PSYCHOPHYSIOLOGY
Vol. 14, No. 1
Printed in U.S.A.

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The Influence of Musical Training on Patterns of EEG Asymmetry During Musical and Non-Musical Self-Generation Tasks

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ABSTRACT

Musically proficient and non-proficient right-handed subjects were requested to list in a pre-experimental questionnaire three familiar songs, whose words and melody were well known. They were then instructed in two separate experiments, to whistle the melody of a song, talk the lyrics to a song, or sing a song each for 3 1-min trials performed with eyes closed. EEG was recorded from the left and right occipital areas (O_1 and O_2) in Experiment I and from the left and right parietal areas (P_3 and P_4) in Experiment II, and filtered for 8–13 Hz activity on-line. Comparable results were obtained in both experiments and indicated that non-musically trained subjects show significantly greater relative right hemisphere activation while whistling the melody of a song vs talking the lyrics to a song. Musically trained subjects show no differences in EEG asymmetry between these tasks. In addition, there were no group differences in asymmetry during the talking and singing conditions. These data are consistent with recent evidence suggesting that musical training is associated with the adoption of an analytic and sequential processing mode toward melodic information, and suggest that long term training in complex cognitive skills has functional neural concomitants.

DESCRIPTORS: Cerebral lateralization, EEG asymmetry, Musical training, Self-regulation.

In 1973, the present authors (Schwartz, Davidson, Maer, & Bromfield, 1974) conducted an experiment on EEG asymmetry during the self-generation of musical and non-musical activity. We observed serendipitously that differences in occipital EEG asymmetry between talking the lyrics to a song vs whistling the melody of the song were greater for non-musicians than for musically trained subjects, thus revealing for the latter group a pattern opposite to that usually observed with both behavioral (e.g. Kimura, 1964) and electrophysiological (e.g. McKee, Humphrey, & McAdam, 1973) measures. This difference was largely a function of the greater relative right hemisphere activation displayed by the naive vs the musically sophisticated subjects during whistling.

After the completion of this experiment, a report by Bever and Chiarello (1974) appeared, demonstrating that on monaural listening tasks, musically experienced subjects recognize simple melodies better in the right ear than the left, while the reverse pattern was obtained for naive listeners. Bever and Chiarello (1974) interpreted their data to mean that musically sophisticated subjects were applying an analytic information processing mode to the musical stimuli, a bio-cognitive style which they suggest was acquired through learning. Gordon (1970, 1975) obtained evidence consistent with the findings of Bever and Chiarello. He (Gordon, 1975) reasoned that since musical sophistication is reflected in higher performance scores on tests of melodic recognition (Bever & Chiarello, 1974), there should be a correlation between ear preference and overall performance scores. Gordon confirmed that on a melodic recognition test, subjects with lower overall scores tend to have higher left ear scores and those with higher overall scores tend to have higher right ear scores. However, Gordon did not observe this association on a test of chord recognition.

This research was supported in part by an NSF pre-doctoral fellowship to R. J. D., and by the Advanced Research Projects Agency of the Department of Defense, and monitored by the Office of Naval Research under Contract N0014-70-C-0350 to the San Diego State University Foundation to G.E.S. We gratefully acknowledge the assistance of E. Bromfield and E. Pugash in conducting these experiments, and R. Lenson and M. Finn for computer analysis.

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Based upon our initial findings and the subsequent behavioral studies (Bever & Chiarello, 1974; Gordon, 1975), we performed an additional experiment to further examine this phenomenon using a more sensitive EEG pattern recording procedure as well as a different scalp placement. The present paper reports the findings from both experiments.

Methods

Experiment I

Subjects. The sample was comprised of 14 subjects, 9 male and 5 female undergraduate students who were recruited for an experiment on "patterns of physiological activity during whistling, singing, and talking." Nine of the subjects indicated that they could play at least one instrument well, as well as being actively engaged in the playing of music, and were classified as musically trained, while the remaining subjects were musically unsophisticated. All of the subjects were right-handed paid volunteers in good health.

