A summary of each pre-registered hypothesis' relevant statistical tests, requirements for sufficient power, potential outcomes, and corresponding interpretations. Predicted outcomes are demarcated in bold font. See the Planned Analyses section for additional details on power calculations. Notably, group analyses (3) were pre-registered, but were not conducted. The pre-registered protocol describing the planned approach is provided in supplementary materials.

	Tests	Power Requirements	Possible Outcomes	Interpretation
1)	One-way chi-squared	At least 32 fire versus normal trials in which	The proportion of fire to normal stimuli preferred is not significantly different from chance	Marshall and Halligan (1988) not replicated
	Goodness of fit test	Stimuli were reported to be the same	**The proportion of fire to normal stimuli preferred is significantly different from chance**	Marshall and Halligan (1988) **replicated**
2)	2 × 2 chi squared	At least 32 shaded versus normal trials in which	**The proportion of shaded to normal stimuli preferred is not significantly different from chance**	**Physical differences are not pre-attentively processed**
		Stimuli were reported to be the same	The proportion of shaded to normal stimuli preferred is significantly different from chance	Physical differences are pre-attentively processed
3)	Correlation	At least 36 patients	Preference biases correlated with egocentric neglect severity	Semantic pre-processing predicted by egocentric neglect severity
	(Spearman or Pearsons)		Preference biases correlated with allocentric neglect severity	Semantic pre-processing predicted by allocentric neglect severity
			Preference biases correlated with both egocentric and allocentric severity	**Semantic pre-processing predicted by general neglect severity**
			Preference biases not correlated with egocentric or allocentric neglect severity	Semantic pre-processing unrelated to neglect severity

Table 2 – Pilot Data for this experimental procedure. Pilot06 and Pilot 10 committed a sufficient number of same/different judgment errors to be included in the planned investigation. Stars denote significant neglect impairment and significant preference biases. Fire Miss = number of trials in which fire and normal stimuli were reported to be the same. N Shaded Miss = number of critical trials in which shaded and normal stimuli were reported to be identical. Normal Pref is the percentage of critical trials in which the patients preferred the normal stimuli over the fire/shaded version. Stroke Side reports descriptives of stroke locations depicted on routine clinical imaging. This data was not available at the time of pilot testing and Stage 1 review as imaging was not yet available. NV = none visible, NS = no scan.

	Cancellation Performance				Discrimination Task		Burning Trials			Shaded Trials			Demographics		
	Total	Ego.	Allo.	Neglect Side	N Trials	Accuracy	N Miss	Fire Pref	P	N Miss	Shaded Pref	P	Lesion Side	Age	Sex
Pilot 1	48	0	0		255	99.6%	1	0		0	0		L	**38**	M
Pilot 2	28	**−9***	**2***	B	255	79.6%	1	0		0	0		R	75	M
Pilot 3	45	0	0		255	98.0%	1	0		4	3		No Vis.	59	M
Pilot 4	47	0	**3***	L	255	81.2%	4	2		1	0		No Vis.	77	M
Pilot 5	47	1	0		169	69.8%	17	6		18	7		R	66	M
Pilot 6	20	**5***	0	L	230	31.7%	64	34	.62	67	31	.541	R	64	M
Pilot 7	32	0	0		255	70.2%	16	0		17	3		No scan	76	F
Pilot 8	45	0	−1		255	77.3%	15	10		10	7		No scan	88	F
Pilot 9	26	**−14***	0	R	115	41.7%	27	11		29	17		B	63	M
Pilot 10	43	**−4***	0	R	255	29.8%	74	15	**< .001***	74	12	**< .001***	R	77	M

Table 3 – Cancellation and Burning House Task behavioural scores for all patients. Patients with IDs highlighted in bold are included in pre-registered analyses. Patients in normal font are excluded from pre-registered analyses (due to V1 lesions). For transparency, patients who were excluded from all analyses due to chance-level catch trial performance or unreliable cancellation task scores are reported under "Excluded". Total reports the total number of targets (max 50) identified in the cancellation task. Ego and Allo report egocentric and allocentric asymmetry scores. Scores representing significant impairment are starred. Positive scores represent left neglect and negative scores represent right neglect. Neglect side reports the lateralisation of neglect. N trials reports total number of Burning House trials completed.Accuracy reports discrimination task accuracy. Sensitivity reports the percent of trials containing different stimuli in which differences were reported. Specificity reports the proportion of trials where stimuli were identical which were correctly reported as being identical. Asym summarises the difference in discrimination accuracy for differences presented in the left versus right side of space. Positive scores represent cases in which more errors were made when differences were on the left. Negative scores represent cases where more errors were made when differences were on the right. Preference task performance statistics are reported separately for trials in which burning and shaded stimuli were presented. N miss reports number of trials where differences were presented, but stimuli were reported to be identical. N fire/shaded Pref. reports the number of these missed trials where the burning/shaded difference stimulus was preferred. P reports the *p*-value from the chi-squared tests assessing whether these preference proportions were significantly different from chance. Comparisons which survive 5% FDR corrections for multiple comparisons are starred. Lesion Side reports the lateralisation of lesions depicted by the neuroimaging described in exploratory analyses. Scans which were unable to be normalised are classed as No Scan ($n = 1$). Test Side reports the test version (80% difference on left or right) used in each patient. R= Right, L = Left, B = Bilateral. ET range = exposure time range.

