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THE EFFECTS OF ORIENTING TASK ON DIFFERENTIAL HEMISPHERIC EEG ACTIVATION*

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Abstract—Sixteen right-handed men heard 12 brief cue questions pertaining to each of four tasks. Each cue question was followed by the announcement of a single trait adjective, which was either positive, neutral or negative. Judgments of self reference and volume discrimination evoked greater relative left hemispheric EEG activation than judgments of evaluation and rhyme. Differential hemispheric EEG activation was not affected, however, by the depth-of-processing. Once the assigned task was completed, affect-laden (positive or negative) adjectives elicited less relative left hemispheric EEG activity than neutral words.

INTRODUCTION

THE EVIDENCE from a number of clinical and experimental studies of functional cerebral asymmetry in right handed men clearly suggests that the major (left) and minor (right) hemispheres are associated with differential modes for processing information (e.g. see [1–5]). Chronometric and performance data reveal faster and/or more accurate solutions result when verbal or semantic rather than nonverbal or nonsemantic stimuli are presented to the left hemisphere first (e.g. through the right ear or right visual hemi-field), whereas the opposite result is inclined when the stimuli are presented first to the right hemisphere [6]. Similarly, data from bilateral electroencephalographic (EEG) recordings reveal greater hemispheric activation of the left than right hemisphere when performing verbal/semantic tasks, presumably due to the relative utilization of the left hemisphere (cf. [7, 8]); and, as in the behavioral studies, the pattern of results is attenuated or reversed when non-verbal/nonsemantic tasks are performed (e.g. [9, 10]; cf. [11]).

In a recent review of the work on functional cerebral asymmetry, MOSCOVITCH [12] suggested that a necessary precondition for the emergence of lateralization is the categorical analysis of the stimulus. Tasks whose solutions are contingent upon the peripherally (sensorially) represented physical features of a stimulus (e.g. the iconic or echoic representation) are performed equally well by normal people (e.g. [13]) and by split-brain patients

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[14] regardless of the hemisphere to which the stimulus is first introduced. Tasks whose solutions are contingent upon higher order encoding or response (i.e. categorical) processes often yield behavioral and electrophysiological asymmetries (e.g. [15–17]). Therefore, MOSCOVITCH [12] suggested that "all processes beyond those at which relational or categorical properties emerge will be functionally lateralized to the left or right hemisphere (transmitted-lateralization hypothesis)" (p. 411).

In his review of the cross-fertilization of research on hemispheric asymmetries and human information processing, MOSCOVITCH [12] discussed CRAIK and LOCKHART's [18] "levels-of-processing" framework for memory. According to this model, the durability of the memorial trace and the mode of representation of a stimulus is determined by the level at which the stimulus is processed. Research since the introduction of the levels-of-processing model has focused on determining the theoretical differences in encoding operations associated with "deep" vs "shallow" processing. Whereas Craik and Lockhart initially proposed that encoding operations could be ordered at mutually exclusive levels along a depth-of-processing continuum as a function of the feature that was analyzed, they now suggest that "deep" compared to "shallow" processing (or encoding) results from more extensively exploring a feature of a stimulus (e.g. identifying more associations to a stimulus) or by analyzing multiple features (e.g. phonetic, associative) of a stimulus, either simultaneously or sequentially (cf. [19]).

The neuropsychological evidence is not in complete agreement with the predictions derived from the levels-of-processing model. For instance, according to the levels viewpoint, patients with a long term memory deficit should do particularly poorly on tasks that require deep (e.g. semantic) processing (unless the deficit lay at a consolidation stage). Tests suggest, however, that though these patients are less likely to employ deep processing strategies when performing tasks requiring them (e.g. [20]), these patients *can* utilize deep (e.g. semantic) processing strategies (e.g. [21, 22]).

The relationship between the depth of processing and hemispheric asymmetries, therefore, is still in question. A study by DUMAS and MORGAN [23], in which subjects from a normal (nonclinical) population were used, suggests that depth of (post-categorical) processing has no effect on interhemispheric activity. Differential hemispheric EEG activity was monitored in male artists and engineers who performed simple and difficult spatial and analytic tests. Dumas and Morgan observed relative left hemispheric EEG activity during the analytic compared to the spatial tasks, but neither occupation nor task difficulty influenced relative hemispheric EEG activity.

