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Brief article

Can blindsight be superior to 'sighted-sight'? ☆

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Abstract

DB, the first blindsight case to be tested extensively (Weiskrantz, 1986) has demonstrated the ability to detect and discriminate a range of visual stimuli presented within his perimetrically blind visual field defect. In a temporal two alternative forced choice (2AFC) detection experiment we have investigated the limits of DB's detection ability within his field defect. Blind field performance was compared to his sighted field performance and to an age-matched control group ($n = 6$). DB reliably detected the presence of a small (2°), low contrast (7%), 4.6 c/° Gabor patch with the same space-averaged luminance as the background presented within his blind field but performed at chance levels at the same eccentricity (11.3°) within his sighted field. Investigation of detection as a function of stimulus contrast revealed DB's ability to detect the presence of an 8% contrast stimulus within his blind field, compared to 12% in his sighted field. No significant difference in detection performance between DB's sighted field and the performance of six age-matched control participants suggests poor sighted field performance does not account for the results. Monocular testing also rules out differences between the eyes as an explanation, suggesting that DB demonstrates superior detection for certain stimuli within his visual field defect compared to normal vision.

Keywords: Blindsight; Contrast sensitivity; Two alternative forced choice detection

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1. Introduction

Lesions of primary visual cortex can result in perimetrically blind areas in the corresponding region of visual field. Despite being clinically blind, some residual visual abilities termed ‘Blindsight’ may remain within these areas, which can be elicited through the use of specific testing conditions and stimulus parameters. Many aspects of visual processing in blindsight have been investigated, including; spatial vision (Weiskrantz, Harlow, & Barbur, 1991; Barbur, Harlow, & Weiskrantz, 1994; Sahraie, Weiskrantz, Trevethan, Cruce, & Murray, 2002; Sahraie et al., 2003), processing of colour (Barbur, Harlow, & Sahraie, 1992; Stoerig & Cowey, 1992), emotional expression (de Gelder, Vroomen, Pourtois, & Weiskrantz, 1999) and semantic processing (Marcel, 1998). Investigation into spatial processing in areas of cortical blindness in a group of 10 patients revealed the presence of a narrowly tuned psychophysical spatial channel optimally responding to spatial frequencies below 4 c/° in 8 of the 10 cases tested (Sahraie et al., 2003). It appears that specific stimulus parameters are vital in determining performance and that in addition to the specific profile of spatial frequency sensitivity, relatively ‘salient’ stimuli (i.e. relatively large, high contrast, temporally modulated or moving) are often required for above chance detection performance. Indeed, dramatic differences in performance have been observed as a consequence of small alterations to stimulus parameters, which apparently make stimuli more salient (see Hess & Pointer, 1989; Weiskrantz et al., 1991; Sahraie et al., 2002, 2003).

DB, the first blindsight case to be tested extensively (Weiskrantz, Warrington, Sanders, & Marshall, 1974; Weiskrantz, 1986), has demonstrated the ability to detect and discriminate a range of visual stimuli presented within his perimetrically blind visual field defect (see Fig. 1). DB’s residual spatial processing channel peaks at the higher spatial frequency of 3 c/° (Weiskrantz, 2001) unlike other cases in which it is optimally tuned to 1 c/° (Sahraie et al., 2003). In a series of temporal 2AFC experiments we have investigated the limits of DB’s detection ability. Blind field performance was compared to his sighted field performance and to an age-matched control group ($n = 6$) and revealed apparently superior detection abilities for stimuli presented within cortically blind areas of visual field compared to his sighted field and age-matched controls.

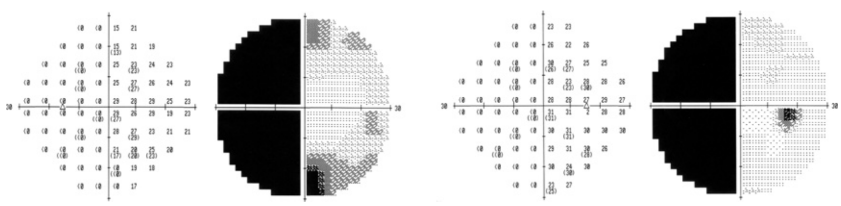

Fig. 1. DB’s field defect, a left hemianopia, measured using a Humphreys perimeter, 30-2 Full Threshold programme. Locations marked at ‘<0’ represent locations where the brightest stimulus (10,000 apostilbs) did not elicit a response.

