SPECIAL SECTION

DORSAL SIMULTANAGNOSIA: AN IMPAIRMENT OF VISUAL PROCESSING OR VISUAL AWARENESS?

Georgina M. Jackson1**, Tracy Shepherd**1**, Sven C. Mueller**1**, Masid Husain**² **and Stephen R. Jackson**³

(1Division of Psychiatry, Queen's Medical Centre, The University of Nottingham, Nottingham, UK; 2Division of Neuroscience and Psychological Medicine, Imperial College, University of London, London, UK; ³School of Psychology, The University of Nottingham, Nottingham, UK)

ABSTRACT

When presented with two objects patients with simultanagnosia show a marked impairment at naming both items. This has led many authors to conclude that the second item is not being processed (e.g., Robinson, 2003). However, this deficit may instead reflect a deficit with explicit, or conscious report. We investigated this issue using a semantic priming paradigm that allowed us to assess implicit processing of the second "unseen" item. We presented a patient, with bilateral parietal damage, with pairs of pictures that were either from the same or a different semantic category. The patient was asked to either classify one of the pictures or to name both pictures. When the items were from different categories the patient's classification performance was significantly poorer than when they were from the same category, even though he could rarely explicitly report both items. These findings are consistent with the notion that the meaning of the "unseen" item influenced the reporting of the "seen" item. Consequently, the deficit seen in this patient does not seem to reflect an inability to process more than one item simultaneously but rather a deficit in explicitly identifying multiple items.

Key words: parietal cortex, Balint's syndrome, simultanagnosia, implicit processing, semantic priming, attention

INTRODUCTION

Balint's syndrome is a rare neuropsychological condition resulting from bilateral damage to parieto-occipital cortex. The syndrome is manifest clinically as a triad of symptoms including: optic ataxia, paralysis of gaze and spatial disorder of attention (Balint, 1909; Husain and Stein, 1988). Optic ataxia refers to a deficit in visually guided reaching movements that does not result from basic deficits in sensory or motor processing (Balint, 1909; Rizzo, 1993). Paralysis of gaze refers to a paucity of spontaneous eye movements, coupled with inappropriate fixation of gaze and difficulties in voluntarily shifting fixation to other objects that is now termed "ocular apraxia" (Balint, 1909; Rizzo, 1993). The spatial disorder of attention associated with Balint's syndrome refers to an inability to "perceive" more than one object at a time that is now termed "dorsal simultanagnosia" (Balint, 1909; Robertson, 2003).

While patients with simultanagnosia are unable to identity two items presented simultaneously unless those items are presented for far longer than is normally required for identification; this does not mean that the unnamed item is not being processed visually. If indirect measures that do not require an explicit or conscious judgement are obtained, then sensitivity to the undetected item can be observed through changes in performance. Many studies of patients with hemispatial neglect have reported implicit processing of visual stimuli presented in the patients' neglected field of which the patient is

unaware (e.g., Baylis et al., 1993; Marzi et al., 1996). The degree of implicit processing of the unseen item can be quite extensive and may include both object identification and semantic priming (e.g., Berti and Rizzolati, 1992; McGlinchey-Berroth et al., 1993). For example, Berti and Rizzolati (1992), presented neglect patients with pairs of objects, either from the same semantic category or from a different semantic category. Patients were faster to classify the item in their non-neglected field when they were both from the same semantic category compared with when they were from different categories. Similarly, McGlinchey-Berroth et al. (1993), using sequential presentations of items, demonstrated speeded reaction times (RTs) if the preceding item presented in the neglected field, was semantically related to the item in the patient's non-neglected visual field.

A few recent studies have demonstrated implicit processing after bilateral damage to parietal lobe resulting in Balint's syndrome. For example, Kim and Robertson (2001) showed that the Balint's patient, R.M., was able to make use of the direction of an arrow cue to aid visual search in the absence of awareness of the direction that the arrow pointed. Implicit processing of the identity of a global letter that could not be explicitly reported has also been demonstrated in a Balint's syndrome patient that was studied by Karnath et al. (2000). In this study, the patient was significantly slower to name the local letters in a "Navon figure" when the local letters had a different identity to that of the global letter. We observed a

similar effect in the patient reported in the current study (Jackson et al., 2004). Using event-related potential (ERPs) recording techniques, we found both slowed RTs and an increased ERP negativity over frontal sensor sites, when the global "Navon" letter was incongruent with the identity of local letters, compared with when local and global letters were congruent. This was the case even though our patient (J.J.) was never able to explicitly identify the global letter. This finding again supports the notion that Balint's patients may process multiple visual stimuli to the level of identification without awareness.