Apparatus and Recording Procedure. Bilateral EEG was recorded from the left and right occipital regions (O_1 and O_2; Jasper, 1958) referenced to a common vertex (C_z) with Beckman miniature electrodes, and all electrode resistances were below 5000 ohms. All measures were recorded on a Grass Model 7 polygraph and each EEG channel was filtered for 8–13 Hz activity and displayed on two additional channels individually calibrated to yield a pen deflection of 1.5 cm for an average peak alpha burst. This calibration was performed during an eyes closed baseline period prior to the commencement of the experiment. Grason-Stadler logic modules were employed to detect and automatically count bursts of criterion alpha on-line. An arbitrary criterion of .5 cm was utilized so that alpha activity had to be at least 33.3% of the average peak amplitude to be counted. Bursts of four alpha waves within a maximum of .5 sec were required to activate the counter and constituted one alpha unit; this effectively removed any movement artifact from being counted as alpha, and provided a reliable, conservative measure of alpha activity. This procedure has been successfully adopted in the present authors' previous research (e.g. Davidson & Schwartz, 1976).

Procedure. Upon entering the laboratory, prior to commencement of experimental trials, the subjects completed a questionnaire requesting them to list three familiar songs, whose words and melody were well known. They were then exposed to 3 blocks consisting of 3 1-min trials where they were required to either whistle the melody of a song, talk the lyrics to a song in a monotone, or sing a song. Each block of 3 trials was preceded by a 1-min rest period, with order of song and condition counterbalanced within and across subjects. All trials were performed with eyes closed. The subjects were instructed to sustain all tasks until being told to stop at the end of 1 min, repeating each task as many times as necessary to fill the trial period.

Data Analysis. EEG data were evaluated by computing the ratio of the difference in alpha units between O_2 minus O_1 over the sum of alpha at O_1 and O_2 (R−L/R+L). This ratio served to "correct" the obtained values for individual differences in absolute amount of alpha activity. Higher ratios are indicative of greater relative left hemisphere activation. Separate scores for the left and right hemisphere sites were also evaluated to determine the precise locus of the observed effects.

Experiment II

Subjects. The sample was comprised of 20 subjects, 10 male and 10 female undergraduate students. All subjects were right-handed. There were 13 musically trained and 7 untrained subjects in the present sample using the criteria described above. All subjects were paid volunteers and in good health.

Apparatus and Recording Procedure. Bilateral EEG was recorded from the left and right parietal areas (P_3 and P_4) (Jasper, 1958), referenced to the left ear lobe[1]; the right ear lobe served as ground. EEG was recorded with Beckman miniature electrodes and all electrode resistances were below 5000 ohms. All measures were recorded on a Grass Model 7 polygraph with each of the two EEG channels recorded through an AC preamplifier. Each EEG channel was filtered for 8–13 Hz, full wave rectified, and displayed on two additional channels individually calibrated (during an eyes closed baseline prior to the commencement of the experiment) to yield a pen deflection of 3 cm for an average peak alpha burst. Level detectors were set to trigger in response to a signal at or exceeding 1 cm so that alpha activity had to be at least 33.3% of the average peak amplitude to be counted. Grason-Stadler logic modules were employed to detect instances of criterion alpha on-line and to sample at .1 sec intervals to determine which of the following four conditions was present: a) $L\alpha_{on}R\alpha_{on}$, b) $L\alpha_{on}R\alpha^{off}$, c) $L\alpha^{off}R\alpha_{on}$, and d) $L\alpha^{off}R\alpha^{off}$.[2]

Procedure. This experiment was a systematic replication of Experiment I with the only differences being the method of EEG quantification and the choice of recording sites. Prior to the experiment, each subject listed three familiar songs. The subjects were then exposed to 3 blocks of 3 1-min trials where they were required to either whistle the melody of a song, talk the lyrics to a song in a monotone, or sing a song. Order of song and condition was counterbalanced within and across subjects. All trials were performed with eyes closed and the subjects were instructed to sustain all tasks until being told to stop at the end of 1 min, repeating each task as many times as necessary to fill the trial period.

Data Analysis. Four scores representing each of the four EEG patterns were obtained for each task trial. Each number represents a .1 sec occurrence of a particular pattern. Each of the four pattern scores obtained for each trial was converted to percent of the total number of samples for that trial. This eliminated effects of slight variance in trial length. From these four scores the identi-

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[1] Parietal sites were chosen for Experiment II because they are association regions and are more likely, on the basis of available neurophysiological knowledge (e.g. Luria, 1973), to subserve complex information processing.