2. Experiment 1

Initial investigations into DB's ability to detect the presence of large (10°), high contrast (98%), temporally modulated (10 Hz) Gabor patches at a range of spatial frequencies between 0.5 and 7 c/° presented in a temporal 2AFC paradigm revealed that he was considerably more sensitive to these stimuli compared to a group of 10 cases previously tested (see Sahraie et al., 2003). Reducing the saliency of the stimuli through static presentation and a reduction in stimulus size and contrast did not eliminate DB's above chance detection performance (although these stimuli became subjectively difficult for the experimenters to see). In order to investigate the limits of DB's detection ability we tested his ability to detect the presence of a small, low contrast, static sinusoidal grating presented either in his normally sighted field or within his cortically blind visual field defect.

2.1. Method

2.1.1. Patient details

DB was born in 1940 (aged 63, 64 during testing). At the age of 26 an angiogram revealed an arteriovenous malformation at the right occipital pole. In 1973, the malformation was surgically removed. Based on surgical notes, the extent of the lesion was reported as "excision extended from the occipital pole forward by approximately 6 cm and was thought to include the major portion of the calcarine cortex – in which the striate cortex is situated – on the medial surface of the right hemisphere" (Weiskrantz, 1986, p. 21). The surgical intervention relieved DB's symptoms but resulted in a left homonymous hemianopia (see Fig. 1).

In 1976 DB experienced some return of vision in his upper visual field, however, when DB was tested using Humphreys automated perimetry (30-2 full threshold program) for the current research in 2003 (using the same stimulus sizes as those reported previously), the fields revealed a complete left homonymous hemianopia. All testing reported here was carried out in the lower left quadrant of the visual field as this was consistent with earlier testing (Weiskrantz, 1986) and was an area of visual field that had remained consistently blind.

2.1.2. Apparatus and stimuli

Stimuli were generated via a PC (Windows, ME), specialised SVGA graphics card (VSG 2/5) and displayed on a 21 in., 100 Hz monitor. The monitor was enclosed in a cubicle with a chin-rest at a viewing distance of 760 mm. Fixation accuracy was monitored throughout testing by the experimenters using a modified ASL 5000 pupillometer.

The stimulus was a static, 2° diameter, 4.6 c/°, 7% contrast, 2 s duration, sinusoidal grating with spatial and temporal smoothing (standard deviation of spatial Gaussian envelope $(\sigma_z) = 0.5°$, diameter limited to $\pm 2\sigma_z$ temporal standard deviation $(\sigma_t) = 500$ ms). The space-averaged luminance of the stimulus was equal to the background luminance of 37 cd/m^2.

2.1.3. Design and procedure

The stimulus was presented in a temporal 2AFC paradigm. DB was informed that a stimulus would be presented in either the first or second time interval and responded by pressing button ‘1’ or ‘2’ on the response box. The fixation point was a high contrast black cross-hair subtending 0.5°. The stimulus was presented at an eccentricity of 11.3° in the lower quadrant of the sighted (right) visual field at 8° to the right of and 8° below fixation or blind (left) visual field at 8° to the left of and 8° below fixation. In the first set of trials the blind and sighted field stimuli were presented in separate blocks (30 trials per field). The stimulus was presented at the same screen location in both blocks as the position of the fixation cross was altered. In the next set of trials the blind and sighted field presentations were interleaved (50 trials per field). In the interleaved trials the fixation cross was presented centrally on the screen and the stimulus was presented at an eccentricity of 11.3° in either the blind (left) or sighted (right) field. DB reported his subjective awareness of the stimuli using a commentary key paradigm in which he pressed button ‘3’ on the response box if he was ‘aware’ of the stimuli and button ‘4’ if he was ‘unaware’. DB was instructed to classify responses in which he experienced any awareness *whatsoever* as ‘aware’ and only to respond ‘unaware’ if he experienced absolutely no subjective awareness of any kind.