In the current study we tested whether a patient presenting with Balint's syndrome as a result of bilateral damage to parietal cortices, could process semantic information from visual stimuli that were not available for conscious report. Four experiments are reported, two used simultaneous presentations of two visual items, and two used a pair of sequential presentations of a single item. In all of the experiments, our patient's semantic judgement performance was significantly worse when the item to be identified and the item to be ignored were from different semantic categories, compared to when they were both from the same category. Naming both items within a display was extremely poor across all the experiments.

METHODS

Patient Details

Our patient, J.J., is a 65-year-old right-handed male who has suffered recurrent cerebral haemorrhages over the past 6 years. A recent magnetic resonance imaging (MRI) scan revealed asymmetrical bilateral atrophy to areas of the parietal, temporal and occipital cortices with damage to left parietal cortex extending further into the superior region. J.J. complains of difficulty seeing objects in his peripheral vision and frequently bumps into objects. Systematic testing of J.J.'s visual fields uncovered a quadrantopia in the left inferior quadrant. J.J. demonstrates optic ataxia in that, when reaching for an object presented extrafoveally, he misreaches by greater than 5 cm. Furthermore, like the Balint's original case report, J.J. shows impairments largely with his right hand when pointing to extrafoveal targets presented in the left or right hemifield (Jackson et al., 2005a). J.J. also exhibits clear signs of ocular apraxia (Jackson et al., 2005b). When he executes an eye movement they are typically full, however, his spontaneous eye movements are sparse, and he exhibits relatively long periods of fixation, mostly some 20 degrees to the right of midline (again, this is similar to the description given for Balint's original case). Finally, J.J. shows clear evidence of attentional impairment, characterised by a profound

Fig. 1 – *A. Record of saccadic eye movements, including fixations, made by patient J.J. while reporting the content of the "Boston Cookie Theft" picture. B. Record of saccadic eye movements made by a neurologically healthy control subject performing the same task*.

simultanagnosia, when assessed using a number of tasks. For example, when presented with a complex visual display such as the "Boston Cookie Theft" picture J.J. can correctly report isolated items from the picture. For example, he will report seeing the following "boy", "stool", "woman", "taps", "cup", "knife", "sink", "pot", but when he is asked to interpret what is happening in the picture, he fails to comprehend the picture globally and makes an incorrect guess of what is happening in the picture, stating "A woman cooking, I think". Furthermore, if J.J.'s eye movements are recorded during his visual inspection of the "Boston Cookie Theft" picture (and other similar displays), then analyses of the pattern of saccades and fixations produced clearly reveals that his simultanagnosia cannot be explained as a failure to execute saccades in order to fixate appropriate screen locations (Figure 1). Inspection of this Figure 1 clearly shows that J.J. fixates all of the relevant locations within the display but nevertheless, cannot correctly report what is happening "globally" within the image.

When presented with two visual stimuli, for example a pair of coloured line drawings or a pair of coloured letters, J.J. will invariably report only one item from each pair. Moreover, on repeated testing with the same stimuli, he will vary which of the two items that he reports, and will, on average, report each item equally often. Most importantly, however, J.J. shows clear evidence of a preserved ability to apply "top-down" selection criteria in his verbal reports. For example, if asked to report the "red" letter, or the "red" item, in each display, J.J. will always accurately report that item (100%) correct), but will invariably be unable to report the other item in the display, unless the displays are presented for very long periods. Psychophysical investigations using staircase procedures have revealed that, in order to report the identity and colour of a single coloured letter correctly, J.J. requires that the letter to be presented for ≈ *150 msec*. In contrast, he requires that the stimuli to be presented for ≈ 2500 *msec* to correctly report the colour and identity of a pair of coloured letters (Jackson et al., 2005b).

