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The Effect of EEG Biofeedback on Hemispheric Specialization for Language*

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1 Rationale

We applied a common EEG Biofeedback (EEG BF) protocol to a group of children in an attempt to change their hemispheric specialization for language as measured by a common dichotic listening test. Specifically, we compared the effects of EEG BF training sites on the left and the right side of the scalp by comparing performance on dichotic listening to nonsense consonant-vowel syllables before and after training. This test is known to be exclusively specialized to the left hemisphere (LH) and it is believed to be a reliable measure of LH specialization for speech and language (Zaidel et al. 1990).

2 Background

2.1 EEG Biofeedback (EEG BF)

EEG BF is an operant conditioning procedure in which individuals can directly change their long term emotional, cognitive and linguistic profiles in response to online feedback of the individual's own EEG spectrum (between Delta and Gamma). Conditioning occurs by modulating the amplitudes and the connectivities of the stable cortical networks that the individual uses for solving problems. These long-term changes are presumably implemented by temporarily engaging a control network (the DMN). The feedback typically consists of negative or positive reward signals to the amplitudes of some combination of bands. EEG BF has been shown to result in long-lasting changes in attention, mood and cognitive style (Gruzelier, in press). The procedure can be effective for optimizing performance in the normal brain as well as for ameliorating cognitive and emotional deficits following acquired and congenital disorders. Barnea et al. (2005) used a common clinical protocol consisting of simultaneously decreasing the amplitude of the Theta band (6–8 Hz) and increasing the amplitude of the SMR band (12–15 Hz). Training was applied at electrode C3 or C4 in normal boys and girls ten to twelve years of age. The experiment was designed to measure hemispheric specialization for reading (word recognition) in Hebrew employing a lateralized lexical decision task. Participants were required to indicate whether an orthographically regular character string shown briefly to either the left or the right visual hemifield was a Hebrew word or not; responses were indicated by using a two-finger unimanual button press. Right-handed individuals, with left hemispheric specialization for language, typically show a significant advantage in accu-

* The data in this abstract are published here for the first time.

racy and latency for targets in the right visual hemifield compared to targets in the left visual hemifield. Experiments with split brain patients, with hemisphere damage patients, and with normal participants demonstrated that this task can be processed by each hemisphere independently of the other, so that left hemifield targets are "decided" by the right hemisphere and right hemifield targets are "decided" by the left hemisphere ("direct access," Zaidel et al., 1990). The experiment found differential effects of the two training sites as a function of gender. Specifically, boys showed an increase in the right visual hemifield advantage following training at C4, whereas girls showed an increase in the right visual hemifield advantage following training at C3. This suggests that language is represented in both hemispheres of the (young) participants and that this organization is different between boys and girls.

2.2 Dichotic listening

Dichotic listening is a standard procedure for measuring hemispheric specialization for auditory stimuli. When similar acoustic stimuli are presented simultaneously to the two ears, the ipsilateral auditory projections—left ear (LE) to left hemisphere (LH) and right ear (RE) to right hemisphere (RH)—are suppressed, so that the LE signal projects directly to the RH and the RE signal projects directly to the LH. When participants are required to identify the sounds in both ears, the superior ear is generally opposite the hemisphere that is specialized for the task. For example, dichotic listening to nonsense stop consonant–vowel (CV) syllables is a reliable test for left hemispheric specialization for phonetic perception, presumably because this ability is parasitic on speech which is highly lateralized to the left hemisphere in right-handed people. The test shows excellent suppression of the ipsilateral auditory pathways and it is relatively resistant to manipulation of attention and right-handed participants exhibit a robust right ear advantage (REA). Experiments with split-brain patients, with patients who had hemispheric damage, and with normal participants together demonstrate that this task is exclusively specialized to the LH (Zaidel, 1976, Zaidel et al., 1990). According to the anatomical model proposed by Kimura (1967), the normal REA reflects the privileged access of the direct RE signal to language centers in the LH. The LE signal has to be relayed from the RH to the LH through the isthmus of the corpus callosum before being processed in the language-gifted cortex of the LH. This relay results in reduced signal strength of the LE stimuli, leading to reduced accuracy in identifying them. Thus, in this task, the RE signal reflects the relative efficiency of the specialized phonetic/speech hardware in the LH, whereas the LE signal reflects also the strength of colossal transfer through the associated interhemispheric channel (Figure 1).