2.2. Results

As Fig. 2 shows, DB reliably detected the presence of the stimulus when it was presented within his field defect (87% correct, $p < .001$, binomial distribution). When the stimulus was presented at the same eccentricity in his normally sighted visual field, DB did not perform above chance levels (50% correct, $p = 1.00$). A significant difference in detection ability between the blind and sighted field was confirmed by chi-square analysis ($\chi^2 = 10.908$, $v = 1$, $\phi = .369$, $p = .001$). DB reported no subjective

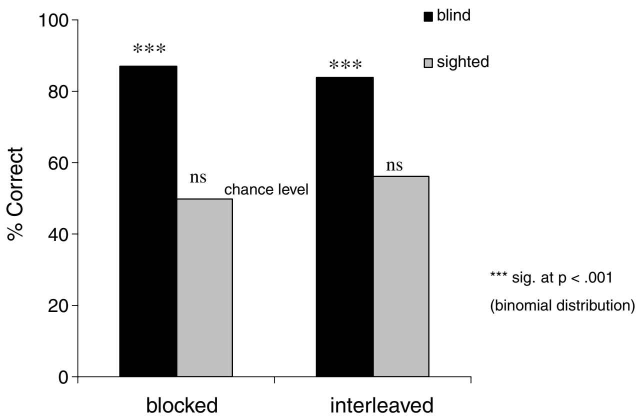

Fig. 2. % Correct detection of a 4.6 c/°, 2° diameter, 7% contrast Gabor patch in DB’s blind (black) and sighted (grey) visual field presented in blocked and interleaved trials at an eccentricity of 11.3°.

awareness of the sighted field presentations but, interestingly, reported awareness of 80% of the presentations within his visual field defect. DB described his awareness as "feeling as if a finger is pointing through the screen", nevertheless, he denied any visual experience akin to his sighted field of vision whatsoever. When DB was tested with exactly the same stimuli with randomly interleaved sighted and blind field presentations (not separate blocks), the dissociation between blind and sighted field detection performance remained (Fig. 2). DB continued to demonstrate reliable blind field detection (84% correct, $p < .001$, binomial distribution) but was unable to detect the stimulus within his normal vision (56% correct, $p = .480$, ns, binomial distribution). Once again, there was a significant difference in detection performance between the blind and sighted field with the blind field demonstrating superior detection ($\chi^2 = 9.333$, $v = 1$, $\phi = .306$, $p < .01$). The results of SDT analysis support the assertion that DB demonstrated increased sensitivity in his blind field ($d' = 2.033$, $c = 0.81$) compared to his sighted field ($d' = 0.34$, $c = 0.41$) in the absence of any obvious response bias. Interestingly, during the blind and sighted field interleaved trials, DB's subjectively reported awareness of the stimulus presented within his field defect diminished and he reported no subjective awareness.

2.3. Discussion

DB was unable to reliably detect the presence of the stimulus presented in his normally sighted visual field but was 87% correct at 'guessing' in which of two intervals the stimulus was presented in his cortically blind field defect. Although DB reported high levels of subjective awareness, he did not report any experience of vision in response to presentation of the stimulus. Consistent with previous reports (Weiskrantz, 1986), DB reported finding the sighted field trials hard work and tiring, whereas the blind field trials "are no problem, I'm just guessing". Consequently, DB may have been approaching the task differently according to whether he *expected* to actually *see* the stimulus. Interleaved blind and sighted field presentations during the same set of trials effectively forced DB to apply the same approach or criteria throughout the testing block. The issue of decision criterion is an important one and has stimulated considerable debate (Azzopardi & Cowey, 1997, 1998; Campion, Latto, & Smith, 1983; Weiskrantz, 2001). The results of the interleaved trials revealed that the dissociation in detection performance remained. The blind field again outperformed the sighted field (see Fig. 2), suggesting that the performance difference between the fields represents a difference in sensitivity rather than a difference in DB's approach to the task.

3. Experiment 2

In Experiment 1 an apparent dissociation between sighted and blind field detection of a specific stimulus was demonstrated in two separate experiments, one with separate blocked trials and one with interleaved stimulus presentation. In Experiment 2 in order to replicate and extend these findings DB was tested with the same stimuli (2° diameter, 4.6 c/°, static, Gabor patch) presented at a range of contrast levels within his blind and sighted fields (separate testing blocks for each field).

3.1. Method

3.1.1. Patient details

For details see Section 2.1.1.

3.1.2. Apparatus and stimuli

Testing was carried out using the same equipment as described previously (see Section 2.1.2).