	Cancellation Performance				Discrimination Task					Preference Task						Lesion Side	Test Side	ET Range
	Total	Ego.	Allo.	Neglect Side	N Trials	Accuracy	Sensitivity	Specificity	Asym.	Burning Trials			Shaded Trials					
Impaired + preference bias:										N Miss	N Fire pref.	P	N Miss	N Shaded pref.	P			
P01	41	−2	0		255	50.6%	44.4%	75.5%	.07	58	7	**< .001***	42	7	**< .001***	No scan	L	.25–1
P02	48	1	0		255	77.3%	75.0%	91.2%	.02	18	2	**.001***	27	6	**.004***	L	L	.188–1.5
P03	48	−2	0		255	89.8%	87.2%	98.1%	.03	9	0	**.003***	14	2	**.008***	B	L	.188–.75
P04	49	1	0		255	85.5%	83.3%	95.5%	−.12	15	4	.071	15	2	**.005***	R	L	.188–1.5
Pilot 7	32	0	0		255	70.2%	81.7%	77.4%	−.14	16	0	**< .001***	17	3	**.008***	No scan	L	.25–.5
Pilot 10	43	**−4***	0	R	255	29.8%	1.3%	100.0%	−.02	74	15	**< .001***	74	12	**< .001***	R	R	1.5–1.5
Impaired + No preference bias:																		
P07	47	3	0		255	51.4%	33.9%	92.4%	.07	60	26	.302	59	23	.091	R	L	.375–1.5
P08	50	0	**3***	L	84	85.7%	88.0%	100.0%	.02	2	1	1.000	4	2	1.000	R	L	.188–1.5
P09	6	**9***	**3***	L	135	62.2%	72.8%	100.0%	.13	11	8	.132	11	5	.763	R	L	.25–1
P10	11	**11***	**2***	L	168	83.3%	79.0%	100.0%	.11	7	3	.705	14	5	.285	R	L	.188–1.5
P11	6	**5***	**2***	L	234	84.6%	82.5%	100.0%	.07	5	3	.655	19	10	.819	R	L	.188–1.5
P12	38	**−4***	**−3***	R	248	65.7%	74.7%	100.0%	−.05	15	10	.197	22	13	.394	L	R	.25–.5
P13	6	**6***	0	L	255	53.3%	46.7%	100.0%	.33	36	16	.505	44	22	1.000	B	L	.188–1.5
Pilot 5	47	1	0		169	69.8%	70.6%	84.0%	.11	17	6	.225	18	7	.346	R	L	.25–.5
Pilot 8	45	0	−1		255	77.3%	86.1%	82.4%	−.03	15	10	.197	10	7	.206	No scan	L	.25–1
Pilot 6	20	**5***	0	L	230	31.7%	2.2%	100.0%	.05	64	34	.617	67	31	.541	R	L	.5–1
P21	5	**5***	1	L	255	51.8%	31.3%	100.0%	.65	49	29	.199	54	32	.174	R	L	.25–.5
Spared																		
P23	0	0	0		84	97.6%	98.3%	98.3%	.02	1	0		0	0		L	L	.188–.75
P24	5	**5***	0	L	255	70.2%	98.0%	100.0%	−.01	0	0		3	0		R	L	.25–.24
P25	48	0	0		253	98.0%	98.9%	98.3%	−.07	0	0		2	1	1.000	R	L	.188–.75
P26	21	**15***	0	L	218	84.9%	98.4%	100.0%	−.06	1	1		1	1		R	L	.25–.5
P27	50	0	0		258	92.2%	96.2%	93.1%	.05	4	2	1.000	3	3		R	L	.25–.5
P28	50	0	0		255	99.6%	99.4%	100.0%	−.03	0	0		1	1		No Vis.	L	.25–.25
P29	35	−1	0		129	91.5%	98.9%	90.0%	.01	0	0		1	1		B	L	.25–.5

P30	49	0	0		255	89.8%	90.6%	94.8%	−.13	1	1		16	11	.134	R	L	.25−.5
P31	45	−1	−1		169	97.6%	97.5%	99.1%	−.09	3	1	.564	0	0		B	L	.25−.25
P32	45	−2	0		169	88.2%	98.3%	86.7%	−.04	2	2		0	0		No Vis.	L	.1875−.75
P33	47	1	0		255	73.7%	99.4%	73.1%	−.03	0	0		1	1		R	L	.1875−.75
P34	15	**15***	−1	L	168	98.8%	99.0%	100.0%	.01	0	0		1	1		L	L	.188−.75
P35	50	0	0		255	96.5%	100.0%	95.2%	.00	0	0		0	0		L	L	.188−.75
P36	42	−3	0		255	95.7%	99.4%	94.7%	.03	0	0		1	0		L	R	.188−.75
P37	49	1	0		253	91.3%	95.5%	92.4%	.02	4	1	.317	4	1	.317	L	R	.188−.75
P38	49	0	0		255	97.6%	100.0%	96.8%	.00	0	0		0	0		L	R	.1875−.75
P39	50	0	0		253	100.0%	100.0%	100.0%	.00	0	0		0	0		L	L	.1875−.75
P40	47	1	0		255	93.3%	97.8%	93.1%	.03	2	0		2	1	1.000	B	L	.1875−1.5
P41	48	1	**10***	L	255	81.2%	99.4%	79.2%	.01	1	0		0	0		R	L	.188−.75
P42	48	0	0		255	100.0%	100.0%	100.0%	.00	0	0		0	0		No Vis.	L	.1875−.75
P43	41	−3	0		173	90.2%	91.7%	94.1%	.38	6	3	1.000	4	2	1.000	R	R	.188−.75
P44	38	3	0		255	95.7%	95.0%	98.8%	−.10	7	5	.257	2	2		No Vis.	L	.1875−.75
P45	45	**5***	0	L	245	90.6%	100.0%	100.0%	−.03	0	0		0	0		No Vis.	L	.188−.75
P46	45	1	0		284	95.8%	98.5%	95.6%	.00	1	0		2	1	1.000	R	L	.188−.75
P47	49	1	0		255	97.3%	97.2%	98.9%	−.01	3	1	.564	2	0		No scan	L	.1875−.75
P48	50	0	0		255	98.8%	98.9%	99.4%	.01	2	0		0	0		No scan	L	.1875−.75
P49	49	1	0		255	95.7%	97.2%	96.7%	−.05	2	0		3	0		No scan	L	.1875−.75
P50	48	1	0		255	96.1%	100.0%	94.7%	.00	0	0		0			No scan	R	.1875−.75
Pilot 1	48	0	0		255	99.6%	99.4%	100.0%	−.03	1	0		0	0		L	L	.25−.25
Pilot 3	45	0	0		255	98.0%	97.2%	100.0%	.05	1	0		4	3	.317	No Vis.	R	.25−.5
Pilot 2	28	**−9***	**2***	B	255	79.6%	99.3%	100.0%	−.01	1	0		0	0		R	R	.25−.25
Pilot 4	47	0	**3***	L	255	81.2%	96.7%	100.0%	−.27	4	2	1.000	1	0		No Vis.	L	.25−.25
Excluded:																		
P18	12	**−12***	**−3***	R	58	69.0%	75.8%	100.0%	.19	3	2	.564	5	2	.655	No scan	R	.25−.25
P19	7	**7***	0	L	199	43.7%	21.8%	100.0%	.15	38	22	.330	55	34	.080	R	L	.5−1.5
P20	27	**4***	**7***	L	255	54.9%	50.0%	100.0%	−.03	34	19	.493	41	24	.274	R	L	.188−1.5
P22	4	1	**−2***	R	35	37.1%	19.0%	100.0%	.06	9	5	.739	8	6	.157	L	R	1−1
Pilot 9	26	**−14***	0	R	115	41.7%	17.6%	100.0%	−.21	27	11	.336	29	17	.353	B	R	1.5−1.5