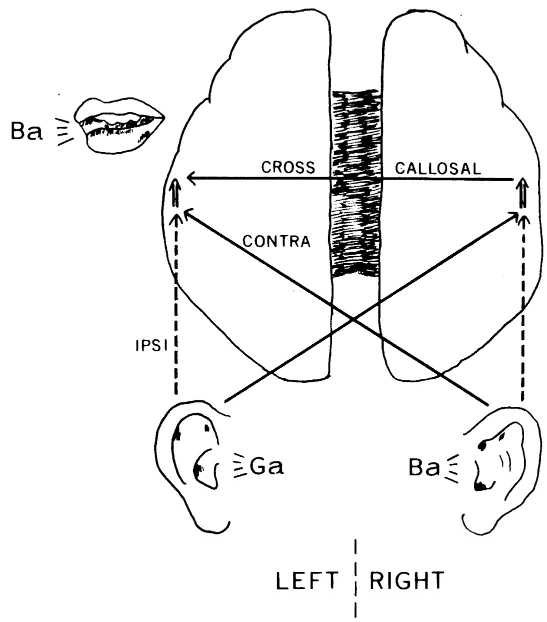


Figure 1: The anatomical model of dichotic listening (Kimura 1967). Verbal report of dichotic pairs of nonsense stop consonant–vowel syllables results in more accurate identification of right ear than left ear stimuli (right ear advantage) because the left hemisphere is exclusively specialized for the task. The stronger contralateral pathway from the right ear to the left hemisphere suppresses the weaker ipsilateral pathway from the left ear to the left hemisphere. Similarly, the contralateral pathway from the left ear to the right hemisphere suppresses the ipsilateral pathway from the right ear to the right hemisphere. Consequently, the direct signal right ear → left hemisphere dominates the indirect signal left ear → right hemisphere → left hemisphere, so that the syllables are reported more accurately from the right ear than from the left ear, resulting in a significant right ear advantage. With some music stimuli and environmental sounds, the primary analysis is in the right hemisphere and consequently such stimuli give rise to a significant left ear advantage.

2.3 Predictions

A novel feature of this experiment and of Barnea et al. (2005), from the point of view EEG BF, is the inclusion of a behavioral test of perception in each hemisphere before and after lateralized training. In this case, the test was dichotic listening to LE and RE syllables, and in Barnea et al. (2005), it was lexical decision of character strings in the LVF and RVF. Effective training at C3 may be expected to improve the accuracy of the RE, “direct access,” signal, whereas training at C4 may be expected to selectively improve the accuracy of the LE, “colossal relay,” signal (Zaidel et al., 1990). In both cases, the change in the REA would indicate an apparent shift in the degree of LH specialization for language.

A significant interaction EEG BF (pre, post) × Training Site (C3, C4) × Ear (left, right) × Gender (girl, boy) would demonstrate that this EEG BF training protocol is effective, that it is “site-specific,” and that it is gender-specific.

3 Methods

3.1 Participants

Twenty Israeli children ten to twenty years old (ten boys and ten girls) from a large kibbutz in Israel participated in the experiment. All participants were screened for neurological and psychiatric histories and for learning or attention disorders. All of the participants received monetary compensation.

3.2 Apparatus and materials

Neurofeedback training was administered using the Neurocybernetics EEG Biofeedback system (Encino, California) and the ProComp differential amplifier (Thought Technology, Montreal, Canada).

