

## Posterior Parietal Visual Dysfunction: An Explanatory Review

*Difficulty seeing one's feet, 'clumsiness', and seeing only part of the scene at each glance, related to posterior parietal dysfunction: a common form of cerebral visual impairment.*

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### ABSTRACT

Dysfunction or injury of the posterior parietal lobes impairs 3D mapping of the visual scene and can...

- (1) Make body movement guided by vision inaccurate (optic ataxia).
- (2) Limit the number of items seen at a glance, due to simultanagnostic visual dysfunction.

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- (3) Cause inability to move the eyes to a specified target (apraxia of gaze), despite intact pursuit and fast (saccadic) eye movements. (Perhaps because the target cannot be located.)

When severe, these features comprise Balint syndrome, but when less marked, the term dorsal stream dysfunction has been used.

Associated lower visual field impairment due to the superior optic radiations passing through the parietal lobes being affected as well, can cause the feet not to be seen during locomotion. While accompanying inability to see fast moving targets, or dyskinetopsia is not uncommon. In our experience, a wider in-flight gap between the fingers and thumb of a hand reaching in the lower visual field than when reaching in the upper visual field, and disability locating where sounds are coming from, may also be evident.

Central and peripheral visual functions can be diminished if the occipital lobes are affected as well, while recognition can be impaired by this and / or associated temporal lobe dysfunction.

Those with accompanying intellectual impairment and four-limb cerebral palsy may 'wake up' and start to look around, even reaching out for a single object, when surrounded by a monochromatic tent that excludes extraneous visual and auditory distraction.

In the authors' experience, dorsal stream dysfunction is the commonest pattern of cerebral visual impairment seen in children and in many affected (often previously undiagnosed) adults.

A series of case history data is presented to illustrate the origin, nature and heterogeneity of this condition, as well as its potential management.

### INTRODUCTION

The way the brain processes the visual image is the subject of a vast literature. This mandates

the need for an academically sound practical model that helps ensure that visual disorders due to brain injury are recognised, identified, understood, and optimally managed. In-depth studies of the visual outcome of focal brain injury have historically proven an effective basis for such an approach.<sup>1</sup>

Without our being aware of it, the top of the brain near the back on both sides (the posterior parietal lobes) subconsciously maps and monitors the three dimensional characteristics of the surroundings in relation to the body, in terms of visual,<sup>2</sup> auditory<sup>3,4</sup> and tactile (5) constructs, allowing us both to map our surroundings and to locate ourselves within them. This ever-changing ostensibly non-conscious internal mental representation of our environment, is integrated with proprioceptive mapping of the location of all parts of one's body, and data provided by the balance system, to provide the framework for visual guidance of movement, visual search and visual attention.<sup>2,6,7</sup>

The posterior parietal lobes on both sides are where the three arteries that supply each side of the brain terminate in a 'watershed zone', leading to an enhanced risk of damage in this area due to reduced blood flow,<sup>8</sup> impaired oxygen delivery<sup>9</sup> or insufficient glucose supply.<sup>10</sup> Head injury can also affect this site,<sup>11,12</sup> as can many other disorders.

The outcome is disabling, but the diagnosis can be missed because neither long-term impairment, nor recent loss of these non-conscious visual functions can be recognised or described by those affected, culminating in 'hidden disability'. Unilateral and bilateral posterior parietal brain injury adversely affecting vision is, in our experience, common in both children and adults, but its disabling features can easily be misinterpreted or even go unrecognised.

This paper presents key aspects of a series of salient case reports, that when assembled, help explain the nature of disorders of visual function due to bilateral posterior parietal brain

injury. The aim is to provide a coherent set of insights into this common disabling condition.

