Virtual reality technology in the assessment and rehabilitation of unilateral visual neglect

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ABSTRACT

Unilateral visual neglect affects a very large proportion of patients immediately after stroke. The presence of neglect has been found to be the major determinant of recovery of everyday function (Denes, Semenza, Stoppa & Lis, 1982). Interventions for the rehabilitation of neglect are not very effective. Picking up from the suggestions of Robertson, Halligan & Marshall (1993) potential ways forward employing VR technology are discussed.

Keywords: virtual reality, unilateral visual neglect, assessment, rehabilitation

1. INTRODUCTION

1.1 Unilateral Visual Neglect

Immediately following an acute hemispheric stroke over 60% of patients exhibit unilateral visual neglect (Stone, Halligan & Greenwood, 1993) - that is the disregard of objects in the space contra-lateral (opposite) to the major cerebral damage. Classic, textbook signs of neglect are eating food on just one side of the plate and then believing it to be empty, combing the hair on just one side of the face. Clinical measures such as line bisection (the centre of the line is marked by the patient and found by the examiner to be far off to the ipsi-lateral side) and object cancellation (objects on the side contral-lateral are omitted when instructions are given to cross-out all the objects present, e.g. all the ‘o’s on a sheet of paper containing ‘o’s and ‘x’s) demonstrate equivalent behaviour. Figure 1. captures the mis-perception of space of a patient with neglect. Traditional accounts would have it that the left side of the bar is ‘neglected’ or not seen, thus the patient is reaching for the middle of the bar that they perceive. An alternative theory (Milner, Harvey, Roberts & Forster, 1993) suggests that the world becomes ‘compressed’ so the true ends of the bar are perceived but the left half appears shorter than the right.

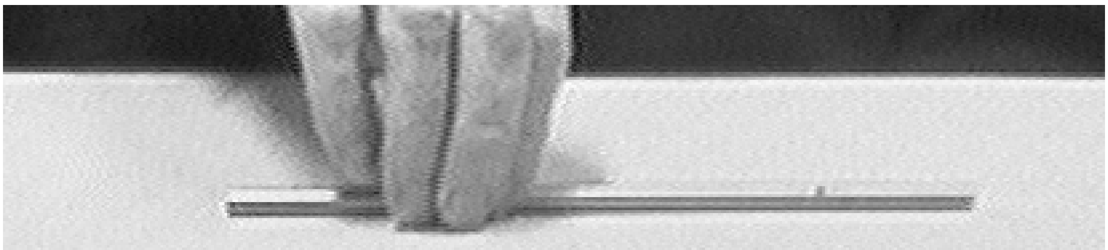

Figure 1. *A patient with neglect attempting to pick up the bar between finger and thumb from the “centre”. (see Rushton, Johnson & Wann, in press)*

Unilateral visual neglect is an attentional or representational deficit, it is not a visual field deficit. Although often accompanied by hemianopia (the loss of half the visual field), unilateral visual neglect dissociates from it. Neglect is

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also found of auditory and tactile space. Lastly, neglect of ‘imaginary’ space has also found in patients’ incomplete (omission of contra-lateral objects) recall from memory of familiar spaces such as city squares viewed from a certain vantage points (e.g. Bisach, Capitani, Luzzatti & Perani, 1981).

The presence of neglect has been identified as the major determinant of recovery of everyday functions following a stroke (Denes, Semenza, Stoppa & Lis, 1982). Consequently, successful interventions to aid recovery from neglect are vitally important.

1.2 Rehabilitation

Unfortunately, in contrast to the burgeoning number of published case studies and theoretical models, documented work on successful interventions for the rehabilitation of neglect is conspicuously lacking.

In a recent review Robertson, Halligan & Marshall (1993) proposed five possible future ways forward for rehabilitation of neglect: eye-patching, Fresnel prisms, vestibular stimulation, dynamic stimulation and optokinetic stimulation. ‘Forced usage’ and general attention retraining can also be added to this list.

1.2.1 Eye-patching. Eye-patching is founded on differential projection of each eye to the contra and ipsi-lateral hemispheres. By patching the eye that has the stronger connections to the ‘dominant’ intact hemisphere, the hemisphere’s ‘over-influence’ should be reduced so attenuating the attentional bias. Attention should then be more evenly distributed over the left and right hemi-fields.