While J.J. requires extremely long stimulus durations to correctly report two coloured letters correctly, this does not necessarily demonstrate that J.J. only "sees" one item in the display. In fact, at stimulus presentations of 1000 msec (far less than the 2500 msec required to correctly report both items), J.J. is highly accurate (94%) in reporting whether one or two letters were presented, even though he cannot report the identity of both letters. Furthermore, if the duration of stimulus presentations are substantially reduced to only 100 msec, then J.J. remains very accurate (86%) at reporting whether one or two items were presented.

Finally, when J.J. is presented with displays containing two different coloured letters and instructed to make a judgement about the presence or absence of a specified the target (e.g., 'Is a blue letter A present in the display?'), he is at chance in correctly identifying that the target letter was present in the display (*target present* trials) at short stimulus durations (100 msec). However, J.J. is not simply guessing in such circumstances as he is 90% correct at reporting that a target was not present in the display on *target absent* trials (i.e., neither target colour or form are present in the display). In contrast, on *target absent* trials in which the target colour or target form are contained within the display (but on separate objects), J.J. makes a large number of conjunction errors, and his accuracy drops to chance levels ($\approx 40\%$) correct) (Jackson et al., 2004).

Apparatus and Stimulus Materials

The visual stimuli used in this study consisted of: (a) Digital photo-images of two semantic categories – tools and non-tools (fruit/vegetables). Each category contained 8 images, with each item used as a prime and a probe (Figure 2A). Thus giving a total of 32 images. In order to make the images visually similar they were all converted into greyscale images. The images were created by one

Fig. 2 – *A. Example display – simultaneous digital images. B. Example display – simultaneous line drawings.*

of the authors (Shepherd) from real objects. (b) Line drawings of two semantic categories, animals and non-animals (transport vehicles) were selected from the Snodgrass and Vanderwart (1980) test battery. Each category contained 8 drawings that were reproduced as blue (prime) and red (probe) outlines, giving a total of 32 drawings (Figure 2B). The line drawings were selected for comparable visual complexity.

Different pairs of primes and probes were combined randomly to obtain three conditions as follows: *Highly congruent (HC)* – consisted of stimuli that were physically identical (e.g., hammer and hammer) and therefore from the same semantic category; *Congruent* (C) – consisted of stimuli that were from the same semantic category but were physically dissimilar (e.g., bear and pig); *Incongruent (INC) – consisted of stimuli that were* from different semantic categories (e.g., hammer and pig). Each stimulus was displayed in a white rectangular box that measured 4° (width) \times 3^o (height) of visual angle (at a viewing distance of 60 cm) upon a grey background. The stimuli were displayed on a 21-inch Dell Trinitron colour

monitor. The experimental was controlled by software using E-prime running on a Dell CPU. Pairs of visual stimuli could occupy one of two locations on the screen and were presented according to two different experimental conditions – simultaneous presentation and sequential presentation.

Experimental Procedure

Extensive familiarisation was undertaken, prior to each experiment, to ensure that J.J. could identify the prime from the probe and make a semantic judgement within 2 seconds of the probe onset. Only, when J.J. could reliably and successfully complete these tasks did the experimental task begin. The experiments were conducted in one afternoon session lasting for three and a half hours in total.

EXPERIMENT 1A – SIMULTANEOUS PRESENTATION OF DIGITAL PHOTOGRAPHS

Semantic Judgement Task

Two images were presented simultaneously for 700 msec. One of the images was presented without a border (the 'prime' item) and the other, the "probe" item, was presented within a red border (see Figure 2A). The location of the probe was varied randomly across trials. J.J. was instructed to make a semantic judgement about the object in the red box (i.e., tool *vs.* non-tool) as fast as possible. If the object was a tool J.J. was asked to press the right mouse key with his right index finger. If the object was a non-tool he was asked to press the left mouse key with his left index finger. J.J. was allowed 2 seconds to respond. There were a total of 250 trials with approximately 82 trials in each condition (i.e., HC, C and INC prime and probe items).