The dichotic listening test consisted of 60 pairs of syllables from the set Ba, Da, Ga, Pa, Ta, Ka (Track 5 of the Tonal and Speech Materials for Auditory Perceptual Assessment). Participants had to identify the syllables they heard in both ears by pointing to a choice on a card with the written letters B, D, G, P, T, K. The members of each stimulus pair differ from each other in one or two phonetic features, i.e. Place of Articulation and Voicing. Accuracy is measured by the number of correct identifications of syllables in the LE signal (out of 60) and in the RE signal (out of 60).

3.3 Procedure

The EEG BF training protocol consisted of receiving positive reward for reducing the Theta/SMR ratio i.e., decreasing the amplitude of Theta and increasing the amplitude of SMR. Half of the participants received training in electrode C3 and half in electrode C4. An equal number of boys and girls received training in each site. EEG BF training was conducted over a period of 4 weeks. Each participant received 20 training session, each session lasting 30 minutes and consisting of ten 3-minute game periods.

The dichotic stimuli were presented on a personal disk player that had a channel balance control and balance was adjusted individually for each participant.Design

The experimental design was EEG BF (pre, post) × Ear (left, right) × Training Site (C3, C4) × Gender (boys, girls). The following combination of results would demonstrate effective EEG BF training: a significant main effect of EEG BF (i.e. “post” accuracy better than “pre” accuracy), a significant main effect of ear (i.e. a right ear advantage), and a significant interaction EEG BF × Training Site × Ear. This would show that training has Site Specificity as well as a Site-of-Action Specificity (i.e. differential effect of training on the two cerebral hemispheres). There may also be a significant interaction EEG BF × Training Site × Ear × Gender, showing that training affects different components of the system in boys and in girls (cf. Barnea, Rassis, and Zaidel, 2005).

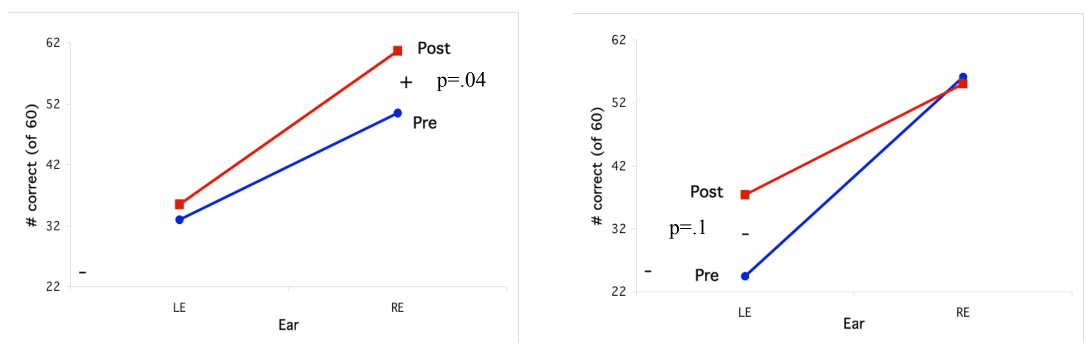
3.4 Design

The experimental design was EEG BF (pre, post) × Ear (left, right) × Training Site (C3, C4) × Gender (boys, girls). The following combination of results would demonstrate effective EEG BF training: a significant main effect of EEG BF (i.e. “post” accuracy better than “pre” accuracy), a significant main effect of ear (i.e. a right ear advantage), and a significant interaction EEG BF × Training Site × Ear. This would show that training has Site Specificity as well as a Site-of-Action Specificity (i.e. differential effect of training on the two cerebral hemispheres). There may also be a significant interaction EEG BF ×

Training Site × Ear × Gender, showing that training affects different components of the system in boys and in girls (cf. Barnea, Rassis, and Zaidel, 2005).

