Chapter 7
Measuring and Modulating Hemispheric Attention

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Abstract Studies combining electrophysiological and behavioral laterality measures hold great potential to illuminate hemispheric relations in attention. However, data from event-related potentials as well as spectral analyses (quantitative EEG and band power) are conflicting, and do not support a coherent theory of the electrophysiology of hemispheric attention. At the same time, a definitive behavioral measure of attention does not currently exist. To remedy these lacunae, we carried out the following experiment. Four groups of learning-disabled young adults received the same EEG biofeedback (EEGBF) protocol, consisting of training theta (4–8 Hz) down and training sensorimotor rhythm (12–15 Hz) up at four different electrode sites: C3 (seven subjects), C4 (ten subjects), Cz (nine subjects), and Fz (eight subjects). The C3 site is over left sensory motor cortex, C4 is over right sensory motor cortex, and Fz and Cz are over the front and middle regions of the central strip, respectively. Attention in each hemisphere was measured before and after EEGBF training using the computerized Lateralized Attention Network Test (LANT). The LANT estimates four separate networks of attention: executive-frontal conflict resolution, the benefit and cost of spatial orienting, and alerting, or sustained attention. EEGBF affected different networks maximally at different sites: Training at C3 reduced conflict in the right hemisphere, training at C4 improved alerting bilaterally and training at Cz increased the benefit of spatial orienting bilaterally. Generally, C3 training improved attention in the right hemisphere and C4 training improved attention in the left hemisphere. This suggests that training at C3 and C4 activates a metacognitive control system which is contralaterally organized. We concluded that EEGBF has site-specific and function-specific effects on attention. Further, unilateral training can have bilateral effects or even predominantly contralateral ones. This procedure suggests a new way to probe discrete physiological correlates of discrete behavioral changes following EEGBF. Such data inform functional theories of attention and clinical interventions in disorders of attention.

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Abbreviations

ADHD	Attention deficit–hyperactivity disorder
ANT	Attention Network Task
EEGBF	EEG biofeedback
ERP	Event-related potential
LANT	Lateralized Attention Network Task
LH	Left hemisphere
LVF	Left visual field
RH	Right hemisphere
RT	Reaction time
RVF	Right visual field
SMR	Sensorimotor rhythm
TVF	Target visual field

Introduction

Electrophysiological Wars

There is overwhelming EEG evidence suggesting functional hemispheric asymmetry in attention, although contradictory data are reported for specific EEG frequency bands. Changes in hemispheric specialization are also seen in pathological conditions, with atypical frontal activation in attention deficit–hyperactivity disorder (ADHD) (Baving, Laucht & Schmidt, 1999). These authors found that boys with ADHD exhibited a *reduced* right-lateralized frontal activation when compared with normal controls (as indicated by relatively higher right-frontal alpha power), while girls with ADHD exhibited *increased* right-frontal lateralization (as indicated by relatively higher left-frontal alpha power). At the same time, Ciçek & Nalçaci (2001) suggest that in normal participants greater resting alpha power as well as decreased alpha power during a task can be positively correlated with better performance on the Wisconsin Card Sorting Test. In addition, Clarke, Barry, McCarthy, Selikowitz, Johnstone, Hsu., ~~et al.~~ (2007) found that ADHD children showed increased interhemispheric EEG coherence (in theta and beta bands) in frontal and parietal regions, suggesting reduced functional laterality. Furthermore, Valentino & Dufresne (1991) demonstrated that directed attention produced a shift in alpha and beta asymmetry towards right-hemisphere (RH) lateralization. On the basis of such evidence, cogent theories of right-hemisphere systems of attention have been advanced (Fan, McCandliss, Sommer, Raz, & Posner, 2002), although it is not clear whether right lateralization is due to cognitive specialization or is simply a result of interhemispheric interaction in early visual perceptual processes (Jutai, 1984). The relation of hemifield attention to hemispheric activation is also not clear, as research has found that both hemispheres respond to selective attention demands related to stimuli in either visual field (Heilman & Van Den Abell, 1980).

The findings of event-related potential (ERP) studies are also often contradictory. Among the most interesting ERP studies, Miniussi, Rao & Nobre (2002) demonstrated that foveal attention increased the evoked N1 component bilaterally, when attention was directed to the right visual field (RVF), but increased the N1 component only in the RH when attention was directed to the left visual field (LVF). This suggests that the RH systems of directed attention affect the hemispheres asymmetrically. In contrast, Yamaguchi, Yamagata & Kobayashi (2000) found that the N1 component was increased in the posterior temporal lobe contralateral to the stimulus field and was reduced over the ipsilateral hemisphere.

Combined evidence from spectral EEG and ERP demonstrates the effect of attention on gamma-band EEG frequencies. Müller, Gruber & Keil (2000) have shown that gamma is increased in the hemisphere contralateral to a presented stimulus, but only when attention is paid to the stimulus. Other researchers (Gobbelé, Waberski, Schmitz, Sturm & Buchner, 2002) have shown that the gamma band synchronizes in the RH in response to selective attention (suggesting a temporoparietal network driving selective spatial attention). However, Doesburg et. al. (2007) have suggested that gamma synchronization occurs not only contralateral to the attended stimuli but also throughout the cortex. Indeed, Senkowski, Talsma, Herrmann & Woldorff (2005) demonstrated gamma changes in medial-frontal areas in response to attended (but not unattended) stimuli.