Verbal Reports of Explicit Knowledge

In order to assess J.J.'s levels of explicit awareness of the objects presented in the primeprobe displays, he was re-presented with the stimulus displays used in the semantic judgement task and asked to name both objects in each display. Stimuli were presented for 700 msec as before. A total of 42 such trials were presented (14 HC, 14 C, and 14 INC). From many previous assessments of J.J., we knew that he would be unlikely to be able to name more than one item in each display at this stimulus duration. J.J. was instructed to name all of the items that he could see in the display.

Data Analysis

Initial inspection of the RT data revealed that the data were not normally distributed. Non-

parametric tests (Kruskal-Wallis) were therefore used to analyse mean RTs. RTs less than 200 msec were excluded from the analysis. Mann-Whitney tests were performed to carry out planned contrasts between conditions. Accuracy data were analysed using chi-square.

RT Data for Correct Responses

Analyses revealed that there was a significant effect of category upon RT $[U = 3822, p < .02)$. J.J. was slower in responding to tool stimuli [mean = 835 (192) msec] compared to the non-tool stimuli [mean = 777 (217) msec]. However, the effect of prime-probe congruency was not statistically significant [means: INC = 800 (187) msec, C = 807 (165) msec, HC = 816 (220) msec; χ^2 (2) = .42, p = .8].

Error Data

There was no effect of category upon number of errors $[\chi^2(1) = .001, p = .99$; error rate: nontool stimuli = 21.2% , tool stimuli = 21.2%]. Importantly, however, there was a significant effect of congruency upon error rates $[\chi^2 (2) = 33.5, p <$.001]. Error rates were: INC = 41.9% , C = 9.8% and $HC = 11.0\%$. Data are presented graphically in Figure 3. The data indicate that J.J.'s ability to correctly categorise the probe item was significantly impaired when the prime item was semantically incongruent.

Verbal Reports

J.J. managed to correctly identify both items on only one trial (1/42). On the majority of trials he was able to correctly report only one item from each pair of stimuli (31/42). Finally, when given no explicit instruction as to which item to report, J.J. shows no evidence of any bias to report probe items over prime items (20/31). Testing has repeatedly revealed that when instructed to report by colour, J.J. is completely accurate at reporting the target item. Finally, J.J. made no response on 2 trials and an incorrect response on the remaining trials (8/42).

EXPERIMENT 1B – SIMULTANEOUS PRESENTATION OF LINE DRAWINGS

Semantic Judgement Task

The procedures used were largely identical to those described for Experiment 1A. One difference, however, was that the probe item was no longer identified by enclosing it within a red box. Instead, the prime object was presented in blue and the probe item in red. If the probe object was an animal then J.J. was asked to press the right mouse

Fig. 3 – *Error rates by condition for Experiments 1A and 1B*.

key with his right index finger. If the probe object was a non-animal he was asked to press the left mouse key with his left index finger.

Explicit Assessment

Upon completing the semantic judgement trials, J.J. was again required to explicitly report the items presented in semantic judgement trials. The procedures used were identical to those described for Experiment 1A.

RT Data for Correct Responses

In contrast to Experiment 1A, there was no significant effect of category upon RTs $[\chi^2 (1) =$.25, p = .62; means: non-animal stimuli = 808 msec, animal stimuli = 735 msec], and no significant effect of congruency upon RT $[\chi^2 (2) =$ 2.71, p = .26; means: INC = 804 (184) msec, C = 791 (188) msec, HC = 747 (152) msec].

Error Data

There was no effect of category upon number of errors $[\chi^2(1) = .61, p = .44;$ error rates: nonanimal stimuli = 31.0% , animal stimuli = 26.0%]. Importantly, however, as in Experiment 1A there was a significant effect of congruency upon error rates $[\chi^2 (2) = 77.2, p < .001$; error rates: INC = 65.1%, C = 13.4%, HC = 9.7%]. Data are presented graphically in Figure 3. Again, these data confirm that J.J.'s ability to correctly categorise the probe item is significantly impaired when the

prime item is semantically incongruent with the probe item.

Verbal Reports

The results from this study confirm the findings reported above in Experiment 1A. J.J. could not correctly report both items on any trial, but he did correctly report one item on the majority of trials (31/42). He made no response on 4 trials, and an incorrect response on 7 trials.