Table 4 – Descriptive statistics for neglect and no neglect patients with and without significant preference biases. "Differences Identified" reports preference statistics for trials in which differences were successfully reported in the discrimination task. "Differences Missed" reports preference statistics for cases in which differences were not identified in the discrimination task. Means are presented with standard deviations and individual patient ranges in parentheses

	Spared Discrimination	No Preference Bias	Preference Bias
Patients with neglect:			
Egocentric	4	4	1
Allocentric	2	1	0
Egocentric & allocentric	1	3	0
Discrimination task accuracy	83.8% (70.2–98.8)	64.8% (31.7–85.7)	29.80%
Differences identified			
Burning preferred	15.4% (1.3–56.0)	36.5% (14.0–53.8)	0%
Shaded preferred	14.8% (0–47.2)	48.8% (22.0–100)	0%
Difference missed			
Burning preferred	37.5% (0–1)	56.1% (42.9–72.7)	20.30%
Shaded preferred	50.0% (0–1)	49.8% (35.7–59.3)	16.20%
Patients without neglect:			
N	25	3	5
Discrimination task accuracy	94.6% (73.7–100)	66.1% (51.4–77.3)	74.7% (50.6–89.8)
Differences identified			
Burning preferred	14.4% (0–82.8)	41.3% (32.6–56.7)	11.8% (4.9–28.1)
Shaded preferred	15.7% (0–89.8)	39.2% (34.1–48.4)	16.8% (9.2–31.2)
Difference missed			
Burning preferred	33.1% (0–1)	48.4% (35.3–66.7)	10.0% (0–26.7)
Shaded preferred	57.9% (0–1)	49.3% (38.9–70.0)	16.8% (13.3–22.2)

8. Results - pre-registered analyses

8.1. *Sample descriptives*

Overall, 44 patients completed the pre-registered experimental protocol. One patient (P22) was excluded for failing to complete the cancellation task reliably, one patient (P21) was excluded due to exhibiting visual field impairments and a lesion impacting V1. Finally, three neglect patients (P18, P19, P20) were excluded for exhibiting chance-level accuracy within the Burning House Task's catch trials. These exclusions yielded a final sample of 39 patients including 11 patients with visuospatial neglect (6 egocentric, 2 allocentric, 3 both egocentric and allocentric neglect). Demographic details and performance statistics for these patients are reported in Table 3. All patients included in pre-registered analyses were unimpaired on the OCS visual field test (score = 4/4), with the exception of P13 who failed to report a left-lateralised target (total score = 3/4). In line with the pre-registered hemianopia criteria, P13 is included in the final sample as their stroke damage (small R putamen/external capsule lesion) is inconsistent with a visual field deficit diagnosis.

8.2. *Individual patient analyses*

Three patients (P13 with left egocentric neglect, P07 and P01 with no neglect) met the power threshold necessary for inclusion in analyses aiming to identify evidence of preference biases in burning and shaded stimuli. All other patients committed an average of 3.39 (SD = 4.77, range = 0–18) and 4.86 (SD = 7.21, range = 0–27) errors in which different stimuli were reported to be the same in burning trials and shaded trials respectively. Within trials where differences were missed, P13 (left egocentric neglect) preferred intact over burning stimuli in 55.6% (20/36) of trials [$X^2(2) = .44$, $p = .505$] and preferred intact over shaded stimuli in 50% (22/44) of trials [$X^2(2) = 0$, $p = 1.00$]. Similarly, P07 preferred intact over burning stimuli in 56.7% (34/60) of trials [$X^2(2) = 1.07$, $p = .302$] and preferred intact over shaded stimuli in 61.0% (36/59) of trials [$X^2(2) = 2.86$, $p = .906$].

The remaining patient met pre-registered criteria for replicating the unconscious preference bias effect originally reported by Marshall and Halligan (1988). Specifically, P01 reported that they preferred intact over burning stimuli in 87.9% (51/58) trials in which these different stimuli were reported to be identical [$X^2(2) = 33.38$, $p = 7.58 \times 10^{-9}$]. Similarly, this patient preferred intact over shaded stimuli in 83.3% (35/42) trials in which these differences were not reported [$X^2(2) = 18.67$, $p = 1.56 \times 10^{-5}$]. The strength of this preference bias was not found to be significantly different between trials involving burning and shaded stimulus differences [$X^2(2) = .131$, $p = .717$]. Critically, P01 demonstrated no evidence of visuospatial neglect impairment. Given that only 1 patient replicating the critical effect was identified, the pre-registered group analyses aiming to identify factors which may predict the occurrence of this behavioural pattern were not conducted.

Considered in the context of the pre-registered hypotheses, these results are not in line with Hypothesis 1 or Hypothesis 2. Hypothesis 1 is not supported because no patients with neglect (only one patient without neglect) were found to replicate the critical preference bias effect. Hypothesis 2 is not supported because all patients exhibiting preference biases exhibited similar performance in both burning trials and shaded stimulus trials. Hypothesis 3 could not be evaluated as no patients with neglect were found to exhibit preference biases. All patient data considered in this study's pre-registered and subsequent exploratory analyses is presented in Table 3.

9. Exploratory (unregistered) analyses

The pre-registered analysis protocol was optimised for ensuring the reliability of null results and minimising the risk of bias impacting experimental conclusions. However, these analyses' strict inclusion criteria limit the scope of analyses aiming to identify factors which may modulate the occurrence of the critical preference bias effect. For this reason, a series of exploratory (unregistered) analyses were also conducted.