## CASE REPORTS

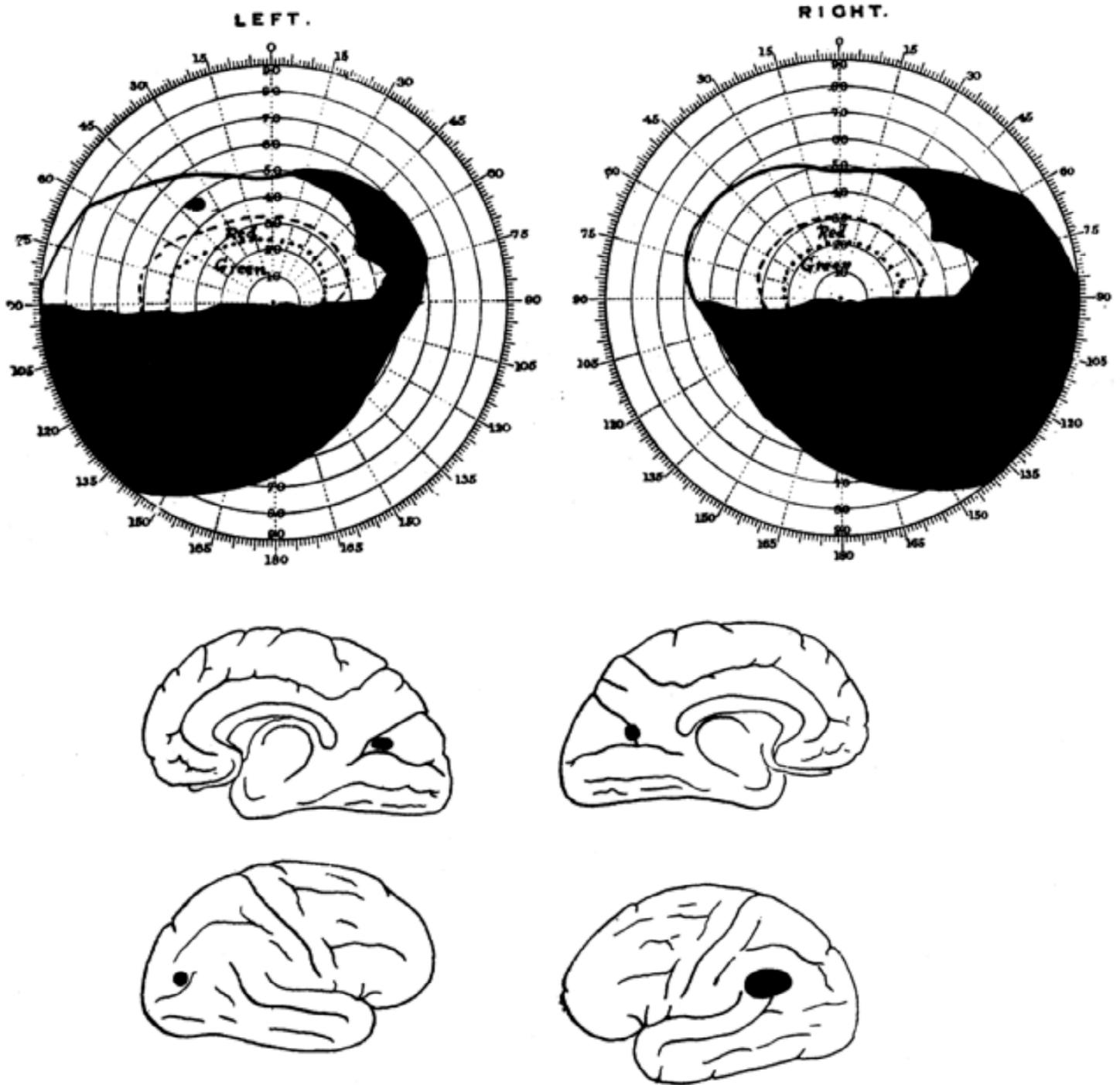
### 1. The woman who learned to walk freely through her invisible surroundings.

MC was 30 when she developed a severe lung infection and very low blood pressure, leading to coma for more than a month. On waking, she could not see because both her occipital lobes had lost their blood supply.<sup>13</sup>

Two years later she presented with little useful vision, but she asked why she had recovered her ability to see rainwater running down a window but not to see through it; why she could see her daughter's pony tail moving from side-to-side when she walked away, but



**Figure 1:** Case 1: Blood oxygen level dependent functional magnetic resonance contrast imaging (BOLD fMRI) head scan of MC (case 1), carried out while she was perceiving moving imagery. This shows the lack of the occipital lobes and isolated signals, shown in orange, that highlight her middle temporal lobe tissue on both sides of her brain. (Kindly provided by Jody Culham, Department of Psychology, University of Western Ontario, London Ontario N6A 5C2 CANADA)



**Figure 2:** Case 2: Original diagram in Gordon Holmes paper (1918) (17) depicting the nature of the penetrating head injury and the visual field in Sergeant K. (With permission of the *British Journal of Ophthalmology*.)

not see her daughter; and why she could see water spiralling down the plug hole but not see her daughter in the bath. As these features indicated intact motion perception with absent static perception (the Riddoch phenomenon),<sup>14</sup> she was invited to walk in figure of eight fashion around a row of chairs. Much to her surprise she could do so. A rocking chair was recommended, and she still uses it to help her see round the room, as she can only see

when the scene is moving. During the ensuing 7 years she has learned to move freely round obstacles. She can accurately catch rolling balls and she can pick up a drinking glass as if she were sighted when she taps the table, because the resulting ripples render the glass visible and accessible to reach for accurately.