EXPERIMENT 2A: SEQUENTIAL DIGITAL PHOTOGRAPHS – SAME LOCATION

Semantic Judgement Task

One image, presented without a border (prime), was shown in one of the two possible locations (see Figure 4) for 350 msec. This display was followed by a blank screen for 350 msec and then followed by a further image for 350 msec, this time presented within a red border (probe item). In this experiment the "probe" item was always presented in the same location as the "prime" image. J.J. was instructed to make a judgement about the object in the red box as fast as possible. If the object was a tool he was asked to press the right mouse key with his right index finger. If the object was a non-tool he was asked to press the left mouse key with his left index finger. RTs were recorded from onset of second (probe) image. There were a total of 250 trials with

Fig. 4 – *Example display sequence – sequential same location*.

approximately 82 in each condition (i.e., HC, C and INC).

Verbal Reports

To assess J.J.'s levels of explicit awareness of the objects presented in the prime-probe displays, he was again re-presented with stimulus displays used in the semantic judgement task. A total of 42 trials were presented (14 highly congruent, 14 congruent, and 14 incongruent). J.J. was instructed to name all of the items that he could see in each display.

EXPERIMENT 2B: SEQUENTIAL DIGITAL PHOTOGRAPHS - DIFFERENT LOCATION

Semantic Judgement Task

The procedure was identical to Experiment 2A, with the exception that the second image (probe item) appeared in the alternate location to that of the first image (prime item) (see Figure 5).

Verbal Reports

The procedure used here was identical to that described for Experiment 2A.

Results

Preliminary analyses of RT and error data in Experiments 2A and 2B revealed that there was no significant difference between these experiments (minimum $p = .8$). Therefore the data from these two experiments was collapsed for subsequent analyses.

RT Measures for Correct Responses

There was no significant effect of category upon RT $[\chi^2 (1) = .002, p = .968;$ means: non-tools

Fig. 5 – *Example display sequence – sequential different location*.

Fig. 6 – *Error rates in Experiment 2 – sequential presentations of prime and probe stimuli*.

 $= 666$ (310) msec, tools= 658 (291) msec]. However, there was a significant effect of prime congruency upon RT $[\chi^2 (2) = 15.75, p < .001;$ means: INC = 801 (272) msec, C = 626 (321) msec, $HC = 600$ (272) msec]. Planned contrasts revealed that there was a significant difference between the INC and C conditions ($U = 1157$, $p =$.01), and between the INC condition and HC condition (U = 1130, $p < .0001$). However, the difference between the C condition and HC conditions was not significant ($U = 2486$, $p = .79$).

Error Measures

There was no effect of category upon number of errors $[\chi^2(1) = .7, p = .4;$ mean error rates: non-tools $= 28.0\%$, tools $= 32.6\%$]. There was a significant effect of prime congruency upon the number of errors observed $[\chi^2(2) = 32.7, p < .0001$; mean error rates: INC = 50.5% , C = 14.8% , HC = 21.3% (see Figure 6). These results replicate the findings obtained for both the simultaneous digital photograph experiment (1A) and simultaneous line drawings experiment (1B). However, inspection of our data suggests that there may be a difference in error rates for stimuli presented simultaneously compared to stimuli presented consecutively. To explicitly test this effect, we directly compared data obtained in Experiment 1 (A and B) against data obtained in Experiment 2 (A and B). These data are presented graphically in Figure 7. Statistical analysis confirmed that error rates were significantly greater for sequential compared to sequential presentations $[\chi^2(1) = 23.9, p < .001].$

Verbal Reports

Sequential – same location: J.J. identified two items correctly on 6 trials (6/42) and correctly reported one object on a further thirty trials (30/42). He incorrectly reported an item on three trials and made no response on three trials.

Sequential – different location: J.J. identified two objects correctly on 7 trials (7/42) and correctly reported one object on twenty-eight trials (28/42). He was incorrect on 7 trials (Table I).

