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Brain Responses Related to Semantic Meaning

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Evoked Potentials from electroencephalogram (EEG) recording were averaged to many visually presented word stimuli whose semantic meanings were specified along Osgood's semantic dimensions of Evaluation, Potency, and Activity [Miron & Osgood, 1966, in R. B. Cattell (Ed.), *Handbook of multivariate experimental psychology*, Chicago: Rand–McNally; Osgood, 1971, *Journal of Social Issues*, **27**, 5–63; Osgood, May, & Miron, 1975, *Cross-cultural universals of affective meaning*, Urbana, Ill.: University of Illinois Press]. Multivariate analyses classified the Evoked Potentials to six semantic classes with success rates more than twice chance expectation. The pattern of brain activity related to the six semantic classes was similar for (i) two sets of words, (ii) 10 subjects used to develop the analyses, and (iii) an added, new subject.

The technique of averaging electrical activity from the human scalp to repeated, discrete sensory, motor, and cognitive events has found extensive use in extracting brain responses (Evoked Potentials or EPs) from the ongoing electroencephalogram (EEG) (for reviews: Callaway, 1975; Regan, 1972). In order to investigate brain responses related to semantic meaning, we extended this technique to averaging EPs across a number of words belonging to the same semantic class (Chapman, 1974b; Chapman, Bragdon, Chapman, & McCrary, 1977). With the aid of a quantified theory of connotative semantic meaning and multivariate statistical techniques, we found brain activity from the human scalp which is related to semantic meaning. Our study focuses on *intralinguistic* differences, that is, on brain response waveform differences related to distinctions within a particular language domain, namely connotative meaning. This strategy strengthens the interpretation of the positive results in that (i) classes of variables such as stimulus differences, general state differences, and information processing differences are less likely to confound the result and (ii) the specificity of the language effects is more

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striking. In order to control commonly confounding variables, the subject's task was held constant, the presentation sequences were randomized, and the semantic classes were represented by a relatively large number of different words in two lists. With regard to the specificity of the linguistic effects, six different semantic classes were distinguished.

MATERIALS AND METHODS

We specified and controlled internal semantic meanings using the conceptions and materials provided by Osgood's analyses of semantic meaning (Miron & Osgood, 1966; Osgood, 1971; Osgood, May, & Miron, 1975). Those analyses indicate that the connotative meaning of a word may be represented by its position in a space spanned by three semantic dimensions: Evaluation, Potency, and Activity (E, P, and A). Such quantitative descriptions of words in a three-dimensional semantic space allow similar words to be selected by those characteristics to form semantic classes. We selected words (Heise, 1971) which are relatively "pure" in the sense that they score high or low on one of the dimensions and are relatively neutral on the other two. Thus, we used six semantic meaning classes (E+, E−, P+, P−, A+, A−) representing the positive and negative extremes of the Evaluation, Potency, and Activity dimensions. Average values for the words were 2.0 and −1.3 for the E+ and E− classes, 1.9 and −.6 for the P+ and P− classes, and 1.0 and −.8 for the A+ and A− classes on their respective semantic dimensions (range = +3 to −3). Some of the words in each of the semantic classes are: E+, peace, food, pleasure, fresh; E−, greed, thief, bitter, lizard; P+, judge, hard, ocean, official; P−, jelly, little, feather, five; A+, tennis, surprise, worker, spicy; and A−, silence, stone, poetry, past.

Twenty words from each of the six semantic classes constituted a list. Two such lists were randomly constructed using a total of 220 different words. The same words were used in both lists for the P− class due to their scarcity in Heise's compilation. The 120 different words within each list were given in different random orders from run to run, so that the subjects could not anticipate either a semantic class or a particular word during the experimental runs. Each word was visually presented on a computer-controlled CRT display while the subject's EEG was recorded.

The sequence for each word presentation (a trial) within each run was: (i) fixation asterisk on for .5 sec, (ii) blackout for .5 sec, (iii) stimulus word flashed (about 17 msec by average photocell measurement), and (iv) blackout for 2.5 sec, toward the end of which time the subject said the word. This simple task of saying each word assured that it was perceived. The average word was 1.5° visual angle, 17 msec in duration, and about 1.4 log units luminance above the word recognition threshold.