[2] This procedure has been effectively employed in other hemispheric asymmetry research from our laboratory (see Schwartz, Davidson, & Pugash, 1976).

cal ratio as was employed in Experiment I was computed: total P_4 minus P_3 alpha over total P_4 plus P_3 alpha (R−L/R+L). Analyses of variance were employed to assess the Condition and Group effects and their interactions; two-tailed *t*-tests utilizing the appropriate error terms from the analysis of variance were employed to assess the significance of individual comparisons. As in Experiment I, separate scores for the left and right hemisphere sites were also evaluated to determine the precise locus of the observed effects. The rejection region is $p<.05$ throughout.

Results

Since previous research has suggested significant sex differences in hemispheric asymmetry during self-regulation tasks (e.g. Davidson & Schwartz, 1976; Davidson, Schwartz, Pugash, & Bromfield, 1976), the percentage of males and females within each group (trained vs untrained) was examined. Forty-five percent of trained subjects were male while males comprised 75% of the untrained group. This difference is not significant by a chi-square ($\chi^2(1)=1.68$, with Yates' correction for continuity) (McNemar, 1969, p. 262). It should be noted that in previous research males showed *less* task dependent shifts in EEG asymmetry than females during self-regulation tasks (Davidson et al., 1976) so that the larger, though nonsignificant proportion of males in the untrained group works against the predictions of the present set of experiments.

Table 1 presents the means for the whistle, sing, and talk conditions separately for each experiment and separately by Group (trained vs untrained). In addition, the means and standard deviations for the talk vs whistle, talk vs sing, and sing vs whistle differences are presented separately for each experiment by training group. Since the ordering of the means for the two experiments are comparable, all subsequent analyses are presented for the experiments combined (total N=34).[3]

Since the ratio scores serve to correct the EEG data for individual differences in absolute amount of alpha activity, it was deemed appropriate to combine these data from Experiments I and II. However, analyses performed on separate right and left hemisphere scores were first transformed to Z scores within each experiment and then combined. Such a transformation insures comparability of the data obtained by the two different methods. It should be noted, however, that each of the significant effects observed with both the non-transformed ratio scores and the transformed left and right hemisphere scores were also obtained when the analyses were performed on transformed scores for the former and non-transformed scores for the latter.

Analysis of variance with Condition (whistle, sing, and talk) as a repeated factor and Group (trained vs untrained) as a between groups factor resulted in no significant main effect for training group, thus indicating no significant overall differences in cerebral asymmetry (as reflected in the ratio score) between groups across task conditions. As predicted, a highly significant main effect for Condition was obtained ($F(2/63)=10.282$, $MS_e=.028$). Separate analyses of variance on each of the three condition comparisons indicated a significant sing vs talk effect ($F(1/32)=21.66$, $MS_e=.044$), and a significant whistle vs talk difference ($F(1/32)=13.41$, $MS_e=.038$). The comparison of sing with

TABLE 1

Mean alpha ratio scores and means and standard deviations for the differences among conditions

Groups	Mean Alpha Ratio Scores[a]							
	Experiment I				Experiment II			
	N	Whistle	Sing	Talk	N	Whistle	Sing	Talk
Trained	9	.028	.027	.057	13	.129	.078	.119
Untrained	5	−.021	.013	.035	7	.070	.086	.190
	Means (SDs in Parentheses) for Differences Among Conditions[b]							
		T-W	T-S	S-W		T-W	T-S	S-W
Trained		.029(.042)	.030(.054)	−.001(.043)		−.010(.098)	.041(.068)	−.051(.100)
Untrained		.056(.046)	.022(.062)	.034(.075)		.120(.068)	.104(.065)	.016(.073)

[a] Higher ratio score values are indicative of greater relative left hemisphere activation.

[b] W = Whistle, S = Sing, T = Talk.

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[3] It should be noted that the differences in the values of the ratio scores between experiments are likely to be primarily a function of differences in recording site and reference electrode placement.

whistle was not significant. These findings indicate that for the total sample (averaged across training groups) both the sing and whistle conditions elicited significantly greater relative right hemisphere activation compared with talking, and confirm other neuropsychological research suggesting that the production of musical behavior, including singing, is associated specifically with the right hemisphere in subjects unselected for musical training (Bogen & Gordon, 1971; Gordon & Bogen, 1974).

