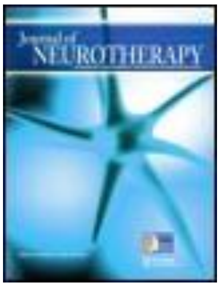

Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience

Effects of 18.5 Hz Auditory and Visual Stimulation on EEG Amplitude at the Vertex

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Published online: 20 Oct 2008.

To cite this article: Jon A. Frederick M.S. Ph.D. , Joel F. Lubar Ph.D. , Howard W. Rasey Ph.D. , Sheryl A. Brim Ph.D. & Jared Blackburn B.A. MD (1999) Effects of 18.5 Hz Auditory and Visual Stimulation on EEG Amplitude at the Vertex, Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience, 3:3-4, 23-28

To link to this article: http://dx.doi.org/10.1300/J184v03n03_03

Effects of 18.5 Hz Auditory and Visual Stimulation on EEG Amplitude at the Vertex

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Recently, audio-visual stimulation (AVS) has been proposed to be effective as an adjunct to EEG biofeedback (neurofeedback) therapy, when used as a "priming stimulus" to activate desired cortical frequencies. Since standard neurofeedback therapies for ADD/HD involve training subjects to enhance activity in the 13-21 Hz bandpass, we hypothesized that this activity could also be enhanced by AVS at a constant frequency in this range. Further, we hypothesized that auditory or visual stimulation alone might induce an entrainment effect. EEG was recorded from fifteen college students under the following conditions: (A) auditory stimulation alone, with eyes open; (B) auditory stimulation alone, with eyes closed; (C) visual stimulation alone, with eyes closed; (D) both auditory and visual stimulation, with eyes closed. An eyes-closed and eyes-open baseline condition were recorded prior to the first session. An ANOVA on the differences between the four stimulation conditions and baseline revealed no significant differences between the conditions, so the averages of all four conditions were analyzed as a single group. A significant increase was observed in the 13-21 Hz band ($p = 0.045$). This increase was of greater magnitude and significance in the narrower, 16-20 Hz band ($p = 0.008$). When this band was analyzed in half-Hz intervals, a prominent peak was observed at 18.5 Hz ($p = 0.001$). Applying this same analysis to the individual conditions suggested that the eyes-closed conditions with auditory or visual stimulation alone had more generalized effects throughout the 16-20 Hz band. These results support the hypothesis that AVS entrains endogenous EEG rhythms, and suggest a possible adjunctive role for AVS in EEG biofeedback therapies. However, the relatively weak generalization to frequencies adjacent to the stimulation frequency suggests that variable-frequency AVS might be more effective at activating the desired range of frequencies within a given bandpass.

INTRODUCTION

The ability of a flashing light stimulus to activate or "entrain" electroencephalographic (EEG) activity, at frequencies corresponding to the frequency of the stimulus, has been observed since the early history of electroencephalography (Adrian & Matthews, 1934; Walter & Walter, 1949). The observation that flashing light stimuli at certain frequencies can induce seizures in susceptible individuals (Walter, Dovey & Shipton, 1946) suggested that this entrainment effect might generalize beyond the primary sensory cortex in normal individuals and alter the activity of endogenous EEG rhythms. Recently, audio-visual stimulation (AVS) has been proposed to be effective as an adjunct to EEG biofeedback (neurofeedback) therapy, when used as a "priming stimulus" to activate desired cortical frequencies (Patrick, 1996). Previous studies from our laboratory have indicated that a diverse range of frequencies- not always the most desirable ones from a clinical standpoint- are activated by fixed-frequency AVS within in the desired range (Timmerman, Lubar, Rasey, and Frederick, 1999).

Since the enhancement of beta (13-21 Hz) activity is a goal of EEG biofeedback for the treatment of Attention Deficit Disorder with and without hyperactivity (ADD/HD; Lubar, Swartwood, Swartwood & Timmerman, 1995a; Lubar, Swartwood, Swartwood & Timmerman 1995b), we wanted to know if a significant AVS entrainment effect could be achieved under conditions that would be optimal for combining AVS with neurofeedback therapy. Specifically, if auditory or visual stimulation alone were sufficient to induce a significant entrainment effect, this would free the unused sensory modality to attend to a simultaneous neurofeedback task. Thus, we compared the effect of auditory, visual, and combined audiovisual 18.5 Hz stimulation on EEG amplitude in 15 college students. We hypothesized that AVS would increase EEG at 18.5 Hz and surrounding frequencies, and that auditory or visual stimulation alone would induce an entrainment effect.