1.2.2 Fresnel prisms. Fresnel prisms are similar to wedge prisms but are lightweight and thin. Prisms produce a rotation of the visual world. The benefit of doing this is that patients with unilateral visual neglect are not aware that they are neglecting half of the world. By wearing prisms parts of the world are brought into view that were previously unsighted and so the patient’s awareness of the contra-lateral portion of space may be increased.

1.2.3 ‘Forced usage’. An idea that converges with the eye-patching and fresnel approaches is ‘forced-usage’. Patients with hemiparesis, following stroke, (a left or right lateralised loss of control of limbs) show significant improvement can be produced in the effected limbs by the restriction of the good limb and the ‘forced use’ of the impaired limb (Taub, Miller, Novak & Cook, 1993). The explanation for improvement following such an intervention is that of overcoming ‘learned nonuse’ (Taub, 1980). Following major neurological damage a shock-like response occurs in the brain and precludes the use of the limb. After a period of time the effect of the shock diss greater detaily possible to express some movement with the impaired limb. However by this point, a habit of nonuse of the limb has been learnt. ‘Forced usage’ techniques attempt to overcome this learned non-use and have shown impressive results in the studies reported (see Taub, in press).

In the case of unilateral visual neglect, it could be hypothesised that a similar pattern of events is taking place. By restricting sight of certain portions of the visual world and ‘forcing’ the interaction with other parts it may be possible to prevent or overcome learned nonuse, or as it might be more appropriately termed ‘learned hemi-inattention’.

1.2.4 Vestibular stimulation. Rubens (1985) showed that vestibular or caloric stimulation by the injection of cold or warm water to the contra or ipsi-lateral ears reduces visual neglect in many patients. The effect is transient but may be valuable in promoting the patients’ awareness of the neglected contra-lateral portion of space.

1.2.5 Dynamic and optokinetic stimulation. Mattingley, Bradshaw & Bradshaw (1994) presented patients with a line bisection task on a computer. The background comprised of small dots above and below the line that were either static, leftward moving or rightward moving (and a control, neutral background). They found that patients were affected by global motion in the background; a leftward moving background showing a significant shift in bisection error. Butters, Kirsch & Reeves (1990) also presented patients with a line bisection task on a computer screen with either static or moving stimuli on the left side. They found that such stimuli had an influence provided that they were situated in the frame of the task, not just within the neglected side of space. Pizzamiglio, Frasca, Guariglia, Incoccia & Antonucci (1990) looked at the effects of optokinetic stimulation. Patients were asked to bisect a luminous strip in half. The strip was surrounded by luminous dots that were either fixed, left or right moving. The dots produced a slow nystagmus in the direction of movement. It was found that neglect was reduced with a leftward moving background.

There are three simple explanations for this interaction between neglect and visual motion: dragging the eye (optokinetic nystagmus) or attention in the direction of dot motion; the invocation of different perceptual-attentional systems because of the addition of a movement attribute to the test element (relative motion against the background flow); reduction in attentional bias between the neglected and non-neglected fields due to visual motion acting as common stimulus to attention across the whole test display.

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1.2.6 General attention retraining. Robertson's (e.g. Robertson & Frasca, 1992) account of unilateral visual neglect suggests that deficits in general attention underlie a major part of unilateral visual neglect. Consequently, an intervention that improves general attention should also reduce neglect. Robertson, Tegner, Tham, Lo & Nimmo-Smith(1995) demonstrated a significant reduction in neglect following training for sustained attention.

2. VIRTUAL REALITY & NEGLECT - POTENTIAL APPLICATIONS

2.1 Assessment

2.1.1 Internal and external validity. A common problem that plagues any assessment is the trade-off between internal and external validity, laboratory or clinical tests provide the former, whereas observation or field study provide the latter (Barker, Pistrang & Elliot, 1994). This is well demonstrated in neglect testing where performance on clinical test batteries may dissociate from every day function.

Virtual Reality Environments offer a testing environment that can be as controlled as the standard laboratory and providing a similar quantity of high quality data. Additionally, however, Virtual Reality based tests can aim for a degree of 'ecological validity' (test that are similar to tasks attempted in real, everyday life) that has never been possible with standard measures.