Many of these discrepancies may be related to methodological choices in data collection, artifacting, or analysis, although most papers specify similar procedures. It is likely that additional, yet unknown causes of discrepancy exist. Regardless of the cause, the current literature on ~~the~~ functional hemispheric asymmetry often does not fit common theories that tie cortical activity to behavior.

The Lateralized Attention Network Test

Recently, Posner and associates developed a brief computerized battery designed to measure executive conflict, spatial orienting, and alerting (Fan et al., 2002). These networks are claimed to be independent of each other, localized in different brain regions, and mediated predominantly via different neurotransmitters. Behavioral and physiological data suggest that conflict is controlled by both dorsolateral prefrontal and anterior cingulate cortices and is predominantly dopaminergic. Orienting is localized in the right parietal cortex and is mediated predominantly by acetylcholine. Alerting engages the parietal/prefrontal cortex and it is predominantly adregenergic.

We adapted the Attention Network Test (ANT) to lateralized presentation by tachistoscopically presenting to the LVF and the RVF "up arrows" and "down arrows," flanked vertically by additional arrows. Target arrows were preceded by cues to target location; cues presented were valid, invalid, central, double, or absent (not presented). The inclusion of invalid cues (not included in the ANT) permitted separate measurement of the cost and benefit of spatial orienting. These two components are thought to be associated with the N1 and N2 deflections of the ERP, respectively (Luck, Hillyard, Mouloua, Woldorff, Clark, Hawkins ~~et al.~~, 1994). Further, split brain and normal data suggest that the cost of spatial orienting ~~(OC)~~ is larger in the LVF or RH, whereas the benefit of spatial orienting ~~(OB)~~ is larger in the RVF or left hemisphere (LH) (Zaidel, 1995). Studies of the Lateralized Attention Network Test (LANT) in normal subjects suggest that the two cerebral hemispheres have largely separate and comparable networks of attention (Barnea et al., in preparation; Greene, ~~et. al., in press~~). Occasionally, orienting is found to be larger in the RH, whereas conflict and alerting may be larger in the LH. In turn, clinical and imaging studies confirm that alerting is specialized in the RH, but there is some evidence that conflict selectively engages the right anterior cingulate cortex (Kaplan & Zaidel, 2001).

The three networks are independent of each other in each hemisphere, but they may cross-correlate significantly between the hemispheres. These results are consistent with the view that each normal hemisphere has a complete cognitive repertoire for interacting with the environment, including its own attentional control system. Thus, attention orchestrates the dynamics of hemispheric information processing in both the normal and the split brain by assigning resources to, and enabling, specific cognitive operations.

Attention and Laterality in Learning Disability

Attention

Probably the most studied subgroup of learning disabilities consists of individuals with ADHD. Although several reports have identified attention disorders in ADHD, some have not. Thus, the covert orienting of spatial attention paradigm adapted from Posner shows conflicting results. Sustained attention, assessed using the classic Continuous Performance Test paradigm and other paradigms, also produced inconsistent results. Perhaps the most consistent finding is evidence of impaired performance in conflict-producing tasks. The evidence is both behavioral and physiological. These results are consistent with the notion that ADHD involves executive deficits.

Laterality

Several cognitive studies have supported abnormal cerebral laterality in ADHD, but the evidence is largely circumstantial and few studies have been explicitly designed to address laterality directly. Some have found spatial deficits in children with ADHD (Sheppard, Bradshaw & Mattingley, 1999; Garcia-Sanchez, Estevez-Gonzolas, Suarez-Romero & Junque, 1997), whereas others have found evidence for LH dysfunction (Cohen et al., 2000; McInnes et al., 2003; Rucklidge and Tannock, 2002; Seidman et al., 1998; Semrud-Clikeman, 2000).

Both structural and functional imaging studies have also reported laterali~~zed~~ differences in ADHD ~~subjects~~. In particular, a number of baseline functional activation studies have indicated abnormal ~~RH > LH~~ asymmetries in subjects with ADHD, AU1 while others looking at activation during cognitive challenges have indicated decreased right-sided activation.

McCracken (1991) has suggested that ADHD may be associated with a dysregulation of the locus ceruleus nucleus in the brainstem, which is thought to produce 80% of the largely right-lateralized norepinephrine projections to the cerebral cortex. This system has been shown to play a key role in regulating arousal, vigilance, sleep, autonomic function, and emotion. This account implies a dysregulation of RH function.

Recent data from our laboratory are directly relevant and more definitive. Adults with ADHD were compared with age-matched controls in tests of lateralized lexical decision as well as of dichotic listening to words (specialized in the LH) and to emotional prosody (specialized in the RH). There seemed to be a selective deficit in LH control of processing strategies. Adults with ADHD appeared to emphasize a RH processing strategy during challenges that did not overtly tax executive processes. This RH emphasis in adult ADHD is associated with deficits for linguistic functions and advantages for processes specialized to the RH. However, processing could be normalized in adults with ADHD under certain attentional states.