MATERIALS AND METHODS

Participants

Informed consent was obtained from 15 undergraduate students at the University of Tennessee (8 female, 7 male, age 18-29) who participated in the experiment as an extra credit research experience. Participants self-reported that they were free of medication use during the study.

Apparatus

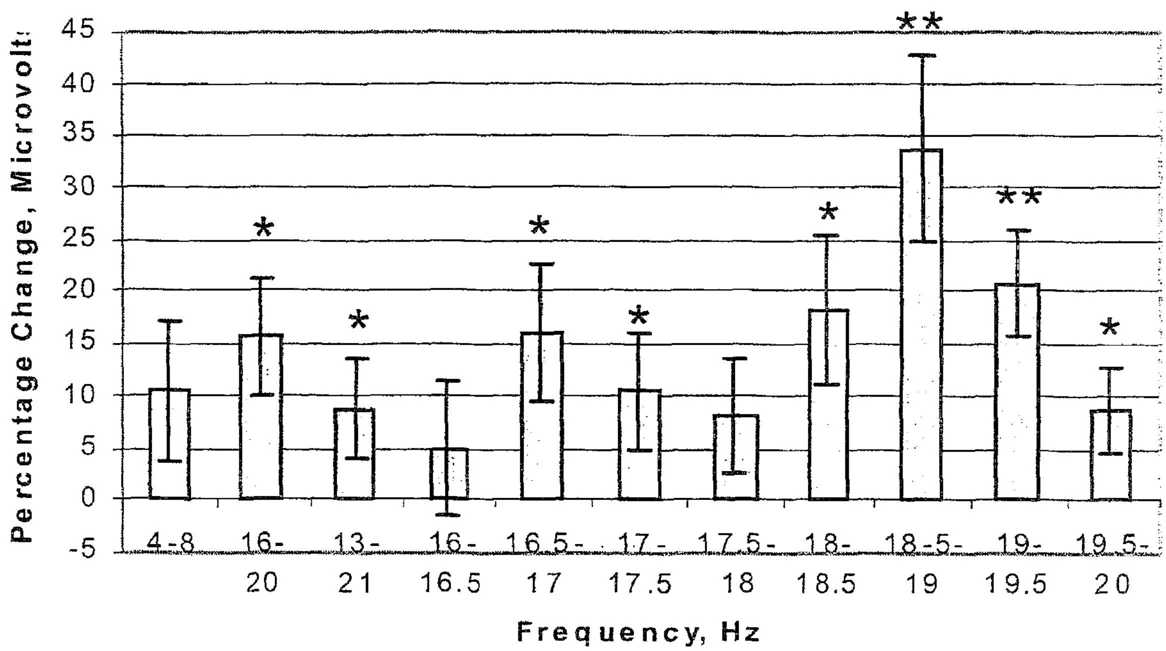
Stimulation was provided by a Polysync Pro (Synetic Systems) device. This unit consisted of headphones and a pair of "photoscopic" glasses that were connected to a small, portable unit that was programmed to deliver 18.5 Hz visual and auditory stimulation. The glasses had eight light emitting diodes (LEDs), four per side, arranged in a cross pattern. The LEDs were situated approximately 1.5 cm from the eyes, and emitted red light at .166 candle power at the frequencies employed. Audio stimulation consisted of a tone with a pitch of 185 Hz, sinusoidally modulated at 18.5 Hz, presented to both ears simultaneously, with a duty cycle of 50% and a loudness level of approximately 81 dB (A scale). Decibel measures were provided by a Type 1565-B sound-level meter (General Radio). Sinusoidal modulation of the auditory and visual stimulation eliminated possible stimulation effects due to harmonic frequencies, producing only the designated fundamental frequency (Sears, 1950). The Polysync Pro equipment did not produce localized electrical fields that might interfere with EEG recording (Timmermann *et al.*, 1999).

