

Virtual reality enriched environments, physical exercise and neuropsychological rehabilitation

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ABSTRACT

This paper presents preliminary data on the effects of physical exercise and virtual reality upon mood and cognition in severely brain injured adults. The work draws upon two established fields of experimental psychology, enriched environments and physical exercise, in order to propose a new orientation for neurological rehabilitation. The results will be discussed in relation to organisation and delivery of clinical services, and to the theoretical model of von Steinbuchel and Poppel (1993).

Keywords: head injury, activation, virtual reality, rehabilitation, physical exercise, enriched environments

1. INTRODUCTION

Neurological rehabilitation lacks a coherent theoretical basis. Whilst rehabilitation has some intuitive appeal there is little evidence that it produces any significant benefit in the long term. The practice of neurological rehabilitation has seen little significant change for the better since the turn of the century and there remains an overall scepticism of therapeutic efficacy. To some, rehabilitation is little more than well intentioned chalantry (Bell 1992). Despite the well meaning and very professional efforts of rehabilitation staff there remains a very substantial degree of handicap in many brain injured patients in the long term..

Consideration of these problems leads us to suggest that the general approach of neurological rehabilitation must be changed. We suggest that, in order to achieve any significant advances, neurological rehabilitation must firstly delineate the “what-” from the “how-” functions of the brain (Von Steinbuchel & Poppel 1993) and regard the brain as a dependent variable (Bakker 1984). To adopt this altered perspective requires little more than was advocated by Zangwill in 1947: “...the more we find out about the brain and its functions the more we are likely to discover methods of rehabilitation based on strictly scientific principals...”. We suggest that experimental neuroscience has provided us with sufficient knowledge about the brain and its functions to enable the adjustment required to achieve a conceptual rethink in rehabilitation. Further, that our neuroscience colleagues have investigated techniques in both intact and brain damaged subject to the extent that there exists sufficient data to make the clinical application of their work an urgent priority.

In this paper we present our attempts to apply two principle areas of experimental data to a clinical brain damaged population with the aim of effecting a significant and beneficial change in the “how-functions” of the brain.

2. HEAD INJURY

Head Injury, which causes traumatic brain injury, is the major cause of disability in handicap across the entire age spectrum. Post traumatic impairments appear in a wide range of functions including arousal-activation, general levels of activity, motivation, mood and cognition. Either singly or, as is more usual, in combination these post traumatic

impairments persist indefinitely and adversely affect inter-personal relationships, social adjustment, academic and vocational status. Persistent impairments give rise to suboptimal physiological status, social withdrawal and isolation.

Rehabilitation has generally failed to address the pathophysiological response to trauma, thus neglecting a potentially important vehicle for effecting neurological change. Rather than focusing efforts on the expected underlying and general depression of the cerebral activation, specific problem areas such as memory or activities of daily living are pursued without adequate attention to the likely contribution from underlying neuropathophysiological factors. Attempts at cognitive remediation, for example, may not produce improvements in the specific areas targeted, but benefit may arise in an improved general state of arousal-activation, effort, or motivation of the individual recipients. Depression of cerebral arousal-activation is a common pathophysiological response to head injury. It is reasonable to suggest, therefore, that the first step in any neurological rehabilitation programme should be to facilitate this fundamental process, thereby increasing the brain's ability to receive, process and act upon information. A more activated brain may be better able to benefit from more traditional rehabilitation interventions. Attempts to improve cerebral arousal-activation by the use of pharmacological agents have generally failed. There is no convincing evidence that stimulant medication has any significant and long-lasting impact upon the functioning of the brain damaged individual. There is also the problem of potentially serious and adverse side effects produced by the drugs used. A more easily accessible route to improve arousal-activation may be by way of physical exercise, which has unequivocal benefits upon physical and mental status.

Inactivity is a common complaint after head injury, even in the absence of physical disability. Patients may demonstrate impaired levels of aerobic fitness and complain of fatigue, both of which can impair the rate of progress within rehabilitation. Mental and physical fatigue are common complaints after head injury. Fatigue restricts the level of effort, the duration and quality of performance in all activities. Loss of control over activity generally creates a state of dependence upon others. The sudden and often dramatic imposition of that state is unacceptable to many, giving rise to significant and persistent dissonance. Motivation becomes eroded and a sense of hopelessness pervades the individual's life. The state of behavioural inactivity may exacerbate any endogenous changes in neurotransmitter activity underlying aberrations of mood caused directly by brain injury. Those changes may compound the perceived lack of control, negative feelings and retardation. Acute recovery from head injury includes a hyperdynamic cardiovascular response and significant disruption of central neurotransmitter activity. It is likely that the early traumatic disruption of the biochemical equilibrium persists after head injury and underlies the chronic post traumatic abnormalities in mood, cognition and behaviour (Johnson, Roethig-Johnston & Richards 1993).