EEG Biofeedback

EEG biofeedback (EEGBF) is a procedure whereby an individual modifies the amplitude, frequency, synchrony, or other derived measures of the electrical activity of his/her own brain. Many authors have demonstrated control of various electroencephalographic parameters in animals and humans (Birbaumer, 1977; Birbaumer, 1984; Birbaumer et al., 1981; Kamiya, 1969; Plotkin, 1976; Sterman, 1977). Work by Monastra et al. (Monastra, 2003; Monastra & Lubar, 2000; Monastra et al., 1999, 2002) concluded that EEGBF is effective in treating attentional disorders, but some methodological issues persist (Loo, 2003). Foremost is the ubiquitous problem of a proper control group. It is critical to exclude experimenter bias, simple repetition, or incidental context/attention effects of the EEGBF training protocol. Although it is possible to demonstrate that EEGBF works by showing the differential effect of different protocols, determination of the degree of change, relative to a neutral or a baseline condition, is problematic. A double-blind sham control, where the subject engages in the same kind of feedback condition as with EEGBF but without veridical feedback, is expensive and often detectable by the subject. Instead, we will contrast several alternative EEGBF protocols, which will enable comparison of the results of lateralized training at C3 and C4 in the LANT. This permits an assessment of the degree to which the laterality of the training electrode determines the laterality of the affected network. A significant interaction of the site of the training electrode by the network by EEGBF would demonstrate the efficacy of training.

There have been few controlled experiments on the effects of EEGBF training on hemispheric specialization and interhemispheric interaction in the normal brain, mostly using the slow cortical potential shift approach (Hardman et al., 1997; Kotchoubey et al., 1996; Rockstroh et al., 1993; Pulvermuller et al., 2000). However, the evidence for hemispheric engagement is at best indirect. Our approach addresses these shortcomings.

Effects of EEGBF on Attention

Primary improvement on attentional symptoms has shown the effectiveness of EEGBF ~~to address~~ ADHD symptoms (Monastra, 2005; Gruzelier & Egner, 2005), although much research still needs to be done to validate the methods of action of EEGBF. Clinically, much EEGBF for attentional symptoms is performed with an “active” electrode placed at C4, Cz, or C3. (We use the term “active” here loosely, as any EEGBF training circuit consists of the difference between two electrodes and thus the “reference” electrode will most likely measure an electrically active area.) As early as 1970, Sterman showed that C4 sensorimotor rhythm (SMR) training produces motorically “calm” cats, with a trained increase of SMR (12–15 Hz) on cortical motor strip. Similar motor stilling has been assumed to have a beneficial effect on attention and impulsivity and most clinicians still choose to train attentional symptoms on the motor strip, at C3, Cz, or C4, even though there is strong functional neuroimaging support for a frontal hypoarousal model of ADHD (Liotti, et. al., 2005; Max, et. al., 2005) along with central and midline cortical slowing (Mann, et. al., 1992; Chabot, et. al., 1996; Monastra, et. al., 1999; Clarke, et. al., 2001).

For training-frequency selection, inhibiting slower frequency ranges including theta (4–8 Hz) is typical, as we replicated here. Reward frequency ranges are usually SMR (12–15 Hz) on the motor strip, as SMR is considered a “resting” rhythm, perhaps analogous in function to alpha elsewhere in the brain. Other frequency ranges are also sometimes chosen for reward by clinicians. While SMR is typically trained at C4, either SMR or low beta (15–18 Hz) may be typically chosen as a reward frequency at C3. Standard Cz reward frequencies could be either SMR or low beta. In addition, clinicians often reward slower frequencies posterior to the motor strip, and faster frequencies anterior to the central motor strip. Interhemispheric training (C3 active, C4 reference, for example) is also used, rewarding frequencies in the 12–18-Hz range. The subjective nature and variety of these choices is one of the large confounding factor in comparing clinical efficacy of training techniques. For the purpose of comparing hemisphere and site specificity, we rewarded all training sites at 12–15 Hz.

The main goal of this chapter is to contrast the effects of four EEGBF training protocols on the attention networks in each cerebral hemisphere of learning-disabled young adults. This was accomplished by probing the three networks of attention, namely, conflict resolution, spatial orienting, and alerting ~~or~~ vigilance. These networks were assessed using a lateralized version of Posner and associates' ANT. The training protocols rewarded the subject for decreasing the power in the theta band (4–8 Hz) and for increasing power in the "SMR" 12–15-Hz band. The training electrode varied systematically between C3, C4, Cz, and Fz, using the standard 10:20 placement system. We addressed the following question: What is the relationship between training site and affected attentional process as a function of inter- and intrahemispheric training and assessment location?

Methods

Lateralized Attention Network Test

Stimuli were presented using E-Prime software, on an IBM-compatible PC. Participants viewed the screen from a distance of 57 cm. Targets consisted of an upward or a downward arrow centered 1.06 cm to the left or to the right of the fixation. This target was flanked above and below (1) by two arrows in the same direction (congruent condition), (2) by two arrows in the opposite direction (incongruent condition), or (3) by two lines without arrowheads (neutral condition). The participants' task was to identify the direction of the middle arrow by pressing the up or down keys on the mouse. We used two slightly different versions of the test. Version 1 was presented in four blocks of 96 trials each, and version 2 was presented in four blocks of 108 trials each. The response hand alternated between blocks in the following order: right hand, left hand, right hand, left hand.