First, all patients who completed the computerised Burning House Task are included in all relevant exploratory analyses. This includes the pilot patients ($n = 9$) and the patient with a visual field deficit ($n = 1$). Pilot patients were included in exploratory analyses, as there was no difference between the experimental procedure completed by pilot and final study patients. This analytical change also increases sample size and enables more detailed group-level analyses.

Second, minimum trial inclusion thresholds for individual patient preference analyses were removed. Whilst the pre-registered minimum power thresholds were calculated based on the effect size reported by Marshall and Halligan (1988), extreme effects are more likely when sample sizes and trial counts are low. There is therefore a possibility that Marshall and Halligan's (1988) reported effect size is not a reliable estimate of PS' implicit processing's true, underlying effect size. This uncertainty means that power inclusion thresholds calculated based on this reported value are likely unreliable. For this reason, exploratory analyses include all patients in individual-level analyses while employing a False Discovery Rate (FDR) correction for multiple comparisons to control false positive rates (FDR = .05). This approach entails a higher risk of type 2 errors compared to the pre-registered analyses but allows for data from 49 patients to be included in analysis.

Third, additional sources of information were considered. Specifically, the exploratory analyses incorporate domain-specific cognitive screening data from the Oxford Cognitive Screen (OCS) as well as lesion data derived from routine neuroimaging. These analyses aim to identify factors which may help differentiate between patients exhibiting and not exhibiting preference biases on the computerised burning house task.

Overall, these exploratory analyses aimed to determine whether (1) preference biases are associated with neglect, (2) preference biases are driven by semantic content, and (3) which factors differentiate between patients with and without preference biases. These additional analyses are intended to supplement and expand upon the results of the pre-registered analyses.

9.1. *Patient descriptives*

Sixteen patients with neglect and 33 patients without neglect were included in the exploratory analyses. Of those with neglect, 9 patients had egocentric neglect (7 left, 2 right), 3 had allocentric neglect (left), and 4 had both egocentric and allocentric neglect (3 left, 1 bilateral (Pilot 02: left egocentric and right allocentric nelgect). Thirty-one patients completed the full 255 trials, while the remaining 18 completed between 84 and 253 trials (mean = 187.9, SD = 56.5) due to fatigue or sustained attention limitations.

9.2. *Discrimination task performance*

For the discrimination task, average accuracy for patients with neglect was 70.9% (SD = .20, range = .20–.98) and 89.1% (SD = .13, range = .51–1.00) for patients without neglect (Table 4). In patients with neglect, discrimination task accuracy was not significantly related to the severity of egocentric neglect [$t(14) = .122$, $p = .905$] or allocentric neglect severity [$t(14) = .319$, $p = .755$].

Neglect patients were far more likely to exhibit impairment on the discrimination task than non-neglect patients, with 9/16 neglect patients and 8/32 patients without neglect exhibiting discrimination impairment. However, it is plausible that patients with impaired discrimination accuracy and no neglect may have mild neglect was not detected by the cancellation task. If this is the case, discrimination errors would be expected to predominantly impact either left-lateralised or right-lateralised differences, rather than being distributed evenly across space. To explore this possibility, discrimination accuracy for differences presented on the left and right was compared in patients with impaired discrimination and no neglect. All patients without neglect exhibited similar discrimination accuracy for differences presented on the left and right side (average accuracy difference between left/right trials = 7.27%) (range = 2.0%–14.0%, min $p = .068$).

9.3. *Can Marshall and Halligan's (1988) preference bias results be replicated (regardless of neglect status)?*

First, exploratory discrimination and preference task results were considered, to evaluate whether the critical preference bias effect reported by Marshall and Halligan (1988) was replicated. Patients who were able to accurately report that stimuli were different in at least 90% of trials in which differences were present, were classed as unimpaired in the discrimination task. For those who were impaired on the discrimination task (i.e., judged at least 10% of different stimuli to be identical), the preference responses were analysed using (one-way goodness of fit) chi-squared tests. This determined whether the proportion of intact stimuli that were "preferred" was significantly different from chance. For neglect patients, preference bias analyses only included trials in which stimulus differences were presented on the neglected side of space. For patients without neglect, all trials were included in preference bias analyses. Preference biases were considered significant in cases where chi-squared tests survived a 5% FDR correction for multiple comparisons.

Seventeen patients (9 with neglect, 8 without neglect) demonstrated an impairment on the discrimination task (32 unimpaired: 7 with neglect, 25 without neglect) (i.e., judged at least 10% of different stimuli to be identical). Of these, eleven patients (8 with neglect, 3 without neglect) did not exhibit a significant preference bias for burning differences (X^2 range = 0–2.27, min corrected $p = .564$, min uncorrected $p = .132$) or shaded differences (X^2 range = 0–2.86, min corrected $p = .36$, min uncorrected $p = .091$) (Table 2). This demonstrates that most patients, who failed to notice the stimulus difference, also provided chance-level choices with regards to preference. Six patients presented with both a discrimination impairment and a preference bias: 5/6 exhibited a significant

preference for intact stimuli over burning stimuli (X^2 range = 9.00–33.38, corrected p-range = 2.27 × 10-7 – .016, uncorrected p-range = 7.58 × 10^{-9} – .003) and all patients demonstrated a significant preference for intact over shaded stimuli (X^2 range = 7.11–33.78, corrected p-range = 1.85 × 10-7 – .038, uncorrected p-range = 6.16x x10^{-9}-.008). The critical preference bias effect was most pronounced in Pilot 10 (right egocentric neglect) who indicated that burning and intact stimuli were identical in 74 trials but preferred the intact stimuli in 59 of these (79.7%) cases. Thus, the preference bias effect reported by Marshall and Halligan (1988) was replicated in a subset of the current stroke patients, supporting the findings presented in the pre-registered analyses.

