

CHAPTER 36

REHABILITATION OF ATTENTION FUNCTIONS

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INTRODUCTION

ATTENTION is what allows one stream of information from the internal or external environment to be selected over others and therefore pervades almost any thought or action we take in our daily lives. It is little wonder then that deficient attention, a common feature of many disorders of the brain (see Manohar et al., this volume; Vallar & Bolognini, this volume), can produce such profound functional impairments. With the benefit of accumulated knowledge from cognitive science, neuropsychology, and neuroimaging it is now abundantly clear that attention is not a simple unitary process. In addition to being able to *select stimuli* for preferential processing according to some attribute (selective attention), we must also be able to sustain that selectivity, particularly in conditions of monotony or repetition (sustained attention), and further, we must have the capacity to change the selection from one feature or stream to another (attention switching) (Posner and Petersen 1990; Robertson et al. 1996). Our ever-increasing understanding of how attention is instantiated in the brain is directly fuelling the development of new treatment strategies that can target specific attention subsystems (Posner and Petersen 1990). The field of cognitive rehabilitation has received a boost in recent years with a number of computer-based training studies reporting promising results. For the most part these studies have addressed deficits in working memory (Jaeggi et al. 2008; Klingberg 2010). In the present chapter we look at the current state of play in the effort to treat deficits in attention. In so doing we adopt the three-component framework of Posner and Rothbart by reviewing studies that have specifically targeted selective attention, sustained attention, and attentional control or switching.

There is rather strong evidence for the effectiveness of rehabilitation of classically 'executive' functions such as initiation, planning, and problem solving (Von Cramon

et al. 1991; Levine et al. 2000, 2007, 2011; Fish et al. 2007; Basak et al. 2008; Chen et al. 2011). However, these are not reviewed here as these cognitive abilities do not fall under the scope of 'attentional functions' as we define them in this chapter. Finally, this chapter does not cover deficits of spatial attention such as unilateral neglect and their rehabilitation (see Vallar and Bolognini, this volume).

REHABILITATION OF ATTENTIONAL SELECTIVITY

Some of the strongest evidence for the considerable plasticity of the selective attention system comes from an unusual source: action video game players. In one of the first studies in this area, Green and Bavelier (2003) showed that habitual players had significantly enhanced visual selective attention abilities on untrained tasks, which had never been practised. Furthermore, individuals who did not regularly play video games also showed strong improvements in attentional selectivity when they were given extended practice, confirming that the game playing has a causal role in enhancing attentional selectivity (Green and Bavelier 2003). Importantly, the benefits of video game playing have also been shown to transfer to complex real-world tasks such as piloting procedures (Gopher et al. 1994).

Specifically, video game practice has been shown to affect fundamental mechanisms of visual attention including inhibition of return (Castel et al. 2005), and the resolution of spatial-attentional (Green and Bavelier 2007) and backward masking effects (Li et al. 2010). A recent electrophysiological study that compared frequent video game players with controls recorded steady-state visual evoked potentials (SSVEPs) while participants monitored for targets in a multi-stimulus display consisting of rapid sequences of alphanumeric stimuli presented at rates of 8.6/12 Hz in the left/right peripheral visual fields, with a central square at fixation flashing at 5.5 Hz and a letter sequence flashing at 15 Hz at an upper central location. Cued to attend to one of the peripheral or central stimulus sequences, video game players detected targets with greater speed and accuracy than non-players. These benefits seemed to be achieved in two ways: (a) an increased suppression of SSVEP amplitudes to unattended peripheral sequences in the context of equivalent SSVEPs to attended-to streams in the two groups; (b) greater P₃ amplitudes by the video game group to targets in the alphanumeric streams. The authors suggest that the behavioural improvements in attentional selectivity that many studies have now demonstrated are attributable in part to better inhibition of irrelevant information and also more effective perceptual decision-making processes. Comparable ERP effects on inhibition of irrelevant stimuli and enhanced processing of targets following attention training in healthy participants were obtained by Melara and colleagues (Melara et al. 2002). A likely reason that action video games are so effective is that they are specifically

designed to be entertaining and immersive, while their fast pace, increasing difficulty, and unpredictability place substantial demands on attentional control. Many games also include the element of adaptive training, with difficulty altering in line with performance, a crucial element of the success of other types of cognitive training including working memory training (Klingberg 2010).