The stimulus was the same as that as used in Experiment 1, a static, 2° diameter, 4.6 c/°, 2 s duration, Gabor patch presented at a range of contrast levels. The space-averaged luminance of the Gabor patch was equal to that of the background (37 cd/m^2). In the blind field stimuli were presented at 2%, 4%, 6% and 8% contrast. In the sighted field stimuli were presented at 8%, 12%, 15% and 20% contrast.

3.1.3. Design and procedure

A temporal 2AFC paradigm was used and was the same as described previously (see Section 2.1.3). DB's blind and sighted fields were tested in separate blocks of trials. In the blind field, there were 60 stimulus presentations at each contrast level (2%, 4%, 6%, 8%). In the sighted field there were 70 presentations at 8% contrast, 60 presentations at 12% and 15% contrast and 50 presentations at 20% contrast. Each block of testing included randomly interleaved presentation of stimuli at a number of contrast levels. The same commentary key paradigm for measuring subjective awareness was used as described in Experiment 1.

3.1.4. Results

Fig. 3 shows blind field (filled circles) and sighted field detection (open circles) across a range of contrast levels. Within his normally sighted visual field DB was unable to reliably detect the presence of the stimuli at 8% contrast (60% correct, $p = .120$, ns, binomial distribution) but was able to detect the 12% (72% correct, $p = .001$, binomial distribution), 15% (77% correct, $p < .001$, binomial distribution) and 20% stimulus (88% correct, $p < .001$, binomial distribution). Within the cortically blind field, DB was unable to detect the presence of the 2% (50% correct, $p = 1.000$, ns, binomial distribution) and 4% stimuli (55% correct, $p = .519$, ns, binomial distribution), however, he was able to reliably detect the presence of the 6% (77% correct, $p < .001$, binomial distribution) and 8% stimulus (92% correct, $p < .001$, binomial distribution). DB's ability to detect the presence of the 8% contrast stimuli was significantly higher in his blind field compared to his sighted field ($\chi^2 = 17.105$, $v = 1$, $\phi = .363$, $p < .001$).

3.1.5. Discussion

In Experiment 2, the initial finding of superior discrimination in DB's blind field compared to his sighted field was supported and extended. DB was able to reliably

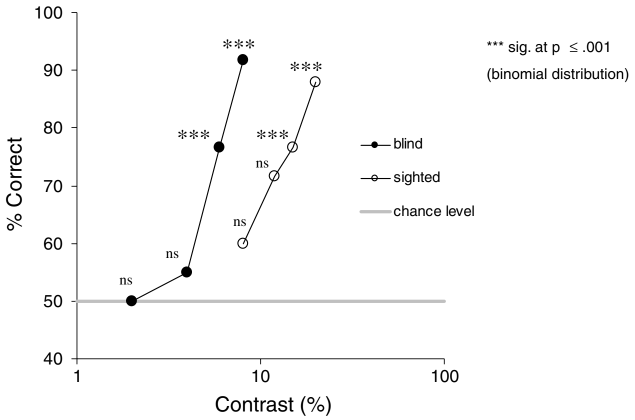

Fig. 3. Blind (filled circles) and sighted (open circles) field detection across a range of contrast levels. Within his normally sighted visual field DB was unable to reliably detect the presence of the stimuli at 8% contrast but was able to detect the 12%, 15% and 20% stimulus. Within the cortically blind field, DB was unable to detect the presence of the 2% and 4% stimulus, however, he was able to reliably detect the presence of the 6% and 8% stimulus.

detect the presence of 6% and 8% contrast targets presented in his blind field but required a 12% contrast target in his sighted field for successful detection.

4. Experiment 3

In Experiments 1 and 2, DB demonstrated the ability to successfully detect the presence of certain stimuli presented within his cortically blind visual field defect which he was unable to detect when they were presented within his normal vision. These findings appear to represent a dissociation in detection ability between DB's blind and sighted field, with his blind field outperforming his sighted field. One question this immediately raised was whether DB's sighted field was actually performing less well than would be expected normally. This is a pertinent issue as reduced sighted field sensitivity in cases of hemianopia has been reported previously (Hess & Pointer, 1989).

In Experiment 3 a group of six age-matched control participants with normal or corrected-to-normal vision were tested on the same detection task as used in Experiment 1. The aim was to address the issue of whether DB's sighted field was significantly different to a normal control group, which would also elucidate whether DB's blind field sensitivity was superior only to his own sighted field or to normal vision.