Statistical analyses were made of the stimulus words in relation to their luminance and luminance distribution. The stimuli were composed of dot-matrix characters, so the relative luminance flux could be measured by the relative number of dots in each word. When this measure was statistically analyzed for its ability to discriminate the six word classes, it resulted in an overall classification success of only 19.6 per cent, which was not significantly different ($.20 < p < .30$) from the chance level of 16.7%. The possibility that the luminance distribution might be different for words in the various semantic classes was assessed by comparing letter frequencies. The distribution of letters was not significantly different for the six word classes. This was assessed by counting the number of times each of the 26 letters occurred in each word of each semantic class represented in two different lists of words and entering these values into an analysis of variance. As expected, the letters differed significantly in their overall frequencies of occurrence in the words as a whole (e.g., "E" was quite frequent and "X" was infrequent). These differences, however, did not change systematically according to the semantic class of the words. There was no significant interaction with semantic class or with word list.

The subjects were run individually in a dark, sound-damped chamber to reduce contamination from eye movements and sounds. Subjects sat and directly viewed the CRT display at a 1-m distance within the otherwise dark chamber.

The data reported here were recorded monopolar between a scalp electrode located on the midline over the central-parietal area (CPZ) and linked earlobes. The scalp electrode was a Grass electrode (silver, cup shaped) attached by bentonite CaCl paste one-third of the distance from CZ to PZ (International 10–20 System). Grass ear electrode clips on the earlobes served as reference electrodes and were electrically connected at the input to the amplifier. The electrical potentials were amplified by Grass EEG amplifiers and monitored on a Grass polygraph. The data were recorded on an AMPEX FM tape recorder and later fed to a computer via an interface containing operational amplifiers. The frequency bandpass of the overall recording system was .1 to 70 Hz (half amplitude). Eye movements were monitored by bipolar EOG recording using another recording channel (the same gain and frequency response).

The 10 unselected subjects were female (six) and male (four) paid volunteers. Their ages were 18–23 years and their educational background varied considerably (typically high school graduates). None appeared to know about Osgood's analyses.

Beginning with the stimulus word and lasting 510 msec, EPs for each semantic class were averaged from the EEG by a program using 102 time points (5-msec interval). Each EP was averaged over 20 different words of the same semantic class. Thus, EPs were collected for each of the six semantic classes for each of the two word lists. The fundamental idea is that the neural components which are common to the words of a given semantic meaning class will appear in the average EP, while those aspects of brain processing which are not common will tend to cancel out.

Over a number of sessions, each subject was given 12 to 20 runs of 120 words (20 words in each of six semantic meaning classes) and equal numbers of List 1 and List 2 runs were randomly interspersed. Due to scheduling problems different subjects received different numbers of runs. However, the design was balanced for each subject (word classes within runs and lists within sessions). Twelve EPs (six semantic classes for List 1 and for List 2) were obtained for each subject by further averaging the appropriate EPs from the available runs. Thus, the analyses were based on EPs averaged from 6 to 10 runs for various subjects ($N=120$ to 200 for each semantic class for each list).

RESULTS

Summary data from 10 subjects are presented here. Although the overall average brain responses to the six semantic classes (the left part of Fig. 1) appear very similar to each other, the small differences associated with the semantic classes were consistent for both lists and all 10 subjects. The same data after standardizing separately for each subject (see below) and then averaging (the right part of Fig. 1) clearly show different waveforms for the different semantic classes.

Our data analyses involved: (i) standardizing the EPs for each subject separately, (ii) computing a Principal Components Analysis using all of the standardized data for the 10 subjects, and (iii) computing Multiple Discriminant Analyses using the component scores obtained from the Principal Components Analysis as the input variables and the six semantic classes as the criterion variables.

The data were standardized separately for each of the subjects. Using the BMDP1S Multipass Transgeneration Program (Dixon, 1975: program