There have been fewer studies of selective attention training with individuals suffering from brain lesions or disease, but those studies which have been carried out have been broadly consistent with studies of healthy participants using commercial video games. Sturm and his colleagues in Aachen, Germany (Sturm et al. 1997), developed computerized training programmes which targeted either alertness/sustained attention or selective/divided attention, using a progressive shaping procedure where tasks became more challenging as performance improved (adaptive training). Patients with vascular lesions and associated attentional impairments showed training-specific (14 one-hour sessions) improvements on untrained tasks, with the selective/divided attention training programmes improving only on selective attention measures and not on the sustained attention/vigilance measures, and vice versa. Similarly specific improvement in test-measured attention performance has been found in patients with multiple sclerosis (Plohmann et al. 1998) trained for 12 hours on computerized attention training programmes aimed at different attentional functions, with selectivity showing improvements following selective attention training. Age-related selective attention deficits have also been successfully improved using progressive training in maintaining attention to stimuli in the face of auditory or visual distracters (Mozolic et al. 2011).

A more general computerized attention training which addressed a range of different attention functions but which included a selectivity component also yielded specific improvements in attention in a group of 29 traumatic brain injured patients (Niemann et al. 1990) and other studies have shown similarly promising results with this patient group (e.g. Ruff et al. 1994). General attentional training programmes have also shown promising effects following stroke (Barker-Collo et al. 2009). A systematic review of the literature by the Cochrane group, however, concluded that while there was evidence of the effectiveness of attentional training, there was insufficient evidence of generalizability to real-life function (Lincoln et al. 2008).

Training on tasks that are more ecologically valid may be one way of achieving greater transfer to real-life function. For example, an early single case study with a patient suffering from severe distractibility following a traumatic brain injury showed significant increases in the amount of text he could read by practising at home reading against distracting verbal auditory stimuli—this behavioural goal was important for this person's college studies (Wilson and Robertson 1992). We recently completed a study with traumatic brain injured patients with self-reported difficulties in attending against background noise and conversations could be trained to improve their selective attention to, and consequent memory for, spoken material, by applying a behavioural shaping method similar to that devised by Wilson and Robertson (1992) (Dundon et al. in

preparation). Patients listened to spoken text in one ear, against initially low volume competing text in the other. Gradually the volume of the competing text was increased. After training, patients showed better memory for the target text. Furthermore, patients with the greatest amount of pre-training self-reported distractibility and associated stress showed the greatest improvements in memory post-training. The trained group also showed evidence of generalized attentional selectivity improvements on an untrained oddball auditory attention task: the trained group showed a specific increase in the amplitude of the ERP P3b response to targets, without any change in the ERP P3a response (see Fig. 1).

In summary, there is clear evidence that training in selective attention can improve attentional selectivity in both healthy and brain-impaired individuals, though the evidence for the generalization of these effects to real-life function is still lacking, in the main. The mechanisms by which selective attention training operates are not clear, except that both inhibitory and selective processes appear to be upregulated, down to quite low levels of perceptual processing (e.g. inhibition of return and backward masking). A key ingredient of the training methods that have proved successful is the use of *adaptive training*, namely increasing the difficulty level of the selective attention challenge in line with progression in performance, a method which has also been used successfully with working memory training (see Klingberg 2010).

With respect to the second set of attentional functions (sustained attention and attention switching), however, the range of approaches has been more varied, and hence the theoretical basis for them requires some elaboration.