9.4. *Are preference biases associated with neglect?*

Overall, within the exploratory analyses, the critical preference bias effect was replicated in 5 patients who did not have visuospatial neglect, and one patient with neglect was an atypical individual with right-sided neglect following bilateral lesions. In patients with neglect, logistic regression analyses revealed that neither the severity of egocentric neglect ($z = -.533$, $p = .594$), nor the severity of allocentric neglect ($z = -.003$, $p = .998$), was significantly associated with the occurrence of preference biases. Overall, neglect factors (e.g., type, lateralisation) did not discriminate between patients who did and did not exhibit a significant preference bias within these exploratory analyses.

9.5. *Are preference bias responses driven by semantic content?*

Next, we investigated whether the occurrence of preference biases was related to the presence of semantic content. All patients who exhibited significant preference biases for intact over burning stimuli ($n = 5$) also exhibited significant preference biases for shaded stimuli over intact stimuli in cases where differences were not reported. For each patient with a significant preference bias, the strength of preference was similar for burning and shaded stimuli (X^2 range = .131–1.34, min corrected $p = .717$, min uncorrected $p = .247$) (Fig. 4). Overall, these exploratory analyses demonstrate that unconscious preference bias effects occurred for both semantically meaningful and shaded stimulus differences, and that the strength of preference biases in the two different stimulus types were correlated.

9.6. *Lesion distribution differs across behavioural groups*

Where available, routine post-stroke neuroimaging data were obtained and used to explore the relationship between lesion anatomy and the occurrence of discrimination impairment and preference biases. Of the 49 patients included in supplementary analysis, neuroimaging data were analysed for 36 (34 CT, 2 T2 MRI). All lesion masks were manually delineated by trained experts (MJM, IC) in line with the standard protocol reported by Moore (2022). Native-space lesion masks were smoothed at 5 mm full-width at half maximum in the z-direction, binarized (.5 threshold), reoriented, warped into 1 × 1 × 1 mm stereotaxic space using Statistical Parametric Mapping (Ashburner et al., 2016) and Clinical Toolbox (Rorden et al., 2012) functions, and were visually inspected for quality. Scans were not available for 6 patients. Scans were available (but unsuable) for a further 7 patients due to no visible lesion damage ($n = 6$) or inaccurate normalisation ($n = 1$). Importantly, this study's sample size and lesion distribution are not sufficient to support statistical lesion mapping analyses (Moore et al., 2023). For this reason, this study's lesion analyses do not aim to draw definitive conclusions about the neural correlates supporting pre-attentive processes, but instead aim to identify broad lesion differences between behavioural groups.

Lesion size was not associated with the occurrence of preference biases in patients with (binomial regression, $p = .350$, estimate = 2.27 × 10^{-5}) or without neglect (binomial regression, $p = .085$, estimate = 1.64 × 10^{-5}). However, lesion distribution differences were descriptively present across patients who were spared, impaired with no preference bias, and impaired with significant preference biases (Figs. 5 and 6). Patients (both with and without neglect) who were spared (accurately identified differences in >90% of trials) on the discrimination task exhibited comparatively smaller lesions (mean volume = 41.8 cm^3 and 25.7 cm^3 for neglect and no neglect groups respectively) mainly impacting the territory of the middle cerebral artery (MCA). All patients with lesions confined to the cerebellum ($n = 3$) or pons ($n = 1$) were unimpaired on the discrimination task. Lesions of patients who were impaired on the discrimination task but showed no preference bias, were larger on average (mean volume = 61.9 cm^3 and 61.0 cm^3 for neglect and no neglect groups), though not significantly different in size than those of spared patients [neglect group: $t(10.9) = -.76$, $p = .466$, no neglect group: $t(4.43) = -.83$, $p = .451$]. The highest degree of lesion overlap within impaired neglect patients was present in right anterior MCA territory, while no clear pattern of overlap was apparent within impaired patients without neglect (see Figs. 5 and 6).

Notably, all patients with and without neglect who exhibited preference biases had lesions impacting the anterior MCA territory. The posterior cerebral artery (PCA) territory damage visible in MNI slices 2–20 (Fig. 5) occurred in P4, who had an acute haemorrhagic stroke which primarily impacted right frontal cortical areas but also co-occurred with an additional acute bleed in the PCA territory. These exploratory lesion analyses provide a preliminary indication that the occurrence of preference biases in our study sample may be associated with damage to frontal cortical areas.

9.7. *Preference bias effect occurrence and post-stroke cognitive impairments*

Fourty-seven out of 49 patients included in this study completed the OCS during acute hospitalisation (see Table 5 for summary of scores). Within patients with neglect, patients who were unimpaired on the discrimination task had fewer OCS domains impaired relative to patients who were impaired. In patients without neglect, patients exhibiting preference biases exhibited higher levels of OCS impairment relative to the other behavioural groups. Three patients who