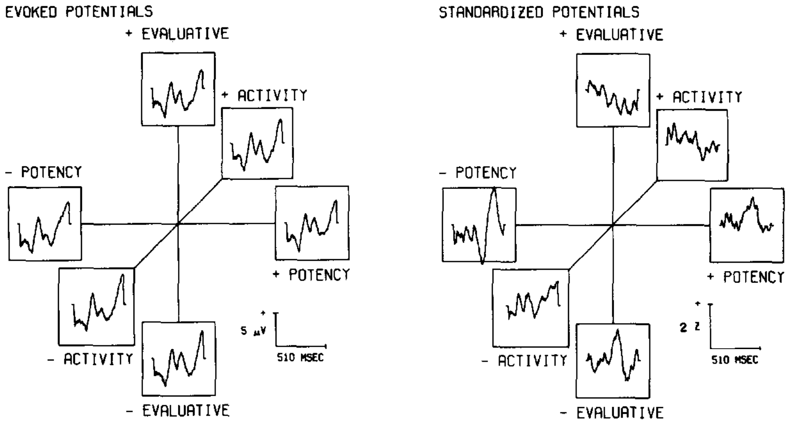

FIG. 1. Average brain responses for six semantic classes before and after standardization. The semantic classes are based on Osgood's Evaluation, Potency, and Activity dimensions (Miron & Osgood, 1966; Osgood, 1971; Osgood et al., 1975) which define a three-dimensional semantic space, represented schematically here. The EPs cover 510 msec (102 time points × 5 msec) along the horizontal axis, beginning at the time the words were flashed. The vertical axes for the EPs are in microvolts, in the left panel, and are in standard units, z, in the right panel. For the Standardized Potentials, each subject's data at each time point were transformed to z scores (means = 0 and standard deviations = 1). Averages include data for two lists and 10 subjects. Monopolar recordings (bandpass: .1 to 70 Hz) are from a scalp location one-third of the distance from Cz to Pz.

revised Oct. 7, 1974), each subject's data at each time point were transformed to z scores with means equal to 0 and standard deviations equal to 1. The general advantages of preparing data for analysis in this way have been described by Rummel (1970, pp. 246–247). The specific reason for standardizing the data within the subjects was to avoid swamping the semantic effects by individual differences in the subsequent analyses.

A Principal Components Analysis (Dixon, 1975; Kaiser, 1958), which followed procedures previously described (Chapman, 1974a; Chapman, McCrary, Bragdon, & Chapman, in press), was computed in order to: (i) determine the EP components and (ii) measure how much of each component is in each EP. The data entering the analysis were 120 EPs (6 semantic classes × 2 lists × 10 subjects) measured at 102 time points. The options used included: correlation matrix with unities in diagonal, eigenvalue = 1 as the cutoff, and rotation to the normalized varimax criterion (Kaiser, 1958). The 12 retained components (eigenvalues > 1) accounted for 94% of the variance. Scores measuring the contributions of the 12 components to the individual EPs were computed.

Having reduced each EP from 102 measures to only 12, the next step was evaluating the extent to which these 12 brain response components contained semantic information. This was done by Multiple Discriminant Analyses (Dixon, 1975) the aim of which was to predict the semantic class membership of the EPs on the basis of the EP measures. A set of linear classification functions was computed by the program choosing the EP components according to how well they discriminated among the semantic classes. Using these classification functions, each EP was assigned to one of the six semantic classes.

Discriminant classification analyses using the evoked potential component scores to distinguish semantic classes were of two kinds: (1) unidimensional and (2) multidimensional. The unidimensional analyses considered the data for one semantic dimension at a time (E, P, or A), in which case two semantic classes (positive and negative classes from one dimension) were discriminated. The multidimensional analyses considered the data for all three semantic dimensions at once, in which case six semantic classes were discriminated from each other (positive and negative extremes of E, P, and A dimensions).

Classification functions were developed separately for the data from each list of words and the results were crossvalidated by several procedures: (i) jackknifed, (ii) other-list, and (iii) fresh data of a new subject. The jackknifed crossvalidation is used to estimate the success which would be expected in classifying other, additional EPs obtained using the development list. In the other-list crossvalidation, the classification rule developed for EPs obtained with one word list is used to classify EPs collected with the other list of word stimuli. This provides a further check on generalizability of the classification functions and tests their likely success rate in classifying other, additional EPs obtained using a different set of words.

The results concentrate upon evaluating the usefulness of EP components in distinguishing among semantic classes and, thus, are reported primarily in terms of EP classification success rates. The extensive tables of the intermediate computational results (rotated component loadings, component score coefficients, and coefficients for 24 group classification functions) are available upon request to the principal author.

Unidimensional Analyses of Semantic Groups

Six discriminant analyses were performed separately on the data from the three semantic dimensions (Evaluation, Potency, and Activity) for the two word lists (List 1 and List 2). In each of the analyses, classification functions were computed which detected statistically significant differences between the groups. These differences were evaluated using the values of F computed from Wilk's λ (U statistic). The chance probabilities of these F values ranged from less than .01 (Evaluation dimension, List 2) to less than .001 (Potency dimension, both lists).