When the effects of musical training were examined, a significant Condition (whistle, sing, and talk) by Group (trained vs untrained) interaction was obtained ($F(2/63)=5.64$, $MS_e=.015$). These findings are illustrated in Fig. 1 and indicate differences in hemispheric patterning in response to musical and non-musical tasks in trained vs untrained subjects.

The interaction of musical training with each of the three separate condition comparisons was examined to determine the precise locus of the training effect. A significant Group by Condition interaction was obtained for the whistle vs talk comparison ($F(1/32)=10.50$, $MS_e=.003$). Separate t-tests revealed that this interaction was a function of a significant whistle vs talk effect for the musically naive subjects ($t(11)=4.20$) and the absence of such a difference for the trained subjects. Furthermore, there was no significant difference in EEG ratio during talking for the trained vs untrained subjects ($t(32)=1.28$), while there was suggestive evidence of a difference, though not significant, between the musically trained groups during whistling ($t(32)=1.89$).

A Group by Condition interaction was not obtained for the sing vs talk comparison. Both musically sophisticated and naive subjects showed significantly greater relative right hemisphere activation during singing compared to talking (for untrained subjects, $t(11)=3.89$; for trained subjects, $t(21)=2.67$).

When the interaction of musical training with the sing vs whistle difference was examined, a nonsignificant effect was obtained ($F(1/32)=3.53$, $MS_e=.011$). However, the direction of the effect suggests that for musically naive subjects whistling elicits greater (though nonsignificantly) relative right hemisphere activation compared with singing while the opposite pattern emerged for the trained group; for these subjects, singing was associated (nonsignificantly) with greater relative right hemisphere activation compared with whistling ($t(21)=1.88$). There were no significant differences be-

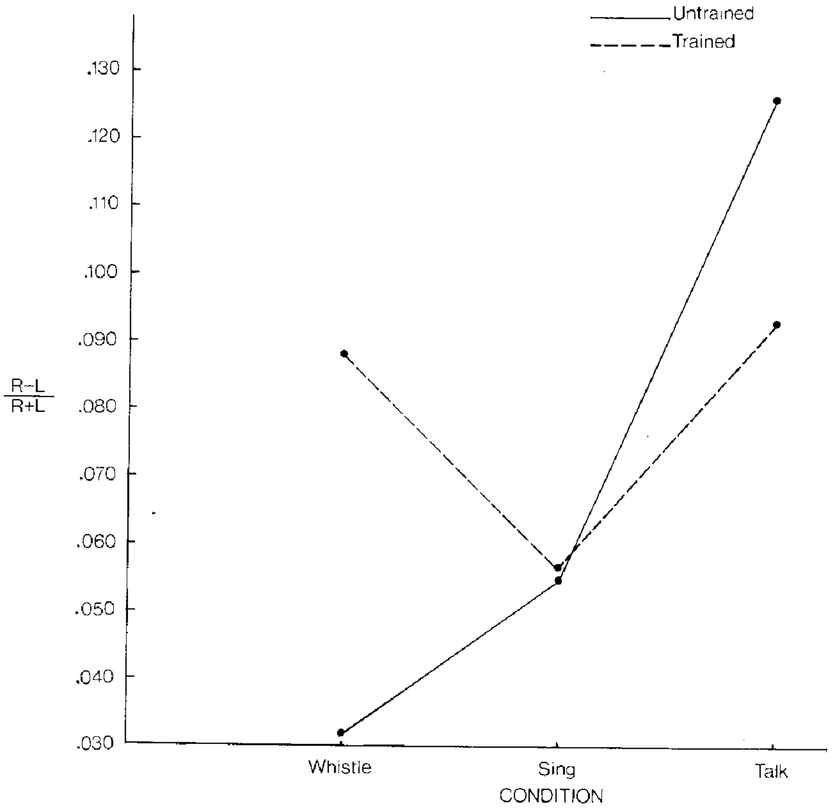

Fig. 1. Mean EEG alpha ratio scores for Experiments I and II combined (averaged across trials) by Condition for musically trained (N=22) and untrained (N=12) subjects.

TABLE 2

Mean left hemisphere Z-transformed alpha scores

Groups	Z-Transformed Alpha Scores[a]		
	Whistle	Sing	Talk
Trained (N=22)	.040	.162	.163
Untrained (N=12)	−.074	−.298	−.298

[a]Lower numbers indicate less left hemisphere alpha (i.e., greater activation).

tween groups in cerebral lateralization during singing.