Her CT scan at the time showed strokes affecting both occipital lobes and both temporal lobes, but her posterior parietal

lobes were not affected. More recent fMRI scanning reveals evidence of bilateral residual functioning middle temporal lobe tissue – serving perception of movement – becoming active in response to moving imagery (Figure 1).<sup>15</sup> As for the similar case DF, described by Milner and Goodale,<sup>2</sup> she has learned to read by imagining she is moving a forefinger over each letter, despite not being able to see them consciously.

MC has little or no occipital lobe tissue. Her type of vision has been described as 'Blindsight',<sup>16</sup> which is conceptually the antithesis of the pattern described in the introduction. This illustrates the nature and character of the visual functions served by the middle temporal lobes and posterior parietal lobes functioning in harmony, but in the absence of occipital lobe function. She can walk accurately through her surroundings, which become mapped in her mind when she starts to move, as the surroundings move in the opposite direction with respect to her body. It is likely that the combination of her functioning middle temporal and posterior parietal lobes allows her to do this in spite of the infarction and loss of both occipital lobes. Once she had gained insight and understanding of the origin and nature of her residual non-conscious vision, she progressively gained the confidence to use it to move independently without assistance. A film about MC's vision entitled 'The Blind Woman who Saw Rain' can be viewed on YouTube (<https://youtu.be/9ABQ-U6V0tY>).

## **2. The soldier who could see but couldn't see.**

In July 1917, Sergeant K sustained a probable rifle bullet injury through the lower part of his posterior parietal lobes<sup>17</sup> (Figure 2). He was 'intelligent and well educated'. His visual acuities were 20/40 and J1 and he could see stereoscopically. He had lost his lower visual fields, and attended poorly to his right. He could only read single words very slowly and

uncertainly, and could not follow a passage unless single sequential words were viewed through a slot in a piece of paper. Apart from impaired convergence and accommodation, his oculomotor functions were intact. He retained good visual memory and could correctly recognise objects, but could not reach out and grasp them. When walking he consistently collided with objects he could see. He was unable to direct his gaze at someone speaking with him face to face. When 4 to 6 coins were placed inside his sighted area, he could not see nor count them all, tending to re-count ones he had already identified.

This First World War account, graphically shows that injury of the lower portion of the posterior parietal lobes leads to loss of the lower visual field in both eyes, accompanied by inaccurate visual guidance of movement (optic ataxia) and inability to see more than two or three items at a time (simultanagnosia), resulting in profound impairment of visual search. In essence the functions lost were those retained by MC (case 1), while those retained were those she has lost. The clinical features described for this soldier are typical of those seen today, in varying severity in children and adults with bilateral posterior parietal dysfunction or injury.

## **3. The woman who couldn't find things and felt clumsy.**

One of the authors was contacted for advice by a 58 year-old family friend. She felt there was something the matter with her vision but wasn't sure what. She was progressively losing her ability to find items in a kitchen drawer, to identify clothes in her wardrobe and to find a friend in a group. She felt she was becoming clumsy, and found it helpful if she ran her hand along a surface to reach for an item. These are typical presenting features of posterior parietal dysfunction. The rare diagnosis of posterior cortical atrophy was mentioned as a possible explanation, and strategies to help were suggested, and immediately taken up and