The results obtained when these functions were used to classify EPs into semantic groups are summarized in Table 1. For example, the results for the Evaluation semantic dimension using the data for List 1 to develop the classification function for E+ vs E− semantic classes are given in the first two rows of the table. In this case, the classification function classified EPs to E+ and E− classes with 100% accuracy. The jackknifed crossvalidation success remained at 100% for both E+ and E− classes. The jackknifed procedure assesses the classification success when each case is left out of the development set and then classified. When the classification functions developed from List 1 data were applied to List 2 data, 80% of the EPs obtained to E+ words were correctly assigned to the E+ class and 80% of the E− EPs were assigned to the E− class. These percentages are to be contrasted with a chance level of 50%, since two classes at a time are considered in the unidimensional analyses.

The success in discriminating along the Potency semantic dimension (P+ vs P−) using List 1 data for development of the classification was also high. The percentages of P+ and P− EPs correctly classified for the data used in development and by the jackknifed crossvalidation were uniformly

TABLE 1

PERCENTAGES OF BRAIN RESPONSES (EPs) CORRECTLY CLASSIFIED IN SIX SEMANTIC CLASSES USING UNIDIMENSIONAL ANALYSES[a]

Semantic dimension	Pole	Development (List 1)	Jackknifed cross-validation (List 1)	Other-list cross-validation (List 2)
Evaluation	+	100	100	80
	−	100	100	80
Potency	+	100	100	100
	−	100	100	90
Activity	+	100	90	40
	−	90	80	50
Overall		98.3	95.0	73.3
		(List 2)	(List 2)	(List 1)
Evaluation	+	100	70	80
	−	80	70	50
Potency	+	100	90	100
	−	90	90	90
Activity	+	100	100	100
	−	100	90	20
Overall		95.0	85.0	73.3

[a] Each individual percentage is based on 10 EPs. The percentage correct expected by chance is 50%. χ^2 tests comparing each of the six overall success rates to chance yielded values from 12.2 to 54.2, each with 1 *df* (*p*s << .001).

100%. Furthermore, the classification functions developed from List 1 data were quite accurate in assigning List 2 data to P+ (100%) and P− (90%) semantic classes.

The accuracy of classifying EPs along the Activity semantic dimension was not as high as for the E and P semantic dimensions, although it was still quite respectable. The jackknifed crossvalidation success for List 1 was 90% for A+ and 80% for A− EPs. However, the A+ vs. A− classification function developed from List 1 data was not successful in classifying EPs from List 2: Correct assignments fell to chance levels (40 and 50%).

When the data for List 2 were used to develop the classification functions (the bottom half of Table 1), the results in general were quite similar to those obtained when the development was based on List 1 data. The differences are minor, with slightly lower percentages for the P semantic dimension and slightly higher percentages for the A dimension. The crossvalidation rates for the E dimension, however, were not significantly better than chance. In this case, one would do better using the classification rule developed with data on List 1.

Overall, the unidimensional analyses have an average apparent success of 97% and an average jackknifed crossvalidation success of 90%. It is to be noted that this success rate was obtained across subjects; the same classification functions were used for all 10 subjects. When the same classification functions were applied to the EP data obtained from the other word list, the overall success rate was 73%.

Multidimensional Analyses of Semantic Groups

Table 2 summarizes the results of classifying the brain responses into one of six semantic classes. The probability of correct classifications by chance is 1/6 (16.7% of the EPs). The classification success rates (column 1) for the EPs used to develop the functions were well above the chance level.

The success rates for the jackknifed crossvalidation (one-left-out procedure) also were above the chance level. Overall, they were 42% for List 1 and 43% for List 2 data, some 2.5 times better than chance.

When the classification functions developed from the data for one list were applied to the data for the other list, the overall success rates were both 40%. This is a stringent crossvalidation, since it assesses the ability to generalize not only to other EPs but also to a different list of words and to generalize across individual data of 10 different subjects.

A further test of the generalizability of the findings was made by applying the already computed classification functions unmodified to the EP data of a new subject. These data were collected and standardized in the same manner as for the 10 subjects in the development group. The component score coefficients obtained from the original 10-subject Principal Components Analysis were used to compute component scores for the new data. The classification functions obtained from the 10-subject Multiple

TABLE 2

PERCENTAGES OF BRAIN RESPONSES (EPs) CORRECTLY CLASSIFIED IN SIX SEMANTIC CLASSES USING MULTIDIMENSIONAL ANALYSES[a]

Semantic dimension	Pole	Development (List 1)	Jackknifed cross-validation (List 1)	Other-list cross-validation (List 2)
Evaluation	+	30	30	50
	−	80	50	50
Potency	+	40	40	30
	−	80	80	70
Activity	+	50	20	10
	−	60	30	30
Overall		56.7	41.7	40.0
		(List 2)	(List 2)	(List 1)
Evaluation	+	60	60	70
	−	70	60	50
Potency	+	30	20	20
	−	90	80	70
Activity	+	20	0	20
	−	50	40	10
Overall		53.3	43.3	40.0

[a] Each individual percentage is based on 10 EPs. The percentage correct expected by chance is 16.7%. χ^2 tests comparing each of the six overall success rates to chance yielded values from 21.9 to 66.3, each with *1* df (*p*s << .001).