The separate right and left hemisphere Z-transformed alpha scores were next examined to assess which hemisphere was primarily responsible for the differences observed with the ratio score. As predicted, a significant Condition (whistle, sing, talk) × Group (trained vs untrained) × Site (left and right hemisphere) interaction was obtained ($F(2/63)=4.02$, $MS_e=.268$). This interaction was primarily a function of differences in left hemisphere alpha between the conditions within each of the groups.[4] Table 2 presents the mean Z-transformed left hemisphere alpha scores for each group by condition. For the untrained group, there is significantly less left hemisphere alpha (i.e., more activation) during both talking and singing compared to whistling ($t(11)=3.57$ for both). For the untrained group, there is a nonsignificant trend toward showing greatest left hemisphere activation (i.e., least amount of left hemisphere alpha) in the whistling condition during which there is nonsignificantly less left hemisphere alpha than during talking ($t(21)=1.96$) and than during singing ($t(21)=1.94$). None of the condition effects within either group were significant on right hemisphere alpha. Thus, musically untrained subjects show greater left hemisphere activation during talking and singing vs whistling while musically sophisticated subjects show the reverse, i.e. greater left hemisphere activation during whistling vs talking and singing.

Discussion

These findings provide support for the hypothesis that the brains of musical and non-musical subjects express themselves differently during the self-generation of musical vs verbal behavior. Specifically, the present data indicate that non-musically trained subjects show significantly greater relative right hemisphere activation during whistling the melody of a song vs talking the lyrics of a song. When the separate right and left hemisphere scores were analyzed, it was found that this difference was primarily a function of the untrained subjects' showing greater left hemisphere activation (less left hemisphere alpha) during talking vs whistling. No significant condition effects were obtained on the independent right hemisphere scores. These data are consistent with other hemispheric asymmetry research from this laboratory, suggesting that the left hemisphere is more labile and more sensitive to a variety of different task demands (Davidson et al., 1976).

The pattern of cerebral asymmetry elicited during whistling for the musically trained subjects was comparable to what they showed when talking. These results suggest that musical training is associated with the adoption of a sequential and analytic processing mode (e.g. Seamon, 1974) during the production of musical behavior. Such findings support and extend the conclusion drawn by Bever and Chiarello (1974) from their study of the effects of musical training on the perception of musical stimuli. They suggest that their data "raise the possibility that being musically sophisticated has real neurological concomitants, permitting the utilization of a different strategy of musical appreciation that calls on left hemisphere function [p. 539]."

It is important to note that musically trained vs untrained subjects were not found to differ on EEG asymmetry during the talking and singing phases while suggestive evidence was obtained for group differences within the whistling condition. This pattern of results may be a consequence of the specificity of effects of musical training. If one were to assume that whistling is structurally most similar to playing a musical instrument, the present findings would suggest that differences in cortical asymmetry between musically naive vs trained subjects are specific to training-relevant tasks only. During the self-generation of behavior and cognition which is training-independent (i.e., talking and singing for musically trained subjects), no group differences were observed. This interpretation may provide a parsimonious explanation for some recently uncovered anomalies in the literature on the relationships of occupation and training differences to patterns of cerebral asymmetry (e.g. Galin & Ornstein, 1974; Dumas & Morgan, 1975).

One limitation of the present study should be noted in interpreting these data. The possibility that the observed differences between musically trained and untrained subjects were a function of predispositional variables and not directly related to musical training could not be evaluated with the present design. Future research in this area might fruitfully

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[4]It should be noted that direct between group comparisons are not appropriate on separate right and left hemisphere scores because of individual differences in absolute alpha abundance. Therefore, only within group, between condition effects are reported.

employ a longitudinal design where these variables may be unambiguously disentangled.

Finally, the present data highlight the perspective emphasized in our laboratory of the importance of recording patterns of biological processes in the study of complex brain-behavior relationships (e.g. Schwartz, 1975; Schwartz et al., 1976). The present findings demonstrate that with such an approach musically sophisticated vs naive subjects can be differentiated on the basis of their hemispheric patterning during musical and non-musical tasks.

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(Manuscript received February 6, 1976; revision received July 8, 1976; accepted for publication July 13, 1976)