4 Results

There was a significant main effect of EEG BF ($F(1,15) = 14.4$, $p = .0016$). This reflects more accurate responses after training (47/60) compared to before training (41/60). There was also a significant main effect of Ear ($F(1,15) = 23.5$, $p = .0002$). This reflects an overall significant right ear advantage in accuracy of report (mean left ear = 31/60; mean right ear = 56/60). The interaction EEG BF × Ear × Gender approached significance ($F(1,14) = 3.5$, $p = .078$). Thus following training on either side, boys showed a selective increase in the LE score and consequently a reduced REA. By contrast, following training on either side, girls showed a selective increase in the RE score and consequently an increased REA. There was no significant interaction EEG BF × Training Site × Ear nor EEG BF × Training Site × Ear × Gender.



Girls Boys

Figure 2: Number of correct identifications (out of 60) in dichotic listening to stop consonant–vowel nonsense syllables before and after applying the EEG BF training protocol "theta down/SMR up" at the C3 electrode (5 boys and 5 girls) and at the C4 electrode (5 boys and 5 girls). The interaction EEG BF × Ear × Gender approached significance ($p = .078$). In boys, EEG BF increased the left ear score, suggesting increased colossal connectivity from the right hemisphere to the left hemisphere. In girls, EEG BF increased the right ear score, suggesting an increase in left hemisphere specialization.

5 Discussion

The critical interaction EEG BF × Training Site × Ear was not significant, thus failing to conclusively show that EEG BF was effective in modulating the REA. Instead, the results may simply reflect repetition effects or even placebo effects that were identical following training on either side. On the other hand, it is possible that training on both sides was effective in changing behavior, and that it did so in similar ways. The latter is a more likely interpretation of our data since typical repetition effects in this test are known to result in little to no effect on the REA.

The borderline significant interaction EEG BF × Ear × Gender suggests that in girls, training on either side selectively increased the RE score, thus increasing the REA. On the other hand, in boys, training on either side increased the LE score, thus reducing the REA by increasing colossal connectivity. The increased colossal connectivity provides more effective relay of the LE signal and more effective competition with the RE signal.

The same group of children demonstrated a significant effect of the same EEG BF protocol on hemispheric specialization for visual word recognition using a lateralized lexical decision task (LLD) (Barnea et al., 2005). Unlike the present dichotic listening task, which showed evidence of "callosal relay," reflecting exclusive LH specialization, the LLD showed evidence of "direct access," with different and independent contributions to lexical access in each hemisphere. As in the present experiment, training at C3 and at C4 in the LLD increased overall accuracy. However, in the LLD task, there was also a significant interaction EEG BF × Target visual field (left, right) × Training site (C3, C4) × Gender, demonstrating different effects of training at C3 and at C4 in boys and in girls. In boys, C4 training improved LH accuracy, whereas in girls C3 training improved LH accuracy. That experiment did provide evidence that EEG BF training was indeed effective. The difference between the two experiments highlights the fact that different language functions are lateralized to different degrees in the LH. Together, these two experiments show that language organization in the two hemispheres varies as a function of gender, at least in children, and that in both cases it can be modified by EEG BF.

It should be noted that the observed change in the REA could reflect changes in the access of the signals in the two ears to the "phonetic decoder" in the left hemisphere, rather than changes in the capacity/competence of the decoder itself. Still, in cases of language deficit following left hemispheric damage, maladaptive changes in access to the phonetic decoder can result in a complete and permanent deficit, whereas adaptive changes in access can result in substantial recovery, depending on the degree of hemispheric specialization for the task and on the extent of the lesion.

These results should be interpreted with caution because of the small number of participants, the lack of concurrent EEG monitoring, and the absence of a Sham group. Nonetheless, regardless of the specific mechanism involved, this experiment suggests that it is relatively easy to modulate markers of even those components of the language system that are highly specialized to the LH. Furthermore, the experiment suggests that such modulations are subject to strong individual (gender) differences.

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