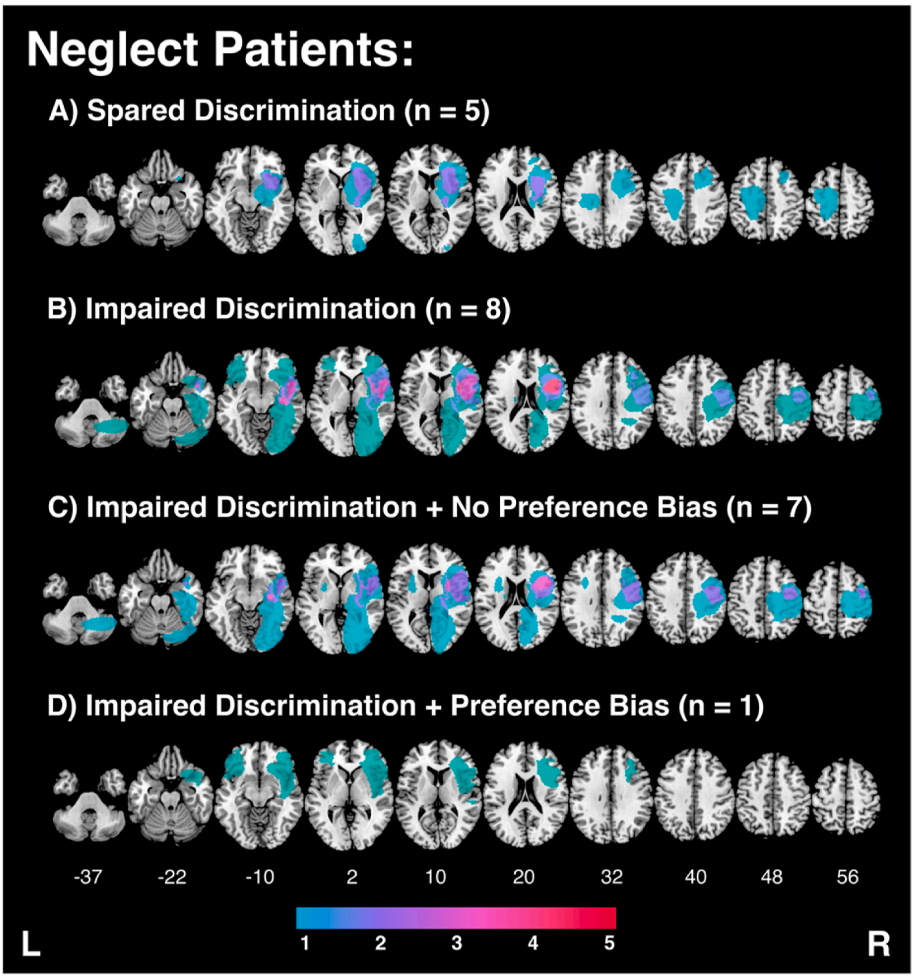


Fig. 5 – Lesion overlays for neglect patients who were spared (A) and impaired (B) on the discrimination task. Panels C & D show lesions for patients who were impaired on the discrimination task, separated by the presence (D) versus absence (C) of significant preference biases on the Burning House Task. Voxel colour denotes number of lesions overlapping at each region. MNI axial -37 –56 are visualised. The figure combines both CT and T2 lesions in standard space. This combination of imaging types is recommended in lesion mapping analyses as it optimises statistical power (de Haan & Karnath, 2018; Moore et al., 2023; Moore et al., 2023).

did not exhibit neglect at the time of this study did exhibit neglect at acute testing (1 egocentric neglect, 2 egocentric and allocentric neglect). However, each of these resolved neglect cases were categorised as spared on the discrimination task. No neglect patients with preference bias were impaired on the OCS visual field test at the time of acute OCS testing. One patient without neglect (Pilot 07), faield the OCS visual field test at the time of acute testing. Patients with significant preference biases (both with and without neglect) demonstrated higher rates of executive impairment relative to other behavioural groups (see Table 5 for overview of all OCS subtasks).

10. Discussion

We present a pre-registered, methodologically stringent replication of Marshall and Halligan's (1988) seminal case study on apparent unconscious processing effects in neglect in a moderately large sample of patients, which was designed to address 3 questions:

1. Can the critical preference bias reported by Halligan & Marshall (1988) be replicated?
2. If replicated, is this effect specific to semantically meaningful stimuli?
3. If replicated, is the strength of this preference bias related to the severity of neglect.

Our pre-registered (and exploratory) analyses demonstrate that the critical preference bias effect reported by Marshall and Halligan (1988) was replicated, with patients failing to discriminate between different stimuli, but nevertheless reporting a strong preference bias. We found no evidence that this preference bias was specific to semantically meaningful informational. The results of both the pre-registered and further exploratory analyses highlight several important complexities in this preference bias effect which suggest that

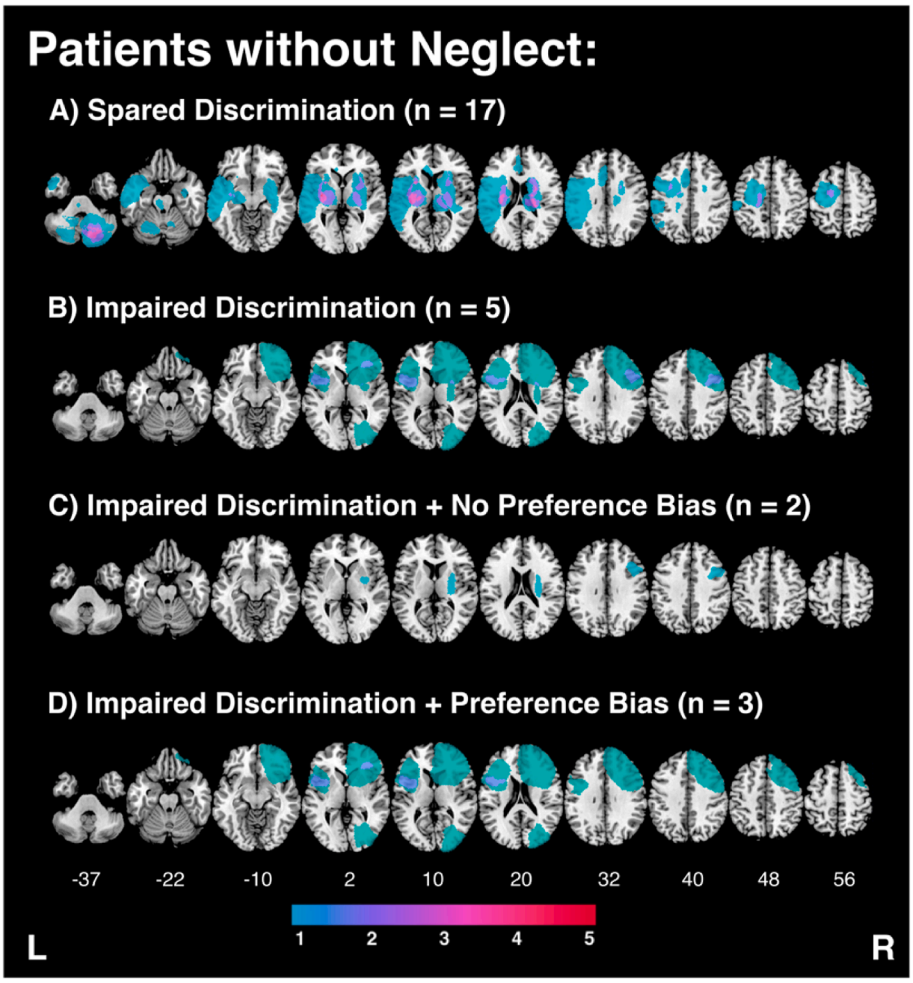


Fig. 6 – Lesion overlays for patients without neglect who were spared (A) and impaired (B) on the discrimination task. Panels C & D show lesions for patients who were impaired on the discrimination task, separated by the presence (D) versus absence (C) of significant preference biases on the Burning House Task. Voxel colour denotes number of lesions overlapping at each region. MNI axial -37 –56 are visualised. The figure combines both CT and T2 lesions in standard space. This combination of imaging types is recommended in lesion mapping analyses as it optimises statistical power (de Haan & Karnath, 2018; Moore et al., 2023; Moore et al., 2023).

the theoretical inferences drawn by Marshall and Halligan (1988) should be interpreted with caution.