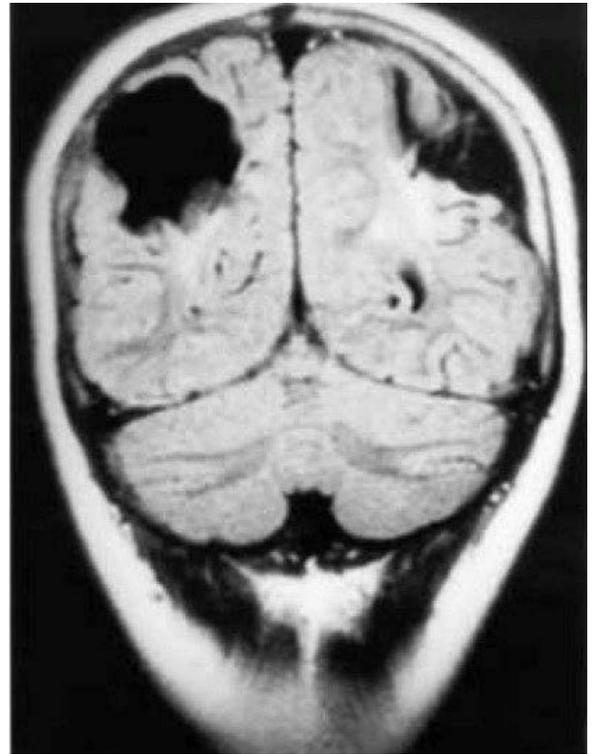
implemented to good effect. Two years, and three separate neurology consultations later, this diagnosis was finally made. Now, despite normal visual acuities for single letters and intact ability to detect peripheral movement, she can see and identify only one or two items at a time. At present her lack of visual function resulting from her focal posterior parietal pathology is frustrating but accepted.

Posterior cortical atrophy causes progressive simultagnostic visual dysfunction culminating in complete simultanagnosia. One item only can be seen at a time. Her visual guidance of movement is inaccurate. She is however, incompletely aware of the severity of her visual disability because the visual functions she has lost are non-conscious. Agnosia is not to know. Anosognosia is not to know that one does not know. Simultanagnosia and optic ataxia tend to be anosognostic (which is arguably a saving grace).

#### **4. Heart infection in a child that led to bleeding into both posterior parietal lobes.**

Jacob was three when he developed infective endocarditis.<sup>18</sup> Bleeding from secondary infected aneurysms in both posterior parietal lobes was drained neurosurgically. He recovered well with antibiotic treatment. He was ten when first referred for visual assessment owing to disability reading long words, following text, writing words in line, and copying. The progressively diminishing text size and increased crowding of print given to 10 year olds were described as rendering the text illegible, and he was losing self-esteem and confidence. He often walked into people as if they were not there. His difficulty visually following moving objects (e.g. a car or an aeroplane) and his difficulty reading text were associated with impaired visual scanning. Difficulty climbing down stairs and stepping off kerbs were evident. He had no refractive error. His visual acuities were 20/15 in each eye. Stereoacuity was normal as was colour vision.

His visual fields elicited using confrontation methods appeared full, but were difficult to plot because he could not simultaneously perceive both the central and peripheral targets. His eyes were aligned but he showed jerky pursuit eye movements. Voluntary saccades to visual targets were difficult to elicit but he had no difficulty making saccades to commands, like 'look up'. He could identify events in the 'Cookie Theft' picture from the Boston Diagnostic Aphasia Examination (used to assess simultanagnosia), yet took a long time to identify a pencil on a cluttered desk. Brain imaging showed severe damage to both posterior parietal lobes (Figure 3). His behavioural features, symptoms, signs and imaging were consistent with the diagnosis of a variant of Balint syndrome.



**Figure 3:** Case 4: Coronal CT scan passing through the bilaterally injured posterior parietal area.<sup>18</sup>

An adaptive approach using his strengths and abilities was encouraged. He learned to scan the ground ahead. His environment was de-cluttered. Well-spaced text and masking of text above what he was reading (rather than below, which interferes with accessing the next line) was adopted. Auditory strategies, of listening and dictating to a scribe were

implemented. The senses of hearing, touch, and proprioception to locate and reach for objects were employed, while deliberate systematic scanning of the environment was achieved. All this led to greater independence and improved self-esteem, while his prior behavioural outbursts due to frustration became infrequent.

Adaptive and training strategies matched to the needs of those with bilateral posterior parietal pathology can prove effective.

### **5. The teenage girl with an arteriovenous malformation in her left occipitoparietal area that bled.**

In 1996 Nicola sustained a spontaneous rupture of an arteriovenous malformation into her left occipital lobe. After 8 days of drug-induced coma the malformation was neurosurgically excised. After an early episode of spontaneously resolving left sided weakness, perhaps due to vascular spasm, she recovered well, with initial reports of 'no lasting damage', but outpatient visual field testing identified a right-sided homonymous hemianopia with central sparing. No other visual difficulties were identified. However, from that time Nicola experienced profound visual difficulties in cluttered or crowded conditions, but was unable to articulate what they were. She called them her 'visual gremlins'. Seventeen years later, she learned at a lecture on cerebral visual impairment that her symptoms fitted with dorsal stream dysfunction. These included her difficulty finding objects in cluttered surroundings, inability to pick out and recognise familiar faces in a crowd, and feeling overwhelmed in crowded places. She struggled to read crowded text and could not locate where sounds or voices were coming from. She has also felt clumsy. All these difficulties persist.