The present study, too, was designed to examine differential hemispheric EEG activation in men as a function of the level of post-categorical processing. The present study, however, was conducted using a procedure commonly employed in experimental studies of processing depth and memory. The procedure we employed, which is sometimes called the depth-of-processing paradigm, involved presenting a cue question (task) and target stimulus (e.g. a trait adjective). The cue questions (orienting tasks) are used to induce encoding operations that are primarily focused on the analysis of a specific feature of the target stimulus (cf. [24]). As in previous research, we monitored reaction time and retention characteristics associated with each orienting task. In addition, we monitored differential hemispheric EEG activity from the right and left parietal lobes. Hence, the present study provides a better basis for relating the electrophysiological data obtained as a function of processing depth with the formulations and results that have emerged in past research on the depth-of-processing model of memory.

In addition, the likeableness of the stimuli (trait adjectives) was varied within each task to enhance generalizability to affective stimuli and to explore EEG asymmetry as a function of stimulus affectivity. No specific predictions were made regarding the effects of this factor, though there is some evidence that the right hemisphere is more horrific [25, 26] or emotional (cf. [27]) than the left.

EXPERIMENTAL METHODS

Subjects and design

Sixteen right-handed undergraduate men between the ages of 18 and 21 yr participated in a 2 (Experimental Replication) × 4 (Processing Task) × 3 (Stimulus Affectivity) factorial. All subjects reported familial histories of right-handedness. The Experimental Replication factor represented two concurrently conducted versions of the study, which were identical except for the use of a different tape recorded ordering of experimental stimuli and tasks. All other factors were within-subjects. Inclusion of the Experimental Replication factor allows statistical evaluations to be derived for the randomization of order and sequence of treatments; should this factor affect the measures generally, then it would suggest that some unsuspected but complicating factors are at work (e.g. carry-over effects). In any case, collapsing across the factor provides a more conservative error term (and more complete randomization of treatments) for the subsequent tests than using a single random order of treatments (cf. [28]).

Materials

The experimental stimuli (i.e. trait adjectives) consisted of 48 words selected from Anderson's [29] list of 555 personality traits. The words were selected such that (a) 16 were listed by Anderson as highly likeable, 16 were listed as being neutral, and 16 were listed as highly unlikeable; and (b) the frequency of usage was approximately equal among these three groups of words [30]. The categories of positive, neutral, and negative words thus created constituted the three levels of the Stimulus Affectivity factor.

During the study, each target adjective was preceded by one of four cue-questions, which defined the processing task. Subjects must process the trait adjective more deeply to solve the evaluation and self-reference tasks than to solve the volume-discrimination and rhyme tasks [31]. Examples of the cue-questions used for these tasks are listed in Table 1.

Table 1. Sample stimuli

Processing task	Cue-question
Rhyme	Does the following word rhyme with . . . ?
Volume-discrimination	Is the following word spoken louder than this question?
Evaluation	Is the following word good?
Self-reference	Is the following word self-descriptive?

The subject was required to respond overtly following the onset of the target adjective by pressing with his finger one of two small buttons under his right hand. One button indicated that the subject's response to the preceding cue-question was "yes", and one indicated that the response was "no". Which button denoted a yes or no response was counterbalanced between subjects within each experimental replication. Furthermore, the pairing of cue-questions and trait adjectives and the ordering of these pairings were determined randomly for each experimental replication.*

Procedure

When a subject arrived at the laboratory, the experimental tasks were explained and electrodes were attached using Grass EC2 electrode cream. Monopolar EEG activity was recorded using Grass gold-plated cup electrodes

*An additional 12 trait adjectives were selected, paired with an associative cue-question, and randomly distributed throughout the experimental sequences of trials. In addition, electrodes were attached to measure speech muscle, nonpreferred forearm muscle, and cardiac activity. These stimuli and measures were employed to address issues irrelevant to the present study and are reported elsewhere [32].

placed over the left (P3) and right (P4) parietal areas [33] referenced to linked ears with Grass ear-clip electrodes.