3. PHYSICAL ACTIVITY

Inactivity accelerates the rates of decline of major physiological adaptive systems which eventually reach the point at which the individual's ability to prevent or recover from acute stresses is impaired. The individual's ability to cope with such stresses and preserve subsequent function depends upon the maintenance of adequate physiological reserves, particularly neurological control, mechanical performance and energy metabolism. It is also assisted by such modifying factors as positive affect (e.g. self-confidence). Activity and exercise are increasingly recognised as a way of improving mental health, with reports of reductions in depression and anxiety, and increased perceptions of self control (e.g. Blackburn & Jacobs 1988). The most likely basis for these benefits is a change in central monoaminergic activity. For example, it is suggested that the antidepressant effect of physical exercise shifts monoaminergic function back to normal in clinically depressed subjects. Brown et al (1992) reported improvements in depression, anxiety, hostility, confused thinking, vigour, self efficacy and fatigue for psychiatric institutionalised adolescents. There are similarities between structural and functional declines associated with ageing and the effects of enforced inactivity, such as arises following severe head injury. It is reasonable to draw parallels between severe head injury and normal ageing in which there is a diffuse loss of physiological capacity and reserve and a reduced ability to adapt to changes.

Results from animal experimental studies suggest that chronic exercise may also result in permanent structural changes in the brain. For example, physical exercise in rats improves vascularisation in the cerebellar cortex, while a combination of motor learning with physical activity results in a greater communication network within the brain (e.g. Black et al 1990). Fordyce & Farrar (1991) investigated the effects of physical activity upon hippocampal cholinergic function. Rats demonstrated improved performance on spatial learning and memory tasks following a sustained treadmill activity programme. Neepser et al (1995) reported evidence that physical exercise can increase brain-derived neurotrophic factor in the hippocampus and neocortex. Neepser et al stated that "... interestingly, the greatest effects of exercise upon brain derived neurotrophic factor occurred in highly plastic areas, responsive to environmental stimuli".

4. ACTIVITY AFTER HEAD INJURY

Brain injury may severely disrupt normal patterns of interaction with the environment (Tinson 1989). Moreover, this disruption occurs in a variety of ways. To the extent that the injury entails motor or sensory impairment the opportunities for active interaction are inevitably diminished. Interaction is reduced still further as a consequence of impaired motivation, fatigue, hypo-arousal and impaired concentration and memory, all of which are common sequelae of brain injury. Further, such problems may increase as the time since injury lengthens and the head injured person becomes more withdrawn and isolated in all spheres of activity. Clinicians agree that to increase levels of interaction between the head injured person and their environment is a vital part of any rehabilitation process.

The importance of interaction with the environment is not simply a matter of clinical experience however. Within the animal literature there is strong empirical support for enforced environmental interaction producing clear beneficial effects upon both brain and behaviour (Renner & Rosenzweig 1987). In this context enforced interaction with the environment is referred to as "Environmental Enrichment" and is produced by group-housing of laboratory animals in large, complex and stimulating environments containing an array of manipulable objects. The effects of an enriched environment upon brain and behaviour are complex. In problem solving tasks enriched animals are superior to impoverished or isolation-housed counterparts, and the more complex the task then the greater the advantage. At the same time, enrichment leads to a variety of structural and functional changes in the brain, including a greater mass of cerebral cortex, greater cellular connectivity within the cortex, increased glial activity, a higher cortical metabolic rate and a range of neurochemical changes. In reviewing the progress in enrichment research Will & Kelche (1992) concluded that the enriched environment for brain damaged subjects constitutes a potentially powerful tool which combines the additive effects of its various social and physical components. However, Will & Kelch called for the therapeutic efficacy of enrichment, whether it reflects true recovery or compensation, to be assessed by clinicians.

5. VIRTUAL REALITY

Virtual Reality (VR) provides a powerful means of increasing levels of environmental interaction in a highly controlled and structured manner. The vital characteristic of VR is that it is interactive. Within the virtual world created by the computer every response that the user makes has a consequence to which he must adapt in terms of mental processes and behaviour. Moreover, since interaction with the virtual environment can be made contingent upon whatever motor capacity the patient has then this technology is particularly well suited to applications in neurological rehabilitation. The application of VR to brain damaged patients offers a unique and powerful way of increasing the quantity and quality of direct interaction with the environment and of reducing cognitive and behavioural impairments. A VR enriched environment offers the potential for significant gains in physical and mental function at all levels. Whilst the real or ideal situation (e.g. cycling in the outside world) would necessarily involve the head injured person using community resources on a regular or frequent basis, these naturalistic situations require a high degree of motivation, physical ability and social contact than is usually present in acute rehabilitation patients. There are also the safety concerns associated with impaired balance and motor control, for example. Thus, the VR enriched environment offers a unique and safe opportunity for intervention.