Nicola cannot focus on a single object surrounded by other objects, because she feels compelled to look at another one, with the result that the first one 'disappears'

and cannot easily be found again. This is consistent with competitive mutual inhibition of object recognition, which is exacerbated when the objects are moving, or competitive simultanagnostic visual dysfunction.<sup>1</sup> This complex difficulty was dramatically demonstrated to others when she was asked to look briefly at a large audience and count how many people she saw. She explained that she could only focus completely on a single face in the crowd. The other people were seen as blurred images surrounding this one face. Her 'need' to look at another face, which she fulfilled, rendered the first face invisible and subsequently inaccessible. On looking away from the audience and back again she found it impossible to locate the person she saw the first time, and once again could only isolate another single clear face. She described her emotional reaction to this exercise. Anxiety had overwhelmed her and led her to frantically scan the audience, darting from one image to another with no discernable pattern to her scanning technique. This panicked approach did not give her time to focus on any individual, and she found it impossible to estimate how many people were in front of her. Prior to this experience she had not been able to describe her simultanagnostic vision because she had had no awareness of what her 'visual gremlins' were, but once she had had her vision explained, everything fell into place. Her 'clumsiness' was found to have the pattern of optic ataxia.<sup>19,20</sup>

This long-term simultanagnosia and optic ataxia had 'impacted hugely' on her ability to cope in congested environments and social settings, whether familiar or unfamiliar. Her prior unawareness of the nature of her visual problems and why she found certain situations hard to cope with had progressively eroded her self-confidence and led her to withdraw from many social activities. However, having gained insight and understanding, and having become able to acknowledge the origin of her 'gremlins', Nicola is now developing coping strategies in crowded and cluttered places.

First she allows herself time to slowly scan a crowded location, and consciously suppress her otherwise overwhelming emotions. Second, to help her identify specific people in a large group, she now slowly scans to seek obvious features. She notes who is wearing a bright red top, for example, and focuses upon their exact location, being ready to relocate them on her next scan, with the aim of building up her best overall picture. Her new knowledge and understanding of her condition have considerably improved her quality of life because she can now use rational approaches to make best use of her vision.

Simultanagnostic visual dysfunction can cause overwhelming discomfort in crowded locations. Giving motivational support to those affected by simultanagnosia, and an understanding of their condition, along with ideas to help them to develop strategies to overcome their unique difficulties, can prove very effective in helping them learn to make best use of their vision. Nicola is one of the authors of this paper and has worked together with the mother of a child with similar visual difficulties to create simulations her own visual difficulties. Figure 4 shows two pictures that look the same to Nicola when she views the person who has been rendered clear in the 'doctored' image and the same person in the 'undoctored' image.

This pair of photographs, illustrates the qualitative nature of Nicola's simultanagnosia as she experiences it, now that she has insight into her condition.

## **6. The boy who couldn't, then could place a peg into a peg board.**

One of the authors was shown and asked to explain a pair of videos at a meeting. In the first, a kneeling boy, known to have bilateral periventricular white matter pathology affecting his posterior parietal territory, was struggling to place a peg into a peg-board. In the second, taken a few minutes later, he easily performed the task. A key feature had been



**Figure 4:** Case 5: Paired photographs of a crowd at an outdoor concert. The first is undoctored. The second has been changed to show how Nicola sees the crowd. Only one person stands out. When she looks at that person in each photograph they both look the same. This therefore provides a close simulation of Nicola's vision. She only sees what she directs her gaze towards.

missed. In the second video, but not the first, the boy's knee was touching the peg-board. This was later found to account for the differing performances.

Tactile input that supplements the degraded non-conscious posterior parietal representation of visual space serves to enhance egocentric localisation, and thereby helps diminish impaired visual guidance of movement.

## **7. The teenager who played the piano using his thumbs to locate the keyboard.**

A 19 year-old man with multiple disabilities and visual impairment enjoyed creating his own 'music' at the piano. It was questioned why he pushed his thumbs against the front of the piano whilst doing so. It was found that he no longer needed to do this when his piano stool was elevated so that his legs touched the piano instead of his thumbs.

Again, this anecdote highlights that tactile supplementation of visual guidance adds data that enhances accuracy of self-localisation in surrounding 3D space.