A single arrow or line subtended 0.55 cm (version 1) or 0.68 cm (version 2), and the contours of adjacent arrows or lines were separated by 0.08 cm (version 1) or 0.2 cm (version 2). The stimuli (one central arrow plus four flankers) subtended a total of 3.07 cm (version 1) or 4.20 cm (version 2). Performance in the congruent condition minus performance in the incongruent condition defines the conflict component of attention. Targets were preceded by one of six types of cues, used to define the cost of spatial orienting, the benefit of spatial orienting, and alerting: no cue, center cue, double cue, a valid spatial cue, and an invalid spatial cue. For the double-cue trials, there were two warning cues corresponding to the two possible target positions – left and right. For the valid-cue trials, the cue was at the target position, and for the invalid-cue trials, the cue appeared in the visual field opposite the target. Alerting was defined as performance in the double-cue condition minus performance in the no-cue condition. ~~Orienting benefit~~ was defined as performance in the valid-cue condition minus performance in the center-cue condition. ~~Orienting cost~~ was defined as performance in the center-cue condition minus performance in the invalid-cue condition. A variable duration of the first fixation was used to produce additional uncertainty about cue onset.

Each trial consisted of five events. First, there was a fixation period for a random, variable duration between 400 and 1,600 ms. Next, a warning cue was presented for ~~1,00~~ms. There was a short fixation period for 400 ms after the warning cue and then the targets and flankers were presented simultaneously for 170 ms. The participants had a window of 1,500 ms (version 1) or 1,000 ms (version 2) to make the response. After the response, in version 1, there was a delay between the response and initiation of the next trial equal to 3,500 ms minus duration of the first fixation minus reaction time (RT). In version 2, there was no delay between the response and the beginning of the next trial. After this interval, the next trial began. Each trial in which a response was made lasted from 3,170 to 4,170 ms for version 1 and a total of 670–2,770 ms for version 2. Trials to which the subject did not respond lasted on average an extra 1,000 ms for version 1 and an extra 500 ms for version 2. The fixation cross appeared at the center of the screen throughout the whole trial. Target location was uncertain except when a valid spatial cue preceded it. Thus, the first two experiments (C3 and C4 training) used smaller stimuli, included no neutral flankers, and used a longer interstimulus interval (3,170–4,170 ms), whereas the last two experiments (Cz and Fz training), used the larger stimuli, included neutral flankers, and used a shorter interstimulus interval (670–2,770 ms). More critically, the first two experiments included a smaller proportion of invalid cues (one quarter of the valid cues) than the second two experiments (half of the valid cues). The two experiments are part of a series designed to produce a progressively more sensitive clinical tool for measuring attention. They were carried out 1 year apart and were parts of larger studies. Thus, the variation in the LANT was a result of improving the clinical sensitivity of the test over time.

Responses were made unimanually on a mouse placed at the midline on its side, facing the responding hand. Thus, “up” responses were made with both index fingers, and “down” responses were made with both middle fingers.

Participants

Thirty young Israeli adults with heterogeneous learning disabilities (mixed ADHD, dyslexia, alcalculia, etc.) were recruited from remedial college preparatory classes at the Academic College of Tel Chai in Israel during July and August of 2004 and 2005. All participants were between 21 and 26 years old, with a mean age of 23 years 8 months. The participants were partitioned into four groups. Each group was assigned to a different training site from the set, C3, C4, Cz, and Fz.

EEGBF Training

EEGBF training was conducted over a period of 8 weeks; each participant received 20 training sessions. Each session consisted of ten segments of 3 min each, for 30-min total session training time. EEG signal was recorded and relevant frequency components were extracted. Feedback was provided in the form of visual and auditory videogame responses. The amplitude of the target frequency was represented by the size or speed of the object in the game. The participants' task was to increase the size and accelerate the speed of those objects. When reward conditions were satisfied for a minimum of 0.5 s, an auditory beep and a visual incentive stimulus (e.g., highway stripe, star in sky) were provided as reinforcement. The participants were instructed to maximize their point scores as well.

EEGBF was administered using the Deymed TruScan 32 system. Signal was acquired at 256-Hz sampling rate, converted from analog to digital and band-filtered to extract delta (0–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), SMR (12–15 Hz), and beta (18–22 Hz) components. An active scalp electrode was placed at C3, C4, Fz, or Cz for the four groups, respectively, according to the standard 10:20 system. The reference electrode was placed on the ipsilateral ear for the C3 and C4 groups and on the left ear for the Cz and Fz groups, and the ground electrode was placed on the contralateral earlobe. Impedance was kept below 5 kΩ, and artifact-rejection thresholds were set individually for each participant so as to interrupt feedback during eye and body movements that produced gross EEG fluctuations.