To test whether there were differences in J.J.'s verbal reports for simultaneous compared to sequential presentations, we directly compared data from Experiment 1 and Experiment 2. Statistical analysis confirmed that J.J.'s ability to correctly report a single item was not different for simultaneous compared to sequential presentations $[\chi^2$ (1) = .31, p = .6]. In contrast, statistical analysis revealed a marginal effect of simultaneous compared to sequential presentations on J.J.'s ability to correctly report *both* items in each display, $[\chi^2 (1) = 3.0, p = .08]$. This suggests, paradoxically, that J.J. is better able to report both

Fig. 7 – *Error rates Experiment 1 versus Experiment 2*.

items when they are presented sequentially compared to when both items are simultaneously present. This effect has been observed previously with patient J.J. using different stimulus presentations (Jackson et al., 2004).

DISCUSSION

The aim of this study was to investigate whether visual stimuli that could not be explicitly reported, were nevertheless subject to implicit processing of semantic information. We investigated this issue using a semantic priming/interference paradigm in a patient presenting with a profound simultanagnosia associated with Balint's syndrome. In two experiments, our patient (J.J.) demonstrated significantly more semantic judgement errors when the probe and prime items were drawn from different semantic categories compared to when they were from the same semantic category. In Experiment 2, where the items were presented sequentially, J.J. also exhibited significantly slower RTs when the stimuli were from a different semantic category compared to when they were from the same category. These findings indicate that both items are processed to a semantic level irrespective of the fact that, on the vast majority of trials, J.J. cannot correctly report both items in the display (i.e., 1/42, 0/42, 6/42, 7/42 trials). They also confirm the results of a previous study of patient J.J. that used quite different visual stimuli (i.e., Navon figures). That study provided behavioural and electrophysiological (ERP) evidence that demonstrated that, whereas J.J. could report only the "local" letters in Navon figures (i.e., he was completely at chance in identifying the "global" letter), he was nevertheless significantly affected by the identity of the "global" level when this was incongruent with the "local" level (Jackson et al., 2004).

Our results also provide some support for a study reported by Coslett and Saffran (1991) in which a patient with simultanagnosia, following bilateral temporo-occipital and unilateral (right) posterior parietal damage, exhibited better identification of two items (naming) when those items were semantically related compared to when they were semantically unrelated. Note, however, that that study provided evidence for explicit semantic priming but not implicit processing of semantic information, since identifying (naming) an item requires access to explicit knowledge. In contrast, in the current study both explicit and implicit semantic processing was assessed. The verbal report task provides a direct explicit measure of whether the patient is aware of both items on each trial. In contrast, the semantic judgement task (RT and errors) provides an indirect measure of whether both items are being processed to a semantic level. While this task can be affected

by explicit knowledge, it does not require that the participant is consciously aware of both objects in order to correctly perform the task. Indeed, presentation rates were selected so as to deliberately minimise our patient's conscious awareness of both items. Since the patient's performance on the explicit knowledge task confirmed that he was rarely able to report both items successfully we can safely conclude that he was nevertheless processing the semantic category of the unreported item implicitly.

A second finding of note in our study was that our patient made significantly more classification errors when the items were presented sequentially rather than simultaneously. This finding demonstrates, rather paradoxically, that the prime item appears to have less influence when it is presented simultaneously with the probe item than when it precedes the probe item. While, because of ceiling effects, it is extremely difficult to precisely compare these two conditions in neurologically healthy individuals, it is nevertheless the case that current models of visual attention such as the integrated competition model (Duncan et al., 1997) would strongly predict that interference effects would increase when semantically incongruent items were presented simultaneously with the probe item compared to when items are presented sequentially. A more plausible account of our data may be that there is reduced competition between items on sequential compared to simultaneous trials. We have suggested elsewhere that our patient's difficulty in reporting more than one item – when two or more items are present in a display – may be caused by a difficulty in disengaging attention once it has had been captured by an object. This difficulty in orienting attention is likely to be improved by sequential presentation of objects since, for objects that are presented sequentially, any competition for attention between the items is largely removed. In several experiments with J.J. we have found that when he is asked to report the identity of two coloured letters, he is significantly more accurate when the letters are presented sequentially rather than simultaneously. Note that this is the case even though each letter is presented for 2 seconds duration on simultaneous trials (Jackson et al., 2004). This suggestion, that competition between items is increased on simultaneous presentations and results in *reduced* processing of the prime stimulus in our patient J.J., is supported by our finding that there is a marginal increase in the sequential condition, in the number of trials on which J.J. can correctly report *both* items in the display compared to only one item.