### **8. The child who did not know where sound was coming from, who lost moving balls and who wouldn't look at his mother when she was talking to him.**

A 10 year old boy with superior posterior periventricular white matter pathology, lower visual field impairment and difficulty finding a toy in a toy box, or his mother in a group of mothers waiting at the school gate, was described as not being able to locate where someone was calling from, and rarely if ever looking at the face of those who talked to him. When asked about this he replied that he could not locate the origin of sounds, and that he was unable to listen when looking at a face, and needed to look away towards an uncluttered area to hear what was being said.

He was given a mobile phone and taught how to use it when out and about so that he could find his family members who now phone him rather than calling out. He was also taught how to glance, then turn and smile at his mother's face once she has finished speaking. This has proved effective in helping to build up their relationship.

When playing football he chooses to play in goal every time. He was asked what a ball looks like when it is kicked. "It disappears for about a meter of course, then it comes back when it slows down" was his reply. On assessment he could not count fingers on a quickly moving hand, only identifying them when the hand moved slowly.

The posterior parietal and middle temporal lobes together dynamically map the surroundings for both sound and sight, and damage to this area can impinge on both functions. Children with posterior periventricular white matter pathology causing cerebral (cortical)

visual impairment can have difficulty dual processing sight and sound. They can also have difficulty locating where sound is coming from. They can be taught simple strategies that help them to overcome these difficulties.

Inability to see fast movement (dyskinesia) is not uncommon and needs to be sought in children with this history. Slowing facial expressions, watching films without fast movement, and training ball skills with light slow balls initially are warranted,<sup>13</sup> and can all prove effective. Playing in goal prevents the need to identify all the players, and approaching balls do not disappear, they simply appear to get bigger.

### **9. The baby who reached out for the first time**

An eleven-month old boy had sustained bilateral posterior parietal damage owing to lack of blood supply to his brain during delivery leading to hypoxic ischemic encephalopathy. Despite apparently normal motor function, he had never reached out for anything, and sat smiling with his hands by his sides. It was hypothesised that the explanation could relate to impaired posterior parietal function leading to deficient visual mapping of his surroundings.

He was placed in a cot lined with a white sheet. A single toy was placed beyond reach. About twenty minutes later he had worked out how to move to reach for the toy. He picked it up and played with it. He had never done this before. Gradually his skills developed, as a sequel to a range of parenting strategies,<sup>7</sup> and he now attends mainstream nursery school.

It was not possible to know why this child would not reach out. However, from the distribution of his brain injuries it was surmised that he could have had simultanagnosic visual dysfunction and optic ataxia. Simplifying his visual environment enabled him to locate and play with a toy for the first time, adding weight to this hypothesis.

## **10. The girl whose upward, but not downward, reach and grasp are accurate**

An 18 year old girl who had been born at 24 weeks gestation approached one of the authors at a meeting where both were contributing. She asked why she was clumsy.

She was found for the first time to have no detectable visual function below thirty degrees from the horizontal. When asked to reach out for objects in her intact lower visual field she consistently did so inaccurately, with a wide gap between fingers and thumb as she did so. However, her reach in her upper visual field was accurate, with a normal in-flight gap between fingers and thumb as her hand reached out for the proffered objects.

In those with periventricular white matter pathology associated with premature birth, lower visual field impairment is common. Not only can the peripheral lower visual field be absent, but also the apparently intact paracentral lower visual field can have a reduced resolution.<sup>21</sup> In our experience this can be associated with inaccurate reach and grasp in the lower visual field, but accurate reach and grasp in the intact upper visual field. This knowledge can be used to advantage.

## **11. The girl who lost her ability to perceive the whole scene, but could still see in minute detail**

At age 9 Lea underwent cardiac surgery for a complex congenital cardiac anomaly diagnosed before birth. Low cardiac output during surgery and probable cerebral emboli led to multiple bilateral infarctions in the parietal and occipital lobes. Good recovery of vision followed a short period of cortical blindness and she returned to school a few weeks later. She had been a gifted pupil pre-operatively, but post-operatively she could no longer read and could not visually encompass a complete page of a textbook, the class or the playground, despite normal visual acuities. Lea found this stressful as she had

been told her vision had recovered. All tasks at school and at home involving visual search had become impossible. She could perceive tiny detail in an object or on a textured carpet but could not find a specified object in a room, in a drawer or on a cluttered table. The apparently inexplicable paradox of her clear detailed central vision but lack of global vision, were a cause of anxiety for Lea and her family.