Results

We carried out a within-subject repeated-measures analysis of variance (ANOVA), site of training (C3, C4, Cz, Fz) × network (conflict, cost of spatial orienting, benefit of spatial orienting, alerting) × target visual field (TVF) (left, right). The dependent variable was the change in z score following EEGBF for each network for each experimental group relative to the respective control group. For conflict and cost of spatial orienting the dependent variable was based on the RT such that it was (RT pre-RT post)/SD of the control group for that condition and for benefit of spatial orienting and alerting the dependent variable was (RT post-RT pre)/SD of the control group for that condition. In this way, positive change indicates improved attention following EEGBF. AU2 AU3

The results showed a significant site × network interaction, $F(9,90) = 5.064$, $p = 0.0157$ (Fig. 7.1a). This shows that conflict improved the most following C3 training; benefit of spatial orienting improved the most after Cz training, Alerting improved the most after C4 training, and cost of spatial orienting did not improve at all.

Given our a priori focus on the separate attention networks in each hemisphere, we carried out two separate ANOVAs of network × site for each visual field. The analysis for LVF trials showed a significant network × site interaction, $F(9,90) = 2.25$, $p = 0.0256$, reflecting a selective and massive improvement in conflict in the RH following C3 training (Fig. 7.1b). The network × site interaction for RVF trials was not significant ($p = 0.374$) (Fig. 7.1c).

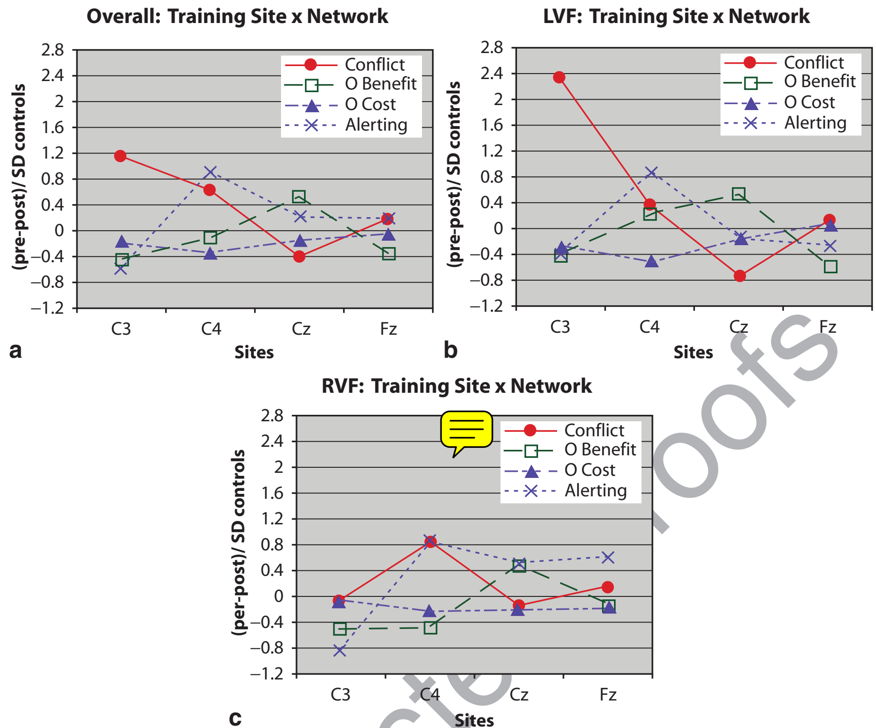

Fig. 7.1 The interaction between the site of the training electrode and the attention networks showing the effect of EEG biofeedback in (**a**) the two visual fields combined, (**b**) left visual field (*LVF*) targets, and (**c**) right visual field (*RVF*) targets. The dependent variable is the effect of EEG biofeedback in terms of standard deviation units of normal controls for the same networks. *C3*, *C4*, *Cz*, *Fz* location of training electrode for the four experimental groups, *O* orienting

We next followed up with separate ANOVAs of site × TVF for each network. The result for conflict disclosed a significant site × TVF interaction, $F(3, 30) = 3.261$, $p = 0.0351$. In particular, the site (C3, C4) × TVF interaction was significant, $F(1, 15) = 4.985$, $p = 0.0412$, showing that the LVF improvement in conflict occurred for C3 but not for C4 (Fig. 7.2). Similarly, site (C3, Cz) × TVF was significant, $F(1,14) = 4.905$, $p = 0.0439$, showing that the selective LVF improvement in conflict following C3 training, did not apply to Cz training. Finally, the site (C4, Cz) × TVF analysis disclosed a significant main effect of site, $F(1,17) = 4.665$, $p = 0.0454$, showing that C4 training resulted in an overall improvement (reduction) in conflict ($\Delta z = 0.63$), whereas training at Cz resulted in an increase in conflict ($\Delta z = -0.406$).