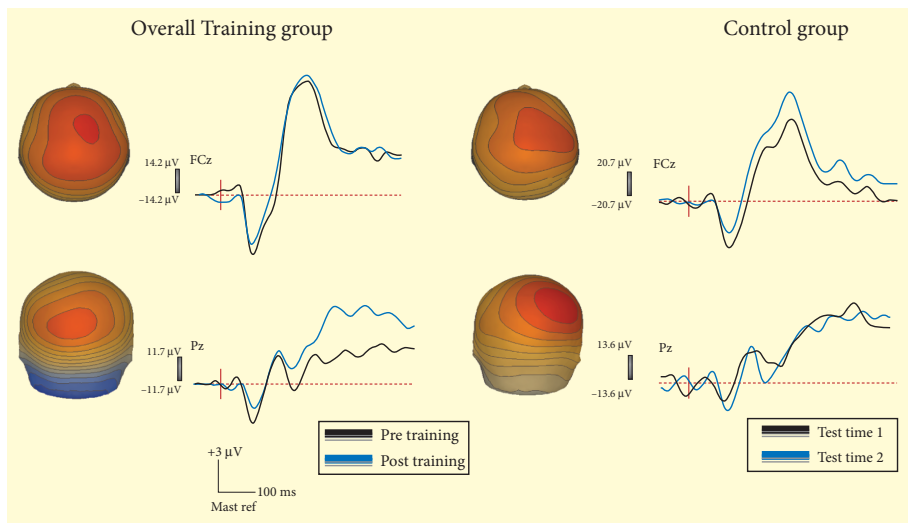


FIGURE 1 ERPs derived from a 3-stimulus oddball task. The overall training group demonstrated no training related change in the P3a component but a post-training increase in the P3b component. By contrast, the control group (receiving no intervening training between test and retest) did not show reliable change in either the P3b or P3a components.

REHABILITATION OF SUSTAINED ATTENTION/ALERTNESS

Human beings find it surprisingly difficult to deploy the top-down aspects enhancing selectivity to unchanging, or unchallenging repetitive stimuli and responses for extended periods of time. This already fragile ability to sustain goal-directed attention is very sensitive to disorders and damage to the brain, and can be a major source of impairment in everyday life in conditions such as traumatic brain injury (Robertson et al. 1997a), attention-deficit hyperactivity disorder (ADHD) (Bellgrove et al. 2005a, 2005b) and tauopathy-related neurodegeneration (O'Keeffe et al. 2007). It is also interesting to note that the ability to sustain attention is an important factor in determining recovery of motor and other functions following stroke (Ben-Yishay et al. 1968; Blanc-Garin 1994). Motor recovery following right hemisphere stroke over a two-year period was significantly predicted by measures of sustained attention taken two months after right hemisphere stroke (Robertson et al. 1997b). This is perhaps not surprising in light of the fact that learning any skill typically requires many hundreds, even thousands, of trials, which is particularly true for the re-learning underpinning recovery following brain damage. As mentioned above, attention is the capacity to allocate processing resources selectively to particular stimuli or classes of stimuli, and as Blake et al. (Blake et al. 2006) showed, this is a critical element in experience-dependent plasticity. If plastic reorganization requires attention to mediate the effects of rehabilitative experience, then the capacity to deploy attention over relatively long periods to relatively unchanging and monotonous stimuli is likely to be a strong predictor of successful recovery. This sustained component of attention has tended to be neglected in the literature but recent research is pointing to new avenues towards its enhancement.

Imaging studies have indicated that this type of attention is controlled by a right lateralized cortical network, including the anterior cingulate gyrus, the right dorsolateral prefrontal cortex, and the inferior parietal lobule, which regulates activity within subcortical arousal structures (Robertson and Garavan 2004). Posner and Petersen (Posner and Petersen 1990) identified the midbrain locus coeruleus (LC) as the critical arousal hub supporting the alert state by increasing perceptual signal-to-noise ratios via the neurotransmitter noradrenaline. The influence of the locus coeruleus system in humans was demonstrated by Smith and Nutt (Smith and Nutt 1996), who reported that suppressing the release of noradrenaline through clonidine administration resulted in the sorts of attentional lapses that are characteristic of diminished vigilant attention. Pharmacological studies have found similarly close links between noradrenergic function and vigilant attention (Coull 1995). More recently, our group has demonstrated a specific linkage in humans between noradrenaline activity and performance on a vigilant attention task in healthy adults who differ in a genotype that codes for an enzyme (dopamine β -hydroxylase) controlling the availability of noradrenaline in the brain.

Individuals whose genotype was associated with relatively low noradrenergic availability showed significantly increased errors of commission (Greene et al. 2009) and we showed similar results in children diagnosed with ADHD (Bellgrove et al. 2006).