EEG was recorded with an A620 (Autogen) on an IBM compatible 486 computer running in DOS mode. A single referential electrode was applied to Cz with a linked ears reference. Recording did not begin until impedances were reduced to 5 kOhms or less.

Procedure

The experiment consisted of four sessions separated by at least one week each to minimize carry-over effects. To minimize order effects, each participant was randomly assigned to a different order for the following four stimulation conditions: (A) auditory stimulation alone, with eyes open; (B) auditory stimulation alone, with eyes closed; (C) visual stimulation alone, with eyes closed; (D) both auditory and visual stimulation, with eyes closed. On the first day of the experiment, a two-minute eyes-open pre-stimulation baseline and a two-minute eyes-closed pre-stimulation baseline were recorded, followed by the first stimulation condition. The stimulation conditions lasted seven minutes, but EEG was recorded from only the final five minutes to allow subjects to habituate during the first two minutes. During the recording, subjects wore the stimulation apparatus while sitting in a sound-attenuated, electrically shielded room, with the door closed to reduce distractions. During the eyes-open condition, subjects were instructed to gaze at a star-pattern drawn in black ink, about 2 in. in diameter, on a sheet of paper posted on the wall about six feet in front of them, and to avoid eye movement except to minimize discomfort. The pre-stimulation baselines and the four stimulation conditions were recorded using the A620's Assessment software, and artifact rejected by visual inspection. Amplitude values in microvolts were obtained by Fast Fourier transform (FFT) for the following eleven bands: theta (4-8 Hz), beta (13-21 Hz), narrow-band beta (16-20 Hz), and individual half-Hz bands at 16.0, 16.5, 17.0, 17.5, 18.0, 18.5, 19.0, and 19.5 Hz. As a measure of treatment effect, percentage differences between the baselines and each of the four treatment conditions were calculated (condition (A) was compared to the eyes-open baseline; the remaining conditions were compared to the eyes-closed baseline.)

Fig. 1. Effect of Auditory and Visual Stimulation on EEG Amplitude at the Vertex (All Conditions Combined)



*significant at α = 0.05; **significant at α = 0.004

Table 1. Effect of Stimulation on EEG Amplitude, Percentage Change

(Values univariately significant at α=0.05 denoted in **bold**.)

	All Conditions		Auditory Eyes Open		Auditory Eyes Closed		Visual Eyes Closed		Audiovisual Eyes Closed	
Band, Hz	mean	p	mean	p	mean	p	mean	p	mean	p
4-8	10.323	0.149	16.659	0.223	10.625	0.391	9.079	0.099	7.212	0.498
16-20	**15.681**	**0.008**	4.059	0.307	**13.701**	**0.001**	**21.397**	**0.011**	16.439	0.051
13-21	**8.699**	**0.045**	0.573	0.467	**10.518**	**0.004**	**10.734**	0.058	8.087	0.157
16-16.5	4.909	0.230	6.594	0.262	10.703	0.121	-1.634	0.420	6.639	0.255
16.5-17	**16.123**	**0.014**	7.342	0.248	**14.210**	**0.005**	**20.350**	**0.020**	**20.112**	**0.024**
17-17.5	**10.467**	**0.029**	4.546	0.330	**12.382**	**0.009**	**12.353**	**0.039**	13.669	0.074
17.5-18	7.933	0.085	4.880	0.333	**11.759**	**0.019**	11.145	0.061	6.594	0.230
18-18.5	**18.298**	**0.012**	14.248	0.143	**14.528**	**0.003**	**26.189**	**0.014**	20.349	0.053
18.5-19	**33.692**	**0.001**	**26.943**	**0.045**	**20.961**	**0.003**	**48.780**	**0.007**	**38.342**	**0.017**
19-19.5	**20.684**	**0.001**	21.072	0.066	**20.641**	**0.0002**	**24.968**	**0.004**	**16.743**	**0.044**
19.5-20	**8.681**	**0.031**	9.577	0.236	**11.836**	**0.013**	**10.074**	**0.030**	3.752	0.297

RESULTS

A repeated measures analysis of variance was performed for each frequency band to determine if the stimulation conditions had differential effects on any of the EEG variables measured. No differential effect was observed (at a = 0.05), so results were averaged across the four conditions. For each frequency band, percentage change data were tested for normality with the D'Agostino-Berlanger test (a = 0.01; D'Agostino, Berlanger, & D'Agostino, 1990). Cases judged normal were tested for significance with Student's t-test (a = 0.05). Only the 17.5-18 Hz variable was not normally distributed, and was thus tested for significance with Wilcoxon's sign rank test (a = 0.05).