For benefit of spatial orienting, the ANOVA site (Cz, Fz) × TVF exhibited a significant main effect of site, $F(1,15) = 5.817$, $p = 0.0291$, showing an improvement in benefit of spatial orienting following Cz training (0.524) but a decrease following

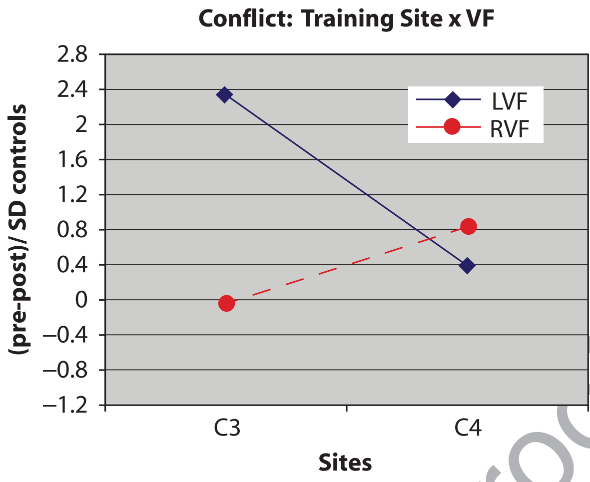

Fig. 7.2 The interaction between the site of the training electrode and the visual field (*VF*) of the target for conflict in the C3 and C4 groups

Fz training (−0.341). Finally, the analysis site (Cz, C3) × TVF showed a trend to significance, $F(1, 14) = 3.644$, $p = 0.077$, contrasting with the improvement in benefit of spatial orienting following Cz training and a decrease following C3 training (−0.455).

For alerting, the analysis site (C3, C4, Cz, Fz) × TVF yielded a significant main effect of site, $F(3, 30) = 3.786$, $p = 0.02$, showing a large improvement following C4 training (0.89), a moderate improvement following Cz (0.219) and Fz (0.201) training, and a decrease following C3 training (−0.586). The analysis site (C3, C4) × TVF confirmed the results that C3 training differed significantly from C4 training, $F(1,15) = 7.947$, $p = 0.013$. Interestingly, the analysis site (Cz, Fz) × TVF disclosed a significant main effect of TVF, $F(1, 15) = 4.6$, $p = 0.05$, showing that there was an improvement in alerting in the LH (0.576) but a decrease in alerting in the RH (−0.155).

Discussion

The significant interaction of site × network shows, first, that EEGBF is effective, second, that training is site-specific, and, third, that training is function (network)-specific. In particular, the theta down–SMR up protocol applied at C3 selectively improved conflict, whereas training at C4 selectively improved alerting, and training at Cz selectively improved the benefit of spatial orienting. In fact, C3 selectively improved conflict in the LVF (Fig. 7.3a). Thus, an electrode placed over the left

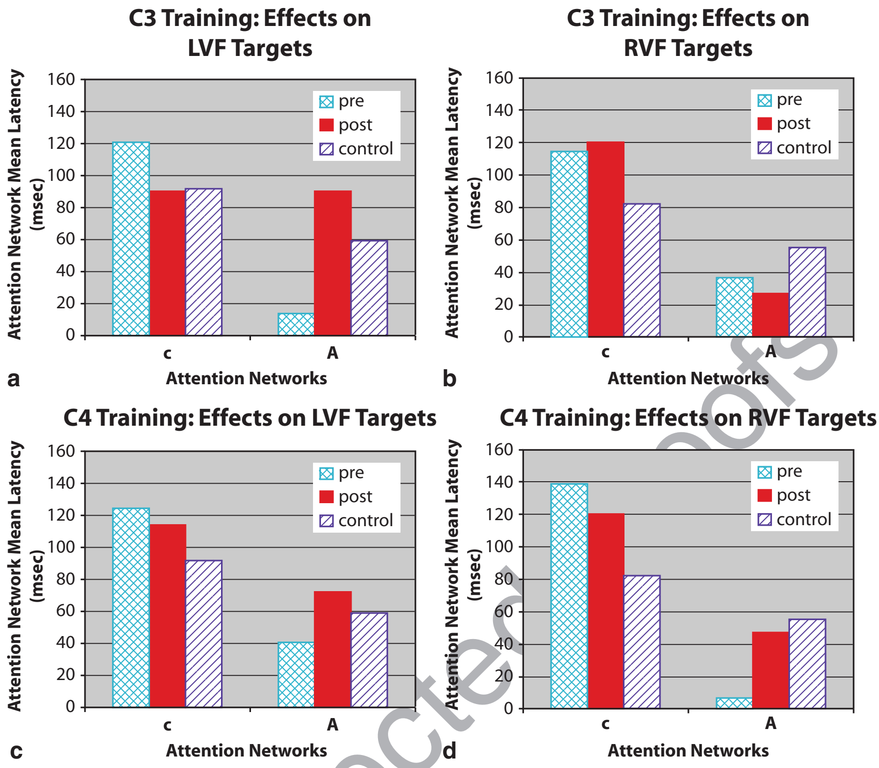

Fig. 7.3 The effect of training on conflict (*C*) and alerting (*A*) compared with normal controls (**a**) on LVF targets in the C3 group, (**b**) on RVF targets in the C3 group, (**c**) on LVF targets in the C4 group, and (**d**) on RVF targets in the C4 group

motor cortex selectively affected the RH. By the same token, C4, placed over right motor cortex, improved conflict in the LH (Fig. 7.3d) and alerting in both hemispheres (Fig. 7.3c, d). Similarly, training with the centrally placed electrodes, Cz and Fz, improved alerting in the LH. Thus, there is no selective effect of the training electrode on the hemisphere underneath it. We found that C3 training and C4 training had greater effects on the attention networks than Cz training and Fz training. Furthermore, C3 training improved attention (conflict and spatial orienting) selectively in the RH (Fig. 7.3a), whereas C4 training improved attention selectively in the LH (conflict, benefit of spatial orienting, alerting) (Fig. 7.3d).