2.1.2 Depth and motion. Two specific qualities that objects may have in a Virtual Environment that are very difficult to manipulate in standard tests are a 3D position and a movement vector. Objects in the real world are characterised by having both of these attributes. On paper and pencil tasks it is not normally possible to see how neglect interacts with these attributes. Given the dissociation demonstrated between neglect in near and far space (Halligan & Marshall, 1991) and the seemingly privileged status of depth (Nakayama & Silverman, 1986) and motion (Mcleod, Driver & Crisp, 1988) in visual attention this would seem to offer a valuable advancement.

2.2 Rehabilitation

We will consider in turn the potential intervention strategies outlined in the previous section (1.2) and examine how Virtual Environments might offer some advantage.

2.2.1 Eye-patching. Neglect appears to occur across different frames of reference: retinotopic (position on back of eyeball), spatiotopic (position in the world), body-centred (relative to the body's midline) and object centred (relative to the axis of an object of attention). Through use of an head-mounted display (HMD), position tracker, eye-tracker and access to object geometry it is possible to selectively occlude portions of space specified in any one of the four frame relative coordinate system. Additionally, occlusion can be transient with periods of occlusion as short as one frame, a fiftieth or sixtieth of a second. With the use of a see-through HMD it is also possible to occlude parts of the natural world.

2.2.2 Fresnel prisms. In an HMD the rotation or displacement of the visual world relative to the patients' proprioceptive space is a trivial matter and just requires the addition of a constant to the position or orientation of the patients head. Additionally, a virtual body could be rendered in a rotated position relative to the head. An immersive VE offers an enviably flexible rig for exploring the relationship of various frames of reference in unilateral visual neglect.

2.2.3 'Forced usage'. Through the occlusion of the 'good' or ipsi-lateral hemifield it should be possible to force attention to be directed into the 'bad' or contra-lateral region of space for lack of anything to attend to elsewhere. If there is a spatiotopic or body-centric organisation in any areas of cortex this should lead to the use and stimulation of areas that are not otherwise activated due to learned nonuse.

Through the non-tracking of the ipsi-lateral limb it should be possible to further bias attention to the contra-lateral hemifield through the forcing of use of the contra-lateral limb for interaction in the VE (simple smoothing and mapping functions should be able to compensate for impaired motor function in the contra-lateral limb provided impairment is not too great) due to the simple fact that the limb is centred in the contra-lateral field. Additionally, the use of that limb should bring about transient reductions in the bias between hemi-field bias (Robertson & North, 1992).

2.2.4 Vestibular stimulation. Although it is not possible to 'virtually' inject water into a patient's ear it is possible to effect other stimulation similar to that produced by a response from the vestibular system. Wertheim (1994) suggests that the vestibular signal, an eye-position signal , and retinal image flow feed into a single 'reference signal' which indicates self-motion. If this is so then it should be possible to substitute optic accelerating locomotor flow patterns for mechanical stimulation of the vestibular system.

It is also possible to further pull apart vestibular and visual frames of reference by the rotation of visual world relative to the vestibular frame of reference by rendering a view that is titled relative to vestibular or gravitational coordinates.

2.2.5 Dynamic and optokinetic stimulation. If the superimposition of motion reduces neglect then it suggests two potential uses of VR technology in the treatment of neglect: a prosthetic, a see through HMD that allows the superimposition of motion in depth over the natural visual world, bringing to attention objects in the neglected field; a rehabilitation training task, that uses motion stimuli to manipulate attention and conscious awareness of objects in the neglected field.

2.2.6 General attention retraining. The companion paper by Johnson, Shaw, Rushton & Smyth (this volume) describes an intervention that should produce improved general attention.

3. SOME PROGRESS

The simple super-imposition of motion over the visual field has been found to not be universally effective for patients with unilateral visual neglect. Whether it transpires that it is effective for specific patients has yet to be determined.

As reported in Johnson et al (this volume) the attention retraining underway and ready for a neglect patient.

The authors are not aware of any of the other approaches outlined being attempted in a VE setting as yet. However, work on the interventions using traditional materials and technologies is progressing.

4. CONCLUSIONS

Virtual Reality provides for modifications of the sensory environment with a degree of ease and precision not possible in the natural world. Virtual Reality technology seems ideally suited for attempting the interventions outlined in this paper and also offers the opportunity to combine one or many.

The progress to date is unfortunately related to the number of clinicians and researchers currently employing VR technology for the purpose of the rehabilitation of neglect. Despite this lack of visible success, for both the assessment of neglect and the development of rehabilitation interventions VR offers great promise.

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