Discriminant Analyses were applied to the new subject's EP component scores. The overall accuracy with which these EPs were correctly classified into the six semantic classes was 42%, essentially the same as the crossvalidation accuracy rates based on the EPs of the previous subjects.

DISCUSSION

Some EP research beginnings have been made at a variety of linguistic levels (Begleiter & Platz, 1969; Begleiter, Gross, & Kissin, 1967; Begleiter, Gross, Porjesz, & Kissin, 1969; Brown, Marsh, & Smith, 1973, 1976; Buchsbaum & Fedio, 1970; Chapman, 1974b, 1976; Chapman, Bragdon, Chapman, & McCrary, 1977; Feldman & Goldstein, 1967; Friedman, Simson, Ritter, & Rapin, 1975a, 1975b; Molfese, 1977; Molfese, Freeman, & Palermo, 1975; Molfese, Nunez, Seibert, & Ramanaiah, 1976; Shelburne, 1972, 1973; Teyler, Roemer, Harrison, & Thompson, 1973; Thatcher, 1977a, b; Wood, Goff, & Day, 1971; Wood, 1975; etc.). The only other EP studies known to be directed at the connotative meaning level of linguistics come from Begleiter and his associates. In general, the research seeking linguistic effects in EPs varies considerably in sophistication and conviction (Chapman, 1976). Alternative explanations of these EP effects in many cases are available in terms of sensory differences in the stimuli, different states of the subject, different cognitive functions, different sequence effects, and individual differences, etc.

Part of the evidence for the specificity of language effects in EPs depends on the dimensionality of the EP measures themselves. Since a prominent, late, positive-going component of the EP (variously called P300, P3, etc.) has been associated with the general relevance of stimuli to the subject's task (Chapman and Bragdon, 1964), it is relevant to ask whether the obtained linguistic effects in EPs are merely variations in this general EP component. The EP measures in the present study were obtained from a Principal Components Analysis which extracted 12 orthogonal components. One general EP component, such as P300 (Chapman, McCrary, Bragdon, & Chapman, in press), is not sufficient to account for the dimensionality of the present EP data. The classification functions used various combinations of a number (two to six) of the orthogonal EP components to distinguish the six semantic classes. Three of the components contributed to discriminations among semantic classes more strongly and consistently than others. One or more of these three contributed to each of the reported classifications. These were also the three components which collectively accounted for the highest proportion (39%) of the total variance in the EP data (all 12 accounted for 94%). All three of the components were principally correlated ($r > .32$) with the original EP measures at time points ranging from 245 to 510 msec, being maximally correlated ($r > .90$) around 295, 410, and 495 msec. In addition, depending upon the particular analysis, various numbers of other components contributed to the semantic discriminations. Only one of the 12 components was not used in any of the reported classifications. Thus, the semantic differences examined were not described by different amounts of any single EP component.

These findings suggest that internal representations of meaning can be assessed by analyzing electrical brain responses. Since the semantic classes were presented randomly, the obtained differences cannot be attributed to any prestimulus variables, e.g., expectancy, arousal, and attention, etc. Since the subject's task (perceive and say word) was constant, the obtained differences do not relate to general poststimulus variables, e.g., differential information processing, response preparation, and uncertainty resolution, etc. It is not likely that the EP differences are related to different muscle activity since (i) the words were spoken after the 510-msec EP interval and (ii) many different words constituted the stimuli for each semantic class. Analyses of the EOG data show that eye movements do not explain the EP effects. Since many different words were the stimuli for each semantic class, the number of luminous dots and alphabet distributions were similar across semantic classes, and the EP results were generalized across two such lists of words, it does not seem likely that the results are due to the physical differences in the visual stimuli. The same aspect of the experimental design guards against interpretations based on surface linguistic features. Finally, distinguishing six semantic classes indicates a degree of specificity which generally taxes interpretations in terms of variables other than connotative meaning.

The finding that the EP effects related to connotative meaning hold for all of the subjects suggests that the physiological representation of meaning may be similar in different individuals. Further substantiation of this finding would parallel, at the physiological level, the universality of the Osgood dimensions found by semantic differential ratings.

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