6. PROPOSAL

This preliminary study aims to combine two different experimental approaches to facilitating recovery after brain damage. Patients will be introduced to a graded physical exercise programme, within or outwith an enriched VR environment, with the aim of increasing physical and mental parameters. The anticipated improvements are in general physical, cognitive emotional and behavioural functioning. Any such improvements may have knock on effects in other areas, such as adjustment and outcome. Generalisation from the training programme will be addressed by the incorporation of lifestyle exercise programmes which teach the individual to integrate multiple short bouts of physical activity into the course of their daily lives.

7. METHOD

7.1 Virtual Environment System

The system consists of an instrumented Monarch exercise bike, a 120Mhz Pentium PC with an analogue to digital converter and a 29 inch NEC 4PG monitor. The handle bar rotated and was connected to a potentiometer thus providing the heading angle. A tacho-generator was attached to the wheel providing a measure of cycle speed. The system ran at 20Hz and the sampled values from the bike produced contingent changes in heading direction and speed

in the virtual environment. The virtual environment was written using Renderware 2.0 and consisted of a ground plane on which were scattered a series of coloured objects with a mountain range in the distance. The subject's task was to cycle over to the various objects in turn. Several levels of complexity increased the memory and motor requirements. The former was achieved by having differing colours of objects and then requesting that the objects be taken in specific order (e.g. all the reds, followed by all the greens; or red, green, red, green etc.), and the latter by changing the size of the objects and also introducing "puddles" that had to be carefully steered between so as to reach the target object. A time course record held the trajectory taken and was available for assessment of improvement in performance time and accuracy.

8. DESIGN

A multiple subjects cross-over design was chosen. The reasons for this are several-fold: in normal clinical studies a commonly employed design is the multiple baseline design. This attempts to demonstrate an effect of an intervention by contrasting the improvement on one set of tasks against another. For example, if a memory training task is being assessed then it would be predicted that after intervention memory tests would reveal an improvement but visuo-spatial tests **would not**. If such a dissociation is found then it can be inferred that the improvement in memory is due to the intervention rather than the endogenous changes. Another design often employed is between groups comparison which assigns participants to either the experimental group or a control group. If there is a statistically significant difference in the improvement between the two groups then it is inferred that the intervention is responsible for this discrepancy. These two designs are unfortunately inappropriate for a small scale investigation of the efficacy of the VR/PE intervention. This is because it would be predicted that any effect would be across the board. Additionally, patients with head injuries are very heterogeneous. Given a large number of patients it would be possible to match them and hope that the confounding factor of individual variations would be attenuated. However, the current study is too modest in size to allow this.

A cross-over design allows the change during an intervention period to be contrasted against the change during a control period. As the results both come from the same patient it removes individual variation as a confounding variable. As endogenous factors will underlie changes, especially during the early stages of recovery it is necessary to compare the rate of increase of change between conditions and also to counter balance the ordering of conditions between patients so that 50% start with VE/PR and 50% start with the control.

9. CONTROL CONDITIONS

The control condition consists of use of standard cognitive rehabilitation software using a BBC Master pc and established training programmes. This is considered to be the one of the most widely used and available interventions. Although no intervention whatsoever might appear to be the best control, ethical considerations require that the best current intervention be used during this time.

10. SUBJECTS

Twenty subjects, aged between 16 and 45 years, will be recruited from patients admitted to the Scottish Brain Injury Rehabilitation Service, Astley Ainslie Hospital, Edinburgh, with a primary diagnosis of head injury. Those patients with a history of previous neurological insult will be excluded. Subjects will be randomly assigned to either experimental or control conditions. Each subject will undergo assessments of cognition, mood and behaviour, physical status and . All assessments will be blind.

11. INITIAL RESULTS

Two early pilot studies (Scott 1995, Shaw 1996) have demonstrated changes on a number of the measures. However, those studies were significantly constrained by their design and the availability of patients so it is not possible to infer more than "promise". At the time of writing a further, more intensive study is underway and the results will be available at the time of presentation to Conference.

12. CONCLUSIONS

Our aim in this work is to combine two different experimental approaches from experimental psychology and apply them to a major clinical population which suffers chronic and severe neurological handicap. Following the approach of von Steinbuchel and Poppel (1993) we seek to tackle rehabilitation at a different, lower, level of analysis than that typically employed in traditional rehabilitation units. The potential benefits from this approach may be substantial and far reaching for the individual patient and for the practice of neurological rehabilitation.

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