4.1. Method

4.1.1. Control participant details

Six normal participants, three female and three male, naïve to the aims of the experiment were tested in total. Participants were recruited from the School of

Psychology general public participation panel. The participant's ages ranged from 61 to 68 years ($M = 64.7$, $SD = 2.5$ years). All participants taking part in the experiment had normal or corrected to normal visual acuity. No participants were excluded from the subsequent analysis.

4.1.2. Apparatus and stimuli

Testing was carried out using the same equipment as described previously (see Section 2.1.2).

The stimuli were the same as those used in Experiment 1, a static, 2° diameter, 4.6 c/°, 7% contrast, 2 s duration, sinusoidal grating with spatial and temporal smoothing (standard deviation of spatial Gaussian envelope (σ_z) = 0.5°, diameter limited to $\pm 2\sigma_z$ temporal standard deviation (σ_t) = 500 ms). The space-averaged luminance of the stimulus was equal to the background luminance of 37 cd/m^2.

4.1.3. Design and procedure

A temporal 2AFC paradigm was used and was the same as described previously (see Section 2.1.3). Stimuli were presented to the control participants in both visual fields in blocked trials with 50 presentations per field.

4.1.4. Results

The mean scores for six age-matched control participants tested in both visual fields (grey), average for the right visual field (vertical stripes) and left visual field average (horizontal stripes) are shown in Fig. 4. Overall, the control group did not demonstrate above chance detection performance in either visual field. Analysis using a modified independent samples *t*-test (Crawford & Garthwaite, 2002) revealed that the control group detection scores (average $M = 57$, $SD = 8.7$, right visual field (rvf) $M = 59$, $SD = 10.5$, left visual field (lvf) $M = 55$, $SD = 5.9$) were not significantly

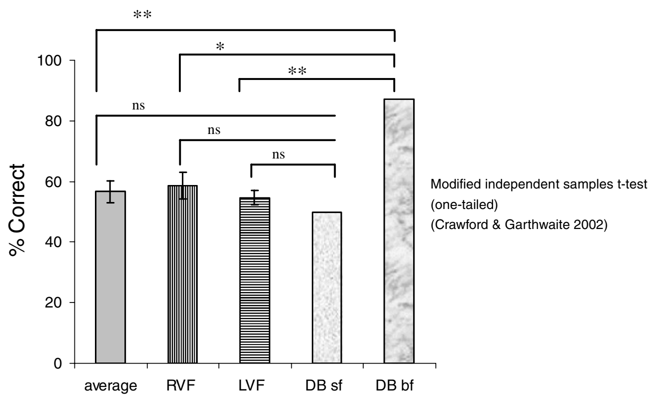

Fig. 4. % Correct detection of the control group and DB's sighted and blind field, showing no significant differences between the control group average (grey), right visual field (vertical stripes), left visual field (horizontal stripes) and DB's sighted field (dots), but a significant difference between the control group and DB's blind field (marbled). $^*p < .05$, $^{**}p \leqslant .01$.

higher than DB's sighted field detection scores (average: $t(5) = -0.745$, $p = .245$, ns; rvf: $t(5) = -.794$, $p = .232$, ns; lvf: $t(5) = -.785$, $p = .234$, ns). Interestingly, DB's blind field detection score (92% correct) was significantly higher than the control group detection scores (average: $t(5) = 3.192$, $p = .01$; rvf: $t(5) = 2.469$, $p < .05$; lvf: $t(5) = 5.021$, $p < .01$). Consistent with the average group results, χ^2 analysis revealed no significant differences in performance between the left and right visual fields in any of the six control participants (DH: $\chi^2 = 3.560$, $v = 1$, $\phi = .189$, $p = .059$, ns; KM: $\chi^2 = .000$, $v = 1$, $\phi = .000$, $p = 1.000$, ns; RJ: $\chi^2 = .043$, $v = 1$, $\phi = -.021$, $p = .836$, ns; IS: $\chi^2 = .364$, $v = 1$, $\phi = -.060$, $p = .546$, ns; GG: $\chi^2 = 3.305$, $v = 1$, $\phi = .182$, $p = .069$, ns; SR: $\chi^2 = .160$, $v = 1$, $\phi = -.040$, $p = .689$, ns). In addition, the hemifield difference in DB's performance was more than two standard deviations from the control mean hemifield difference (DB mean = 14, control mean = −2, $SD = 5.51$).