For all frequencies between 13-21 Hz, including the 16-20 Hz band and the eight half Hz bands between 16-20 Hz, we hypothesized that stimulation would cause an increase in amplitude, allowing a one-tailed test. We did not predict a direction of change for the 4-8 Hz. band and thus, analyzed this variable with a two-tailed test. With all four stimulation conditions pooled, significant increases were observed in all bandpasses in the beta range except 16 Hz and 17.5 Hz (Figure 1). Consistent with the entrainment hypothesis, the greatest increase (33.6 percent, p=0.001) was observed in the 18.5 Hz band. There was a slight, but non-significant, increase in the 4-8 Hz band (10.3 percent, p=0.15). With eleven independent comparisons, however, the likelihood of at least Type I error at a = 0.05 would be $1\text{-}0.95^{11} = 0.43$. To minimize this probability, data were also tested at a Bonferroni-adjusted critical value of a = 0.0045. At this level of stringency, only the 18.5-19.0 Hz and 19.0-19.5 bands were significant. However, the Bonferroni correction inflates Type II error for n > 5, and for highly intercorrelated data. A principal components analysis revealed that these data are indeed highly intercorrelated: only two components had eigenvalues greater than unity, accounting for 88% of the variance, with a clear break in the scree plot. Thus, the appropriate adjustment for experimentwise error is likely to be a factor greater than two but considerably less than eleven.

Although significant differences were not observed between stimulation conditions, it was of interest to determine which treatment might have contributed the most to the overall effects observed. Thus, we repeated our analyses on each of the four treatment conditions separately. Two cases were judged non-normal (4-8 Hz and 16-16.5 Hz in condition B), and so were tested for significance by Wilcoxon's sign rank test rather than Student's t-test. Although a trend toward increased amplitude was observed in nearly all bands, these increases were largest and most significant at the 18.5 Hz stimulation frequency (Table 1). At a = 0.05, these effects appeared to be most significant and generalized with respect to frequency in the auditory eyes-closed and visual eyes-closed conditions. However, with a adjusted to 0.001 to account for 44 comparisons, only the 18.5 Hz band in the auditory eyes-closed condition was significant.

DISCUSSION

These results lend further support to the hypothesis that auditory and/or visual stimulation can entrain the EEG at frequencies corresponding directly to the frequency of stimulation. However, the weak generalization of the 18.5 Hz entrainment to the surrounding EEG frequencies in the 13-21 Hz band suggests the possibility that variable-frequency stimulation might be more effective in the adjunctive use of AVS in neurofeedback therapy for ADD/HD, where activation of this broader range of frequencies is desired. The trend toward increased amplitude in the 4-8 Hz band, while not significant, suggests caution in applying this protocol for treating attentional disorders. The use of normal college students in this study, however, limits the generalization of these results to ADD/HD client populations.

Although a lack of significant differences between conditions was found by analysis of variance, a trend toward more consistent, broader-band increases was observed in the auditory-eyes-closed and visual-eyes-closed conditions, suggesting that simultaneous stimulation in both modalities might interfere with, rather than reinforcing, an entrainment effect in the EEG. Consistent with this interpretation, the relatively weak effects of auditory stimulation with eyes open suggests that merely staring at the fixation point in this condition might have presented an interfering form of visual stimulation. Thus, our hypothesis that auditory or visual stimulation alone might be sufficient to induce a significant entrainment effect, freeing the unused sensory modality to attend to a simultaneous neurofeedback task, is not strongly supported by these findings.

Further studies comparing unimodal vs. bimodal stimulation, and variable vs. fixed-frequency stimulation, are needed to resolve how this technology might best be used in the context of neurotherapy to improve clinical outcomes.

Acknowledgment

We are grateful to Dr. Harold Russell and Synetic Systems for providing us with advice and the Polysync Pro devices used in this investigation.

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