The results are consistent with a model in which C3 and C4 training engages a metacognitive network that is contralaterally organized (Sterman, personal communication, April 29, 2005). Activation of the metacognitive network enables a change in the opposite hemisphere, but training does not affect the organization of the metacognitive network itself. Consequently, the C3 and C4 electrodes need not change their own physiological profile and can reflect the same theta to SMR ratio before and after training. More stable changes in the theta to SMR ratio are likely to be observed in electrodes that reflect the operation of each hemisphere separately.

It is also noteworthy that although conflict and cost of spatial orienting both involve interference and are known to engage the dorsolateral prefrontal cortex and the anterior cingulate cortex, they are affected differently by EEG training, suggesting that they are based on different structures.

Clinical Implications

In clinical EEGBF, C3 is often chosen for inattention symptoms, while C4 is chosen for symptoms of impulsivity and restlessness (cf. Egner & Gruzelier, 2004), but there has been little justification beyond clinical observation to support these choices. Gruzelier suggests that C3 training decreases errors of omission, whereas we found that C3 is *least* effective at improving alerting. However, Egner and Gruzelier rewarded 15–18 Hz at C3, while we rewarded 12–15 Hz, underscoring the importance of different reward frequencies. AU4

For symptoms of inattention as well as for perseveration or problems of switching attention, Cz and Fz are also sometimes selected as training locations, instead of motor strip sites. For Fz and Cz our results match clinical practice, improving the orienting of attention, shown by the improvement of the benefit of spatial orienting measure. However, our results suggest that typical ADHD symptoms of inattention and impulsivity would be best served by training at C4.

Our results converge with clinical practice, in suggesting that C4 training is most effective for modulating sustained attention in both hemispheres.

Methodological Considerations

Our study was limited in several ways. First, let us consider the choice of reference electrode. This is often the ear ipsilateral to the active electrode, i.e., C3-A1 or C4-A2. Some clinicians also use a contralateral ear reference, and some use a linked ear reference. These choices may significantly alter the training protocol. Specifically, our C3 and C4 groups used ipsilateral references and thus localized the feedback to laterally measured changes, while our Fz and Cz groups used the left ear reference for both protocols. While our results at Fz and Cz *do* support the clinical belief that these areas affect switching of attention, it may not be the case that Fz-A2 and Cz-A2 would have effects similar to those seen here with Fz-A1 and Cz-A1.

One must also use caution when generalizing from our sample to all ADHD or learning-disabled individuals. Not only was there considerable variation among individual electroencephalograms, but also our subject pool may have exhibited EEG profiles not typical of adults with attention and learning disabilities. For example, Monastra et al. (1999) used a single EEG measurement at the vertex (Cz) to assess 482 individuals between the ages of 6 and 30 years, and found that a ratio of band power (theta/beta) was able to confirm ADHD diagnoses based on more traditional measures, including a clinical interview, continuous performance test, and behavior survey. This discriminant criterion predicted the diagnoses with a specificity of 98%

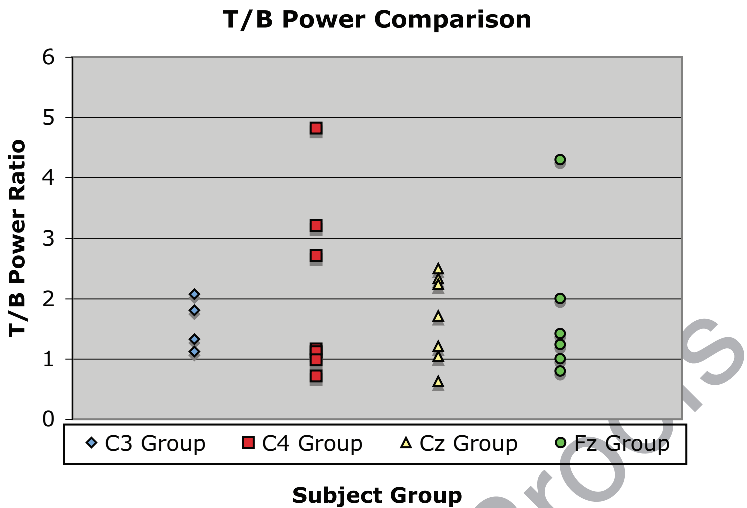

Fig. 7.4 The pretraining theta/beta (*T/B*) ratio in each participant group. All groups of mixed attention deficit hyperactivity disorder/learning-disabled individuals showed a wide range of T/B scores, without the expected high T/B ratios for all individuals

and a sensitivity of 86%. We applied a similar metric to our subject group, and found their theta/beta ratio scores to be widely distributed (Fig. 7.4.) This discrepancy may be more apparent than real. Monastra et al. averaged the EEG signal during eyes open, eyes closed, and task conditions, while we averaged EEG during eyes open and closed conditions only. We do suggest that electrophysiological criteria for inclusion may be useful in future studies.