Our results confirmed that a higher proportion of neglect patients (relative to patients without neglect) failed to detect lateralised differences in two simultaneously presented stimuli. However, the occurrence of preference bias was not predicted by the presence or severity of neglect. Notably, the single identified patient with neglect and pre-attentive processing case was a very mild neglect case (egocentric asymmetry = –4). Additionally, we identified patients with no signs of visuospatial neglect (1 following the pre-registered criteria, 5 in exploratory analyses) who exhibited significant preference bias.

There are several potential explanations for this finding. First, this result could indicate a lack of sensitivity in detecting the neglect impairment. Past research has suggested that specific task factors such as exposure time and stimulus density may induce neglect-like errors in patients who are unimpaired on standardised pen-and-paper neglect tests (Bonato et al., 2013; Husain & Kennard, 1997; Kartsounis & Findley, 1994; Nijboer & Van Der Stigchel, 2019; Gurd, Demeyere, & Moore, 2024; Moore & Demeyere, 2020). We suggest that the present data do not support such an interpretation. This is because, if discrimination errors in patients without neglect were driven by lateralised attentional biases which were not detected by the cancellation task, discrimination errors would be expected to also be lateralised. This was not found to be the case, as the discrimination errors (and subsequent biased preference responses) in the critical patients without neglect were not consistently lateralised (See Table 3). Additionally, all patients who exhibited neglect at the acute stage but who had recovered by the time of testing for this study were able to reliably complete the discrimination task (See Table 5). This further supports the implication that preference bias in the absence of neglect cannot be explained by residual neglect biases, as the patients most at-risk of exhibiting residual neglect were able to reliably identify lateralised stimulus differences.

Table 5 – OCS performance across behavioural groups. The number and proportion of patients impaired on each OCS subtest is reported. Tasks Impaired reports the group mean number of subtests impaired along with ranges.

	Patients With Neglect			Patients Without Neglect		
	Spared Discrimination	Impaired & No Preference Bias	Preference Bias	Spared Discrimination	Impaired & No Preference Bias	Preference Bias
Number tested:	7	8	1	25	2	4
Attention:						
Cancellation total	3 (42.8%)	7 (87.5%)	0	4 (16.0%)	0	2 (50.0%)
Egocentric neglect	3 (42.8%)	4 (50%)	1 (100%)	3 (12.0%)	0	0
Allocentric neglect	2 (28.6%)	6 (75.0%)	1 (100%)	2 (8.0%)	0	0
Executive:						
Trail making task	3 (42.8%)	1 (12.5%)	1 (100%)	3 (12.0%)	0	3 (75.0%)
Language:						
Picture naming	1 (14.3%)	1 (12.5%)	0	2 (8.0%)	0	1 (25.0%)
Semantics	0	1 (12.5%)	0	0	0	0
Sentence reading	2 (28.6%)	3 (37.5%)	0	3 (12.0%)	0	1 (25.0%)
Memory:						
Orientation	2 (28.6%)	4 (50%)	1 (100%)	3 (12.0%)	0	2 (50.0%)
Episodic recognition	0	1 (12.5%)	0	1 (4.0%)	0	0
Verbal recall	2 (28.6%)	1 (12.5%)	0	0	0	1 (25.0%)
Number:						
Calculation	1 (14.3%)	1 (12.5%)	0	1 (4.0%)	0	1 (25.0%)
Number writing	3 (42.8%)	4 (50%)	1 (100%)	3 (12.0%)	0	2 (50.0%)
Praxis:						
Gesture imitation	1 (6.3%)	2 (25.0%)	0	1 (4.0%)	0	1 (25.0%)
Visual field task						
	0	2 (25.0%)	0	0	0	1 (25.0%)
Tasks impaired						
	1.5 (1–7)	4.8 (3–10)	5	1.1 (0–6)	0	3.75 (3–5)

Importantly, the mechanisms underlying the documented preference bias in patients without neglect cannot be assumed to be directly analogous to the pre-attentive processing effect documented by Marshall and Halligan (1988). This is because these patients do not clearly exhibit a lateralised attentional deficit and committed errors which impacted both the left and right sides of space. In neglect patients, discrimination errors were considered in preference biases only in cases where the critical difference was presented on the neglected side of space. However, in patients without neglect, discrimination errors were included in preference bias analyses regardless of stimulus lateralisation. This procedure was adoptedas, in patient without lateralised biases, there is no clear reason to arbitrarily exclude data from one side of space. However, this leads to differences in how the key preference bias effect was defined between patients with and without neglect. Overall, patients without neglect do not clearly exhibit a lateralised attentional deficit and committed errors which impacted both the left and right sides of space. It remains unclear whether these failures to report stimulus differences can be ascribed to inattention, and therefore whether observed behavioural preference bias in patients without neglect can be attributed to pre-attentive processing.

A potential alternative explanation may be that the preference bias could be, additionally, or in part, linked to executive dysfunction. Tentative support for this possibility comes from the non-lateralised errors in combination with the descriptive associations found between the preference bias effect and executive dysfunction as captured by the OCS trail-making task as well as the descriptive differences in lesion anatomy between patients with and without significant preference biases (Fig. 5). In line with this conceptualisation, failure to identify differences in discrimination trials may be linked to a response inhibition or perseveration deficit. For example, patients may have perceived stimulus differences but may have failed to inhibit a predominant response (e.g., saying stimuli were identical) on the discrimination task (Moore and Demeyere, 2023). If this was the case, patients would be expected to have conscious access to the information they need to accurately complete the preference task in cases where stimuli were reported to be identical.