After the electrodes were placed on the subject, he was led into a sound attenuated chamber and seated in a comfortable chair, which was enclosed in a copper-mesh cage to shield electrical interference. Subjects were instructed to keep their eyes closed throughout the study, to breathe normally, and to move as little as possible. Following a 5-min adaptation period, the instructions were repeated, and the subject responded to a set of practice-trials (one for each type of task). Following another 5-min adaptation period, the 48 experimental trials were initiated. Each trial consisted of (a) a 10–20 sec variable intertrial interval (ITI), which served as the prestimulus interval; (b) a 5-sec cue-question; (c) a trait-adjective interval which was initiated by a voice-activating switch when the trait word was announced and was terminated by the subject's button-press response; and (d) a 1-sec poststimulus interval, which immediately followed the button-press. The entire procedure was automated under the control of a PDP-8I computer.

After the experimental trials, subjects evaluated the trait adjectives on a 7-point scale anchored by the terms unpleasant-pleasant and denoted their recognition of each on 5-point confidence-rating scales. These words were embedded in a longer list of 100 adjectives.

Data reduction

The EEG responses were amplified continuously using Grass wide-band AC preamplifiers. The data were transmitted through an 8–13 Hz band-pass filter (12 db/octave), sampled 100 times per sec, and summed on-line by the laboratory computer. The EEG data were also displayed on oscilloscopes for visual monitoring during the experiment. Relative hemispheric activation was determined by calculating a ratio-score expressed in percentages for the alpha activity observed at the right (P4) and left (P3) parietal-area electrode sites (i.e. 100*(P4 − P3)/(P4 + P3)). A large positive ratio indicates the relative presence of alpha activity in the right (minor) hemisphere and, thus, relative activation of the left (major) hemisphere. Lastly, the reaction time of each trait-adjective interval was recorded.

RESULTS

Reaction-time and postexperimental questionnaire data

Three-way mixed model analyses of variance (Experimental Replication × Processing Task × Stimulus Affectivity) were conducted for the reaction-time data, the ratings of recognition confidence, and the likeableness ratings of the trait adjectives.

Depth-of-processing contrast. As expected, Processing Task affected mean reaction time, $F = 38.13$, $df = 3, 42$, $P < 0.001$, and recognition confidence $F = 17.87$, $df = 3, 42$, $P < 0.001$. Likeableness ratings were not affected by this factor ($F < 1$). A planned comparison was calculated to test whether the tasks of self-reference and evaluation affected these variables differently than the simpler tasks of volume discrimination and rhyme. This contrast was highly significant for the reaction-time data, $F = 49.98$, $df = 1, 42$, $P < 0.001$, and for the recognition-confidence data, $F = 50.04$, $df = 1, 42$, $P < 0.001$. We generally found that the more deeply processed the word, the slower the reaction time and the better the recognition confidence for that word (see Table 2). This effect was slightly though not significantly reversed in the comparison of mean reaction time for the rhyme and evaluation tasks. Moreover, we should note that although the relative differences among the reaction times are accurate, the absolute reaction times appear faster than they in fact were. This discrepancy is a result of the voice-activating switch that was employed.

Stimulus affectivity. Two other significant effects emerged in the three-way analysis of variance. First, Stimulus Affectivity influenced reaction time, $F = 5.52$, $df = 2, 28$, $P < 0.05$, with Duncan tests revealing that the slowest responses were made to neutral trait adjectives ($M = 186.7$ msec) and the quickest responses were made to positive trait adjectives ($M = 165.82$ msec). No other pairwise comparison was significant.

Second, Stimulus Affectivity influenced the postexperimental evaluations of the trait adjectives, $F = 208.60$, $df = 2, 28$, $P < 0.001$. Application of the Duncan procedure revealed

Table 2. Effects of task on mean reaction time, memory trace durability, and EEG ratio-score for the processing interval

Processing task	Reaction time	Recognition confidence	EEG ratio
Rhyme	182.38	3.21	8.82
Evaluation	176.70	3.97	8.87
Volume discrimination	125.14	3.27	8.90
Self reference	220.95	4.31	8.90

Note. Entries for reaction time are expressed in msec whereas entries for EEG ratios are expressed in percentages. Larger entries for recognition confidence indicate better subsequent memory of the words. The last column of entries are expressed in terms of percentages and signify the ratio of arbitrary units of EEG alpha activity over the left and right cerebral hemisphere. Larger entries for EEG ratio indicate activation of the left hemisphere compared to the right hemisphere and, thus, relative utilization of the major hemisphere.

that the positive ($M = 6.22$), neutral ($M = 4.69$), and negative ($M = 1.49$) trait adjectives differed from one another. Thus, the manipulation apparently worked.