Anyone who has worked in a rehabilitation hospital will be familiar with the difference between the responses of many individuals—those who have suffered a stroke for instance—first thing in the morning, versus in the early afternoon. Even in those of us who have not suffered an adverse neurological event but who have had to catch an early morning flight or two, it is not uncommon to find that our arousal levels can be so low at certain times of the day that cognitive function becomes severely compromised. Yerkes and Dodson famously studied the effects of different degrees of arousal (by varying the degree of shock) on the ability of mice to learn discriminations between the luminance of two compartments (Yerkes and Dodson 1908). They found that where lightness levels were easily discriminated, the mice performed better at high levels of arousal, whereas difficult light discriminations were best learned at low levels of arousal. On the basis of these experiments, they formulated the Yerkes–Dodson law. This law proposed that any task will have an optimal level of arousal below and beyond which performance will decline; they hypothesized this optimal level is lower in challenging tasks than in routine tasks. Similarly, Broadbent (Broadbent 1971) showed that while stress can improve performance on routine, non-demanding tasks, the same levels of stress can impair performance on more complex and demanding tasks. In a comprehensive review of catecholamine modulation of prefrontal cognitive function, Arnsten highlighted that many studies show a Yerkes–Dodson type inverted-U relationship between levels of noradrenaline release on the one hand, and behavioural performance on the other (Arnsten 1998). These studies, suggesting an interaction between arousal levels, optimal performance, and degree of challenge in a task, mesh well with the notion of exogenous modulation of arousal as previously discussed. They also suggest, however, that the relationship between the system for sustaining attention and that of arousal may not be a simple one of mutual facilitation, and a number of other more recent studies support such a view. Nevertheless, the above research tells us that without adequate levels of arousal, attention will not function well.

As mentioned above, vigilant attention can be impaired through administration of drugs—for instance clonidine—that inhibit noradrenaline release and reduce arousal, as described above in the study by Smith and Nutt (Smith and Nutt 1996). What they also showed, however, was that the deleterious effects of clonidine were much attenuated when the participants were exposed to loud white noise while performing the task. This suggests that external stimuli can induce ‘bottom-up’ or exogenous modulation of the cortical systems for vigilant attention. Coull and her colleagues confirmed that this is indeed the case (Coull 1995), showing that clonidine-induced noradrenergic suppression impaired vigilant attention performance much more when the task was familiar than when it was unfamiliar—and thus more arousing.

Sustained attention is a fundamental cognitive function that underpins many other more complex functions. While Smith and Nutt showed that externally arousing white noise could mitigate the effects of an arousal-depleting drug, we for

instance showed some time ago that left spatial neglect in patients with large right hemisphere strokes could be briefly alleviated—and on average, abolished for a very brief period—by being exposed to a moderately loud and somewhat unexpected tone (Robertson et al. 1998). The intervention derived from Michael Posner's observation of a close linkage between the right fronto-parietal 'alertness' attentional system on the one hand, and a spatial selective attention 'orientation' system on the other: he predicted that the former could modulate the latter (Posner 1993). George et al. (George et al. 2008) demonstrated that externally imposed time pressure could have a similar effect, based on the observation that perceived time pressure is associated with moderate increases in arousal (Slobounov et al. 2000). George et al. asked patients with left spatial neglect to find and cross out visual targets scattered over a sheet of paper. As predicted by the Yerkes–Dodson effect, when the patients thought they were acting under time pressure they missed significantly *fewer* targets than under open-ended testing conditions.

Based on these observations of the interplay between attention and arousal we showed that patients suffering left spatial neglect could learn to 'self-alert' and hence improve both left neglect and their sustained attention (Robertson et al. 1995). Their arousal was first increased by a loud noise—a hand clap—and their attention drawn to their temporarily more alert state. Using a graded self-instructional strategy, patients learned to replace the external stimulus with a simple, internally generated 'self-alert' instruction—a word or phrase which to them signified alertness, and which they applied periodically—and eventually spontaneously—to voluntarily increase arousal. Significant improvements were observed in eight patients, using a carefully controlled multiple-baseline by subject design. Patients were not simply externally alerted, but they were also given a metacognitive strategy with which the temporary arousal could be linked, and hence re-evoked periodically to produce enduring, rather than temporary effects. We further developed these methods with patients suffering from impaired executive function.