Importantly, the data presented here are not sufficient to confidently support this potential alternative explanation, but we tentatively offer it for discussion. Future studies could aim to evaluate this speculation by probing the rationale behind preference responses (e.g., asking why each stimulus was preferred) as done by Bisiach & Rusconi (1990). This manipulation has the potential to test whether patients who failed to report stimulus differences were unaware of these differences or whether they simply failed to inhibit previous responses. Additionally, explicitly probing the reasoning behind preference choices has the potential to evaluate whether differences in preference choice rationale are present between patients who do and do not exhibit consistent preference biases. Overall, asking patients about the reasons for their preferences could help elucidate the mechanisms underlying the occurrence of an 'apparent unconscious' preference bias effect in patients with no neglect impairment. However, doing this for large numbers of trials would significantly lengthen the duration of the experiment and requirements for sustained attention, likely requiring additional breaks and

sessions. This has implications on feasibility and acceptability of such an experiment, particularly for in-hospital, early post-stroke testing.

The results of this pre-registered analysis also indicate that the preference bias effect reported by Halligan & Marshall (1988) appears to be very rare in neglect and any implications of this behavioural pattern should be interpreted with caution. Whilst many patients indeed failed to detect some differences between the simultaneously presented stimuli (e.g., two thirds of neglect patients in our study), all but one showed no preference bias in choosing which stimulus they preferred. This study also presents the first investigation of preference bias in a control group of patients without neglect. This control group illustrates that the occurrence of preference biases can be a behavioural feature that is not specific to the neglect syndrome.

We found no evidence for any difference of preference bias between semantically meaningful and shaded stimuli. This result was consistent across the single patient exhibiting both neglect and preference bias and the remaining 5 patients who exhibited preference biases, but not neglect. Whilst the total number of patients in which this could be investigated was small, exploratory analyses found the strength of preference biases within shaded and burning stimuli to be similar, with no significant differences emerging between the strength of these biases within individual patients. This lack of difference was found even in individuals committing many errors (e.g., > 100), suggesting that this null result is unlikely to be driven by low statistical power. Notably, the statistically significant occurrence of preference bias-like effects within shaded stimuli, regardless of this effect's comparative strength, provides evidence that pre-attentive processing of semantic information alone is not enough to explain the occurrence of unconscious preference biases. It is unlikely the occurrence of preference biases within shaded stimuli was driven by patients subjectively assigning semantic value to the shaded stimuli, as patients were explicitly informed that shading did not mean an object was damaged and that the presence of shading alone should not impact their preference responses. Similarly, it is plausible that any stimulus differences, regardless of semantic content, may be pre-attentively processed at a cognitive level which is sufficient to inform preference choices. Considered in the context of Marshall and Halligan's (1988) case (which did not include a non-semantic control condition), this suggests that the critical preference bias effect reported in PS could have similarly occurred in response to stimuli with no difference in semantic content, though we cannot provide definitive conclusions based on our data.

Marshall and Halligan's (1988) study is one of the most influential case studies in neglect research. However, the results of this study suggest that this seminal case study's core conclusions should be interpreted with caution. This example highlights the need for influential neuropsychological case studies to be critically evaluated using methodologically rigorous experimental approaches before their theoretical contributions can be considered generalisable. Registered reports may have a role to play here, ensuring high quality methodological approaches to neuropsychological studies, though given unpredictability and large ranges of variance inherent to patient data, a different analytical approach may be warranted as was the case here (see also Moore & Demeyere, Under Review).

Neuropsychological case studies represent a uniquely valuable method for highlighting critical theoretical violations and characterising rare behavioural patterns (Medina & Fischer-Baum, 2017; Shallice, 1979, 1988). However, the scientific benefit of the neuropsychological case study approach can only be fully realised when these studies are methodologically stringent. Single case studies often report on important effects which are extremely rare and should not be expected to generalise to all relevant patients. This means that heterogenous results, like those reported in our study, should not be interpreted as evidence that results reported in case studies are not valid. Instead, group studies provide important insight into the prevalence and potential variability of effects which cannot be inferred by considering single case data alone. Even the most seminal neuropsychological contributions need to be critically evaluated to ensure that key theories and future research directions are shaped by findings which are reliable, replicable, and methodologically sound.

CRediT authorship contribution statement

Margaret Jane Moore: Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Georgina Hobden:** Writing – review & editing, Data curation. **Sam S. Webb:** Writing – review & editing, Data curation. **Ibe Couwels:** Data curation. **Jason B. Mattingley:** Writing – review & editing, Supervision, Investigation. **Nele Demeyere:** Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization.

Funding

JBM was supported by a National Health and Medical Research (NHMRC) Investigator Grant (Leadership 3; GNT2010141). ND is funded by the National Institute for Health Research (NIHR) (Advanced Fellowship NIHR302224). The study was further supported by the National Institute for Health Research (NIHR) Clinical Research Network and the NIHR Oxford Biomedical Research Centre (BRC) based at Oxford University Hospitals NHS Trust and University of Oxford. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health.

Acknowledgements

We would like to thank the patients who took part in the Oxford Cognitive Screening study and all research staff who contributed towards data collection. In particular, we acknowledge the contributions to data collection and curation for the OCS data made by Ms Ellie Slavkova, Ms Grace Chiu, and Ms Romina Basting. We would also like to thank our Cortex Editor, Prof. Rob McIntosh, for providing detailed and thorough reviewer feedback on several drafts of the Stage II manuscript.

Scientific transparency statement

DATA: All raw and processed data supporting this research are publicly available at https://osf.io/x2emr/.

CODE: All analysis code supporting this research is publicly available at https://osf.io/x2emr/.

MATERIALS: All study materials supporting this research are publicly available at https://osf.io/x2emr/.

DESIGN: This article reports, for all studies, how the author (s) determined all sample sizes, all data exclusions, all data inclusion and exclusion criteria, and whether inclusion and exclusion criteria were established prior to data analysis.

PRE-REGISTRATION: At least part of the study procedures was pre-registered in a time-stamped, institutional registry prior to the research being conducted. Available at https://osf.io/x2emr/.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cortex.2025.05.005.

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