Lea was offered and underwent intensive training for five half-days a week. She was trained to detect, orient to and grasp visual stimuli presented peripheral to central fixation with the aim of enlarging her attentional visual field. She was trained to pay attention to the global scene, in favour of the local aspects of shape and detail. Hierarchical stimuli (such as a big circle made up of a circular line of small squares) were presented, and she was asked to identify and name each large shape while disregarding the small ones. Reading training included tactile exploration of raised letters and words while reading aloud. After a few weeks, her simultanagnostic visual dysfunction had regressed almost entirely. She regained her reading skills and visual detection in her peripheral visual field, and returned to full time schooling.

The dissociation between intact central detailed vision allowing a child to see and pick up a paper clip from a carpet, in the context of a major deficit in global vision, can be counter-intuitive for parents, teachers and clinicians. Bilateral parieto-occipital damage commonly is accompanied by acute cortical blindness initially. Central visual function tends to recover, but in our experience, a spectrum of visual attentional dysfunctions can persist. This includes the condition of peripheral global attentional dysfunction – yet with persisting capacity to detect single peripheral moving targets – ranging to full-blown Balint syndrome in which only single entities can be seen (simultanagnosia) and visual guidance of movement is profoundly impaired (optic ataxia). The intensive visual training Lea received was accompanied by good recovery. There is need

for clinical trials to standardize and evaluate the efficacy of this approach.

## **12. The 17 year old boy with multiple disabilities and visual impairment (MDVI) who looked around for the first time in a bright monochromatic tent.**

Tom is 17. He has profound quadriplegic cerebral palsy and is registered blind due to CVI. He is sociable, and responds well to sound, but is startled by sudden fast movement. For most of the day he used to hold his head down, which was ascribed to poor head control. He rarely used his limited vision.

However, when surrounded by a fluorescent orange 'tent' for the first time at age 17, he lifted his head to look around and laughed with pleasure, something he had never done before. As a sequel to daily 15-20 minute sessions in the tent, he became motivated. He concentrated on single items, and he reached out and touched a slightly moving tambourine. He also began to track it in his more functional left visual field. Within a week he had started, for the first time, to hold his head up. Later he became able to do this outside the tent as well.<sup>22</sup>

A year later he can still only focus on single items in the 'tent', providing evidence that he can only process one item at a time owing to profound simultanagnosia. Tom has now gained a better posture, holds his head up to view his surroundings and can now locate light and colour movement in a multisensory room. He has also developed more engaging behaviour in communal activities.

It is not possible to test for objective evidence of simultanagnosia in those with profound learning difficulties, but Tom's markedly improved use of vision after a trial of removal of all pattern and clutter in a monochromatic tent, gives compelling evidence that this phenomenon is present. His newly found capacity to look around when not inside his tent, indicates that this ability is transferable to the world outside of it too.

## **EXPLANATION AND DISCUSSION**

Taken together, the case histories described show that the combination of apparent clumsiness, impaired visual search and evident discomfort in crowds are highly suggestive of bilateral posterior parietal dysfunction, or injury. When we became attuned to this clinical picture, it was remarkable how common this disorder in its various guises turned out to be.<sup>9,18,23,24</sup>

Without one knowing, the posterior parietal lobes serve the essential function of creating a moment-to-moment 3D mental non-conscious emulation of the surrounding moving visual scene that facilitates visual guidance of movement amongst the entities that make up that scene.<sup>2,25</sup> These entities are given their conscious identities by interplay with the image libraries within the temporal lobes, while attention to and choice of these identified items, is mediated by the prefrontal area of the brain.<sup>1,2</sup> To ensure accurate visual guidance of movement, the centre of this emulation is coincident with and relates to the midline of the body. Head and eye movement, supported by extraocular muscle<sup>6,26</sup> and neck proprioception<sup>27</sup> to stabilise the imagery with respect to the body, serve to extend this field of perception. The vertical and horizontal orientation of the scene is integrated with the balance (labyrinthine) system,<sup>27</sup> while coincident timing to events in one's surroundings is supported by the motion perception brain areas including the middle temporal lobes, the upper mid-brain and cerebellum.<sup>25</sup>

In our clinical experience posterior parietal dysfunction degrades this non-conscious emulation, potentially resulting in inaccurate visual guidance of movement and/or incomplete visualisation of the scene, in any combination or degree, depending on the nature and extent of the functional deficit.