Future Directions

We have shown here that attention is duplicated in the two hemispheres and that attention in one hemisphere can be affected differentially by lateralized training. C3 and C4 both seem to reduce conflict in the contralateral hemisphere, raising the possibility that conflict is mediated by a competition or interference mechanism. This model contrasts with the metacognitive model proposed in "Discussion" and further studies are necessary to decide between them. Our findings also raise the question of what happens following interhemispheric training aiming at increasing or decreasing interhemispheric coherence. In future studies it will be important to examine the effect of C3-C4 interhemispheric training in the LANT.

Furthermore, given that our results with C4 training have a strong LH effect, and given that C4-A2 training is common in clinical use, the question arises of whether there is a bilateral training protocol that would have similar or superior effects. In particular, what is the effectiveness and mechanism of action of two-channel (bilateral) training protocols involving hemispheric ratios, such as the asymmetry indices suggested by Davidson (2004)?

Finally, the version of the LANT that we used may be too complex, since it mixed components of both automatic and controlled orienting. In particular, in this study we used *peripheral* cues (automatic orienting) that were *informative*, i.e., mostly valid (controlled orienting). Instead, one can contrast the effect of automatic orienting, using *uninformative peripheral* cues, with controlled orienting, using *informative*, *central*, symbolic, cues. In this case, one would expect a reversal of ~~orienting~~ benefit (inhibition of return) in automatic orienting at cue-to-target intervals longer than 300 ms. No such reversal, however, should occur in controlled orienting (Posner & Cohen, 1984). In a recent study, we administered four such conditions of the LANT to 55 young adult participants (Fig. 7.5). Conditions 1 and 2 included uninformative (50% valid) peripheral cues consisting of asterisks, presented 150 and 500 ms, respectively, before the target. Conditions 3 and 4 included informative (75% valid)

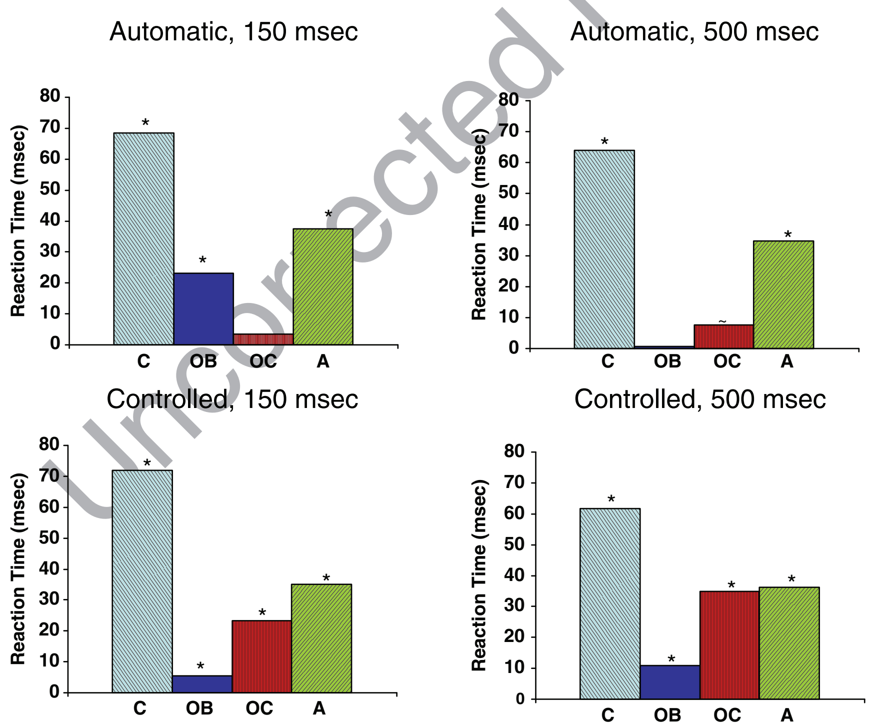

Fig. 7.5 Results of testing 60 young adults with two versions of the LANT at two different cue-to-target intervals (150 and 500 ms). The "automatic version" employs uninformative peripheral cues, while the "controlled version" employs informative bilateral symbolic cues. Only the automatic version shows inhibition of return, at 500-ms cue-to-target interval. *OB* benefit of spatial orienting, *OC* cost of spatial orienting

central, symbolic cues consisting of hands pointing left or right in both visual fields, presented at 150 ms and 500 s, respectively, before the target.

The results showed significant networks in all conditions with the exception of automatic ~~o~~rienting ~~benefi~~t at 500 ms. This reflects the expected inhibition ~~of r~~eturn at the longer cue-to-target interval. Moreover, condition (automatic, controlled) interacted with TVF (left, right): there was an LVF advantage for the automatic conditions and an RVF advantage for the controlled conditions.

In conclusion, we have shown evidence for the existence of lateralized networks of attention and for the ability to affect these networks differentially through different EEGBF protocols. However, many questions remain about the roles of training site and training frequency in affecting attention.

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