In conclusion, this study presents neurological evidence that information that is processed outside of conscious awareness and cannot be explicitly be reported, is nevertheless processed implicitly to a semantic level of identification.

Acknowledgements. The work reported in this paper was supported by grants from the Biotechnology and Biological Sciences Research Council (BBSRC) to Georgina M. Jackson and The Wellcome Trust to Stephen R. Jackson. We are grateful to J.J. for his assistance with our research.

REFERENCES

- BALINT R. Seelenlahmung des "Schauens" optische Ataxia, raumliche Storung der Aufmerksamkeit. *Monatschrift fur Psychiatrie und Neurologie, 25:* 51-81, 1909 (Translated by Harvey M. *Cognitive Neuropsychology, 12:* 265-281, 1995).
- BAYLIS GC, DRIVER J and RAFAL RD. Visual extinction and stimulus repetition*. Journal of Cognitive Neuroscience, 5:* 453-466, 1993.
- BERTI A and RIZZOLATTI G. Visual processing without awareness: Evidence from unilateral neglect. *Journal of Cognitive Neuroscience, 4:* 345-351, 1992.
- COSLETT HB and SAFFRAN E. Simultanagnosia: To see but not two see. *Brain, 114:* 1523-1545, 1991.
- DUNCAN J, HUMPHREYS GW and WARD R. Competitive brain activity in visual attention. *Current Opinion in Neurobiology, 7:* 255-261, 1997.
- HUSAIN M and STEIN J. Rezso Balint and his most celebrated case*. Archives of Neurology, 45:* 89-93, 1988.
- JACKSON GM, SWAINSON R, MORT D, HUSAIN M and JACKSON SR. Implicit processing of global information in Balint's Syndrome. *Cortex, 40:* 177-178, 2004.
- JACKSON SR, NEWPORT R, MORT D and HUSAIN M. Where the eye looks, the hand follows: Limb-dependent magnetic

misreaching in optic ataxia. *Current Biology, 15:* 42-46, 2005a.

- JACKSON SR, NEWPORT R, MORT D, HUSAIN M, JACKSON GM, SWAINSON R, PEARS S and WILSON B. Action binding and the parietal lobes: Some new perspectives on optic ataxia. In Humphreys GW and Riddoch MJ (Eds), *Attention in Action*. Hove: Psychology Press, 2005b.
- KARNATH HO, FERBER S, RORDEN C and DRIVER J. The fate of global information in dorsal simultanagnosia. *Neurocase, 6:* 295-306, 2000.
- KIM MS and ROBERTSON LC. Implicit representations of space after bilateral parietal lobe damage. *Journal of Cognitive Neuroscience, 13:* 1080-1087, 2001.
- MARZI CA, SMANIA N, MARTINI MC, GAMBINA G, TOMELLERI G, PALAMARA A, ALESSANDRINI F AND PRIOR M. Implicit redundant-targets effect in visual extinction. *Neuropsychologia, 34:* 9-22, 1996.
- MCGLINCHEY-BERROTH R, MILBERG WP, VERFAELLIE M, ALEXANDER M and KILDUFF P. Semantic priming in the neglected field: Evidence from a lexical decision task. *Cognitive Neuropsychology, 10:* 79-108, 1993.
- RIZZO M. 'Balint's syndrome' and associated visuospatial disorders*. Clinical neurology, 2:* 415-437, 1993.
- ROBERTSON LC. Binding, spatial attention and perceptual awareness. *Nature Neuroscience, 4:* 93-102, 2003.
- SNODGRASS J and VANDERWART M. A standardised set of 260 pictures: Norms for name agreement, image agreement, familiarity and visual complexity*. Journal of Experimental Psychology: Human Learning and Memory, 6:* 174-215, 1980.

Georgina M. Jackson, Division of Psychiatry, Queen's Medical Centre, The University of Nottingham, A Floor, South Block, Nottingham NG7 2UH, UK. e-mail: Georgina.Jackson@nottingham.ac.uk

APPENDIX

Examples of digital visual images. All the images were greyscale