EEG ratio scores

A three-way mixed model analysis of variance (Experimental Replication × Processing Task × Stimulus Affectivity) was conducted for the mean EEG ratio-scores obtained for each interval (i.e. prestimulus, cue-question, processing, poststimulus). The analyses revealed an overall effect for task on interhemispheric patterning during the processing interval, $F = 4.66$, $df = 3, 42$, $P < 0.01$.*

Depth-of-processing contrast. A planned comparison was conducted to determine whether the more elaborate cognitive tasks of evaluation and self reference affected interhemispheric patterning differently than the tasks of volume discrimination and rhyme. This contrast was not significant ($P < 0.10$). The means for each task are summarized in Table 2. As is evident by inspecting these means, each of the tasks elicited relative left hemispheric EEG activity. Of course, neither the absolute levels of activity (utilization) of each of the hemispheres nor whether left hemispheric utilization is greater or lesser than right utilization is important, but rather the *relative* utilization of the cerebral hemispheres portends the style of information processing (e.g. see [26]). These data, then, suggest that the task typically employed in levels-of-processing research on the encoding of words engage the left hemisphere relative to the right, but the level of processing that is elicited does not alter this asymmetry.

The Duncan procedure was employed next for EEG data obtained during the processing interval ($\alpha = 0.05$-two-tailed tests). The pairwise comparisons indicated that rhyme was associated with *less* relative left hemispheric activation than volume discrimination and self

*Analyses of the raw EEG data were performed using Site (P3 vs P4) as an additional within-subjects factor to determine the effects on overall brain wave activation of the experimental variables. Two findings obtained: (a) The main effects for processing task and stimulus affectivity failed to reach a statistically significant level. This suggests that the asymmetry observed resulted from the increased activation of one and decreased activation of the other hemisphere rather than to the relative activation of a single hemisphere; and (b) the distribution of the alpha scores obtained from the P3 and P4 sites demonstrated no overlap. This effect is probably due to calibrations of the apparatus employed. Thus, the absolute value of the ratios obtained may be slightly biased. However, since the apparatus and calibrations were constant across all subjects and a within-subjects design was employed, the *relative* differences observed as a function of the experimental variables should not be affected.

reference. Similar patterns of interhemispheric activity were observed during self reference and volume discrimination. Evaluation evoked a pattern of EEG activity that fell between but was not significantly different than rhyme and the tasks of volume discrimination and self reference.

Stimulus affectivity. The initial series of ANOVAs also revealed that the likeableness of the target adjective was related to differential hemispheric EEG activation. Stimulus Affectivity was associated with differences in the EEG ratio scores obtained during the cue question, $F=3.39$, $df=2, 28$, $P<0.05$, and had a marginally significant effect on the ratio scores obtained during the post stimulus interval, $F=2.92$, $df=2, 28$ $P<0.07$. The first effect is most likely a Type I error since the likeableness of the target adjective was varied randomly across trials and was not known until the onset of the processing interval. The effect observed during the post stimulus interval, however, is possibly quite interesting and cannot be attributed to carryover from the cue-question interval since the form of the effect differs for these two intervals (see Table 3).

Table 3. Effects of trait-adjective likeableness on mean EEG ratio-score

	Interval			
Affectivity	Pre-stimulus	Cue-question	Processing	Post-stimulus
Positive	8.69^{a}	8.70^{a}	8.88^{a}	8.82^{ab}
Neutral	8.67^{a}	8.65^{b}	8.86^{a}	8.84^{b}
Negative	8.68^{a}	8.65^{b}	8.87^{a}	8.80^{a}

Note. Entries are expressed in terms of percentages and depict the ratio of arbitrary units of EEG alpha activity over the left and right hemispheres. Larger entries indicate relative activation of the left hemisphere. Entries within a column that have dissimilar superscripts differ from one another at the 0.05 level by the Duncan's procedure (two-tailed).

Duncan tests were calculated to examine this latter effect more closely. The pairwise comparisons, which are summarized in Table 3, indicated that the likeableness of the word mattered little during the prestimulus and processing intervals, but that affect-laden words, especially negatively toned words, caused relatively more activation of the minor hemisphere during the *post-stimulus* interval than did neutral words.