Shallice and Burgess (Shallice and Burgess 1991) developed the 6-Element test, where participants were asked to attempt six simple tasks. They were told that they would not have time to complete all of the items in every test. To meet the main requirement (i.e. to do something from all six), participants had to switch spontaneously between the tasks during the 15 minutes available to them. Despite being tested on their comprehension of the rules before and after the test, and their above average IQ scores, the patients with frontal lesions showed a strong tendency to get caught up in one or other of the tasks to the detriment of the overall goal. This may be in part because the ability to maintain the salience of an overarching goal is heavily dependent on sustained attention. Manly and colleagues (Manly et al. 2002) tested whether patients with traumatic brain injury who showed executive problems could improve through a simple manipulation which had elements of the arousal-inducing methods just described. The task was a variant of the 6-Element test, the Hotel Test, in which participants were asked to sample a series of simple tasks involved in running a hotel, such as sorting conference labels into alphabetical order and looking up

telephone numbers. As with the 6-Element test, they were told that they could not complete even one of the tasks during the 15 minutes. In the standard condition, the patients were significantly worse than IQ-matched controls—they missed on average one whole task, and deviated significantly from the optimal time allocation on all the others. However, in a condition in which they were asked to 'think about what they were doing' in response to each of six tones presented at random intervals, their performance improved significantly relative to that of the healthy controls.

Jessica Fish et al. (Fish et al. 2007) extended this approach to realizing goals (making phone calls at certain times) that needed to be executed by patients during normal daily life over a period of two weeks. In training, a particular cue phrase ('STOP': Stop Think Organize Plan) was associated with reviewing one's intentions. Over the study phase, 'STOP' text (SMS) messages were sent to the patient participants' mobile phones on half of the days selected at random. The messages were sent at random times during the working day but, crucially, not within half an hour of the time a call was due. Despite this, success in the telephone task was substantially greater on days with cues than days without. Even given the delay between a cue and the execution of the intention, this periodic interruption/review facilitated performance. Further work is required looking at the persistence and generality of this effect. A merit of the approach, however, lies in its potential flexibility. It does not require intentions to be pre-specified. The aim is to assist patients to manage actively their *own* goals, however recently these were formed.

Our research group has also applied very similar principles to treating the deficits in sustained attention that are characteristic of ADHD (O'Connell et al. 2008). Again, participants learned to produce self-generated increases in alertness first in response to a periodic auditory cue and later in response to an internally generated cue. In order to strengthen the training effect participants were provided with visual feedback conveying the magnitude of each self-alert event via online changes in electrodermal activity (EDA), an index of autonomic arousal. In the first trial of this brief training protocol, neurologically healthy participants who implemented this strategy showed increased arousal levels (as indexed by EDA) during the performance of an untrained sustained attention task and made significantly fewer errors. In the second trial, we found the same pattern of improvement in a group of adults diagnosed with ADHD.

The sustained attention/alertness function has also been tackled using the relatively non-strategic adaptive training methods which have been used with some success in selective attention and working memory training. These have also had significant, sustained-attention-specific effects using computerized adaptive training methods (Longoni et al. 1999; Sturm et al. 1997, 2004), confirmed by a Cochrane Review (Lincoln et al. 2008) which highlighted the effectiveness of such training for sustained attention/alertness, albeit without evidence of generalization to real-life function.

In summary, as with selective attention, there is evidence for promising effects of training aimed at the sustained attention/alertness system.

TRAINING OF ATTENTIONAL SWITCHING/CONTROL

Training of this third set of attentional processes has been less commonly carried out and so the evidence of its effectiveness is very limited. Art Kramer and his colleagues in Michigan have been the main researchers in this area, focusing on elderly cognition, producing promising results albeit without evidence of generalization to everyday function (Kramer et al. 1995). They observed that elderly people had particular difficulties in performing two tasks concurrently, particularly when the two tasks require similar motor responses. But Kramer and his colleagues found that both older and younger adults can learn to perform such tasks more accurately, and that these improvements are associated with cortical reorganization measured by fMRI (Erickson et al. 2007a, 2007b). The results of a number of studies suggested that both older and younger adults showed substantial gains in performance after training, and that the improvement generalized to new task combinations involving new stimuli. The authors conclude that such attentional control skills can be improved in older people and thus that cognitive plasticity in attentional control is possible.

CONCLUSION

The attentional systems of the brain appear to have a significant capacity for plastic reorganization, though the real-life benefits of attentional training remain to be demonstrated. The effectiveness of such training may in future be enhanced by combining training with non-invasive brain stimulation and/or pharmacological methods. The results of attentional training are sufficiently promising to justify a large programme of research into the clinical viability and applicability of these methods, and we hope that such a programme, currently in its very early stages, will accelerate.

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