The posterior parietal lobes thus reconfigure visual information received via the dorsal stream from the occipital lobes<sup>2</sup> and from the middle temporal lobes that process moving imagery.<sup>25</sup> They create the non-

conscious virtual, dynamic three-dimensional pictorial and auditory<sup>3,4</sup> mental emulation of the structure of our surroundings that enables us to move accurately without collision and injury. This constantly changing data-set is integrated and cross-referenced with:

- Synchronous input from the two eyes. (Asynchrony leads to the Pulfrich phenomenon, where the apparent vectors of moving targets are not coincident with their actual vectors.)<sup>28</sup>
- The automatic reflex protective visual system served by the upper mid brain and thalamus<sup>29</sup>
- Conscious visual storage and analysis of what things are, served by the temporal lobes, connected to the occipital lobes via the ventral stream
- Predictive visual memory input allowing one to move amongst moving targets such as in a crowd
- The internal 'plumb line' (vestibular) input from the utricle and saccule of the inner ear that creates the percept of what is vertical and horizontal - even when the eyes are closed
- The dynamic movement input from the semicircular canals of the inner ear that detect and accord knowledge of the rate and direction of one's change of momentum
- Accurate timing – to integrate with one's relative movement through the environment – accorded by the cerebellum
- A dual proprioceptive system –
  - from the body's muscles that inform of the position in space of body parts, and
  - from the extra-ocular and neck musculature, which relates the relative positions of the head and eyes in relation to the body, thereby stabilising image location with respect to the body, despite head and eye movement.<sup>6</sup>

- Frontally mediated choice of attention and action, linked to the capacity to plan and predict outcome

Any of these functions can be disturbed and each needs to be considered in anyone who has suffered brain injury affecting their perception of where they are in visual space.

The clinical presentations of posterior parietal brain injury described in this selected series of clinical vignettes can be drawn together to provide a concept framework that gives a practical working model for recognising difficulties consistent with posterior parietal brain injury, in order to understand, conceive of and implement salient customised strategies to deal with the resulting issues for each affected adult or child, as each is unique.

Initial history taking from a close family member or friend is essential, because those with injury or dysfunction of the posterior parietal lobes can rarely describe their visual difficulties. The non-conscious nature of their visual dysfunctions means that although the resulting behavioral features are evident to those who know them well, those affected often find it very difficult to understand and to describe their own visual difficulties.

Subsequent careful observation of behaviors under the circumstances described in the history, serves to both corroborate and characterise the nature and degree of the specific disabilities identified. For each of the cases described, environmental adaptation and tailored compensatory strategies proved highly effective. While targeted rehabilitational training also proved effective in case.<sup>11</sup> An additional fundamental approach that was particularly effective for case,<sup>5</sup> was in depth explanation of what became her erstwhile anosognostic visual difficulties. Now that Nicola understands the origin and nature of her difficulties she has been motivated to work on her lifestyle and to devise multiple strategies of her own to enable her to deal with her difficulties constructively. This process has been life enhancing not only because

it has been empowering, but it has allowed Nicola to share her new knowledge about her vision with friends and family, who are also empowered to make salient accommodations which have now become second nature. The whole family has benefitted.

The posterior parietal lobes perform myriad rapid computations to create the non-conscious moment-to-moment internal representation of our surrounding environment enabling us to parallel process vast amounts of information to create the ever-changing emulation through which we elect to move and interact. Damage to this area alone or in combination with adjacent brain areas, renders this process deficient, but in ways that are unique for every individual. To complement the systematic evaluation of visuo-attentional processes a specific and structured comprehensive assessment of neurovisual function using investigations matched to the child's, age abilities and vision need to be performed in every case.<sup>30,31</sup> Successful habilitation and rehabilitation are contingent upon starting from scratch with each affected individual to build up a comprehensive profile of the resultant disordered and deficient mapping of surrounding sights and sounds, and the nature and degree of the resulting subjective disruption of knowledge or where one is in the environment (egocentric localisation) and the trajectories of moving surrounding elements of the scene, such as people in a crowd (allocentric localisation).

The impact that this profile has upon the individual concerned is characterised, and the individual's strengths and abilities are ascertained. A customised matching profile of habilitational strategies is designed and implemented in such a way that it evolves to match the progressively changing needs of the affected individual, as quality of life improves.

It is never too late to start this process!

## Addenda

Of the clinical vignettes described in this paper case 5 is autobiographical, cases 1,

4, 9 and 12 describe published material. The remainder are published material co-written by the first author.

Each of the authors contributed case material for this paper and were involved in the design of the overall paper. They have all edited the manuscript and approved the final version.

None of the authors is aware of any conflict of interest. Additional information about CVI is available at: <http://cviscotland.org>.

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