DISCUSSION

The major analysis focused on EEG asymmetry as a function of the complexity or depth-of-processing. The tasks of rhyme and volume discrimination are fairly simple, whereas the tasks of evaluation and self reference require deeper analyses (see Table 2; [31, 34]). For each of these latter tasks subjects had to determine the meaning of the word, whereas this semantic step was not required to perform the former two tasks. By comparing the EEG asymmetry obtained for the tasks of volume discrimination and rhyme vs self reference and evaluation, we were able to explore the influence of depth-of-processing. Despite the strong effects of processing depth on reaction time and retention characteristics of the stimulus, depth of processing had *no* significant effect on differential hemispheric EEG activation. The present data suggest that there is not a strong covariation between the style in which information is processed and the post-categorical *level* at which it is processed.

Pairwise comparisons for EEG asymmetry scores supplied further information about functional cerebral asymmetry and information processing. The self reference task led to greater relative left hemispheric activation compared to the rhyme task. The comparison of self reference and evaluation revealed a similar pattern of lateralization, though it was not as strong. This may indicate that subjects varied in their means of securing an evaluation of the target words, some at times focusing on the overall affective reaction to the word's connotative meaning; and some at times accessing the attributes of the word, determining the values of each, and summing (or averaging) these scalar values to deduce the goodness of the word (cf. [35, 36]). If only some of the evaluative judgments were made in the former, holistic manner, then *relative* minor hemispheric activity would exist compared to the self reference task since this latter task is presumably accomplished by conducting a sequence of nonaffective matching operations of the trait adjective with a hierarchically organized self-schema [37].

Stimulus-related EEG asymmetry

We next investigated the EEG patterns obtained for the various intervals of the experimental trial as a function of the likeableness of the trait adjectives employed. We found that although the task affected EEG asymmetry during the target-adjective interval (which was quite short in most instances—see Table 2), stimulus affectivity had no reliable effect during this period on EEG asymmetry. These data suggest that the subjects were concentrating, as instructed, on performing the task at hand. As soon as the problem was solved, subjects responded by pressing a button, thereby initiating a 1-sec poststimulus interval. It was during this brief poststimulus interval that we observed relative minor hemispheric activation for affected-laden words (particularly for the negative words) as compared to neutral words. This suggests that when subjects completed the task and had a few moments to reflect back on the nature or associations of the stimulus to which he had just responded, the affective nature of these associations influenced the pattern of brain wave activity across the hemispheres. This finding, though unexpected, is consistent with evidence indicating that brief affective reactions, particularly negative responses, are tied closely to relative utilization of the minor hemisphere [25, 38, 27].

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Résumé :

16 sujets droitiers ont entendu 12 brèves questions avec indices sur les stimulus de chacune de quatre tâches. Chaque question a été suivie de l'annonce d'un adjectif à trait unique qui était soit positif, soit neutre, soit négatif. Les jugements de référence à soi-même et de discrimination de volume ont évoqué une plus grande activation relative de l'E.E.G. sur l'hémisphère gauche que ne l'ont fait les jugements d'évaluation et de rime. Cependant, l'activation E.E.G. différentielle de chaque hémisphère n'a pas été affectée par la profondeur du traitement. Après terminaison de la tâche assignée, les adjectifs à charges affectives (positive ou négative) ont déterminé moins d'activité E.E.G. relative de l'hémisphère gauche que ne l'ont fait les mots neutres.

Zusammenfassung

Sechzehn rechtshändige Männer hörten 12 kurze, die vier Aufgaben betreffende Schlüsselfragen. Jeder Schlüsselfrage folgte die Ankündigung eines Adjektives mit nur einem Merkmal, das entweder positiv, neutral oder negativ war. Selbstbezogene oder volumenunterscheidende Urteile riefen eine grössere relative EEG Aktivierung der linken Gehirnhälfte hervor, als Urteile über Auswertungen oder Reime. Die diferentielle hemispherische EEG Aktivierung wurde allerdings nicht von der Tiefe der Verarbeitung beeinflusst. Sobald die zugeteilte Aufgabe beendet war, riefen die gefühlsgeladenen (negative oder positive) Adjektive eine niedrigere relative EEG Aktivität der linken Gehirnhälfte hervor.