4.1.5. Discussion

Experiment 3 demonstrated that DB's sighted field detection ability was not significantly different to an age-matched group of controls with normal vision. Crucially, this rules out the possibility that DB's superior blind field detection performance could be explained on the basis of below average sighted field performance.

5. General discussion

Overall, the results reported here demonstrate that DB was able to detect the presence of certain stimuli when they were presented within his cortically blind field defect although he was unable to detect them successfully in an area of his normal vision. In addition, a group of six age-matched controls were also unable to successfully detect the presence of the target. To our knowledge this is the first clear demonstration of superior performance on a visual detection task within a cortically blind area of visual field compared to normally sighted vision.[1] The results appear to represent a real difference in performance between the blind and sighted field, which cannot be accounted for on the basis of sensory differences between the eyes as additional monocular testing,[2] combined with the interleaved trials make this explanation unlikely.

[1] A dissociation between blind field and sighted field detection performance in DB has been reported before (Weiskrantz, 1986) but the results were explained on the basis of a sensory difference between the two eyes (the right eye was less sensitive as a result of earlier surgery). The previous data were potentially confounded by the use of different stimulus eccentricities for sighted and blind field stimulation (blind field 18° 10′, sighted field 73° eccentricity). Some additional testing was reported at equivalent eccentricities but those were for extremely peripheral locations (80°). At such a peripheral eccentricity only the ipsilateral eye has a visual field (stimuli fall in the monocular crescent), consequently, in DB, the sighted field would be dominated by the right (less sensitive eye) and the blind field by the left eye.

[2] Monocular testing was carried out as part of another experiment which compared performance in DB's blind and sighted fields. In both eyes, the pattern of performance remained consistent with the blind field performing significantly above chance and the sighted field not performing above chance levels.

Blindsight is demonstrated in the form of a dissociation between visual performance in two different paradigms/tasks, namely clinical perimetry and forced-choice tasks. The basis of clinical perimetry is a 'yes–no' task in which one of two possible stimuli (e.g. target or blank) is presented on each trial and the participant's task is to judge which one was presented. This task gives the participant the freedom to say 'blank' or 'no stimulus' on every trial presentation if they wish, for example, if they are subjectively unaware of all stimuli. In forced-choice tasks (*m*afc), each of m different stimuli is presented every trial and the participant has to judge which of m intervals contained a specified stimulus, either in a temporal or spatial (i.e. localisation) interval (Azzopardi & Cowey, 1998). This paradigm ensures that the participant is effectively forced to make a judgement, for example, between two temporal intervals, as the option to judge 'no stimulus' simply does not exist, enabling the revelation of above-chance detection or discrimination performance where it exists, in the absence of subjective awareness (generally required for yn task). One of the main strengths of the 2AFC paradigm is that it is criterion free as any bias reflects a bias towards one or other interval rather than to one or other stimulus (Azzopardi & Cowey, 1998). The use of a 2AFC paradigm to demonstrate DB's apparently *superior* visual sensitivity within his cortically blind visual field defect compared to his normally sighted visual field and to a group of control participants was therefore prudent. In the light of the surprising results, additional perimetric testing was carried out with a larger stimulus size (Humphrey automated perimeter, stimulus size V) and DB's visual field defect remained a consistent left hemianopia. DB's failure to detect the much more salient stimuli presented during perimetric testing is likely to reflect a combination of the 'operating mode' of blindsight, in that a forced choice paradigm is necessary to elicit blindsight, as well as further highlighting the importance of specific stimulus parameters for successful performance.

Additional experimental investigations will be necessary to gain further understanding of the processes underlying DB's remarkable detection abilities. The current findings represent a considerable improvement in DB's residual visual abilities compared to previous results (Weiskrantz, 1986). An improvement in detection ability would not necessarily be expected as DB has participated in little testing since the initial period of intense testing in the 1970s and 1980s and the prevailing view suggests that intense practise is required for improvement (Kerkhoff, 2000). It is interesting to note that DB's detection abilities are considerably more sensitive compared to other cases with cortically blind visual field defects (e.g. Sahraie et al., 2003; Trevethan & Sahraie, 2003) and that DB's performance may not necessarily be representative of other cases. Investigation of any potential functional use or benefit from DB's superior detection ability and further investigation into the potential mechanisms mediating his abilities remain an interesting area for further research.

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