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Electromyographic Specificity During Covert Information Processing

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ABSTRACT

Subjects performed tasks of rhyme, volume-discrimination, association, evaluation, and self-reference for verbal stimuli. The stimuli and overt response (pressing one of two microswitches) were constant across tasks and subjects. Oral and nonoral electromyographic (EMG) and cardiac activity were monitored continuously. We found that the depth of processing was associated with enhanced EMG activity of the speech muscles, but was unrelated to cardiac and nonoral EMG activity. Moreover, this association was observed only when subjects were covertly analyzing the stimuli. It was concluded that the pattern of perioral EMG activity can reflect the extent to which encoding operations are directed toward meaning.

DESCRIPTORS: Depth of processing, Electromyographic specificity, Oral and nonoral EMG activity, Skeletomuscular pattern.

Researchers have long focused on the activity of the muscles in their studies of covert information processing (e.g., Sechenov, 1863). The Soviet psychological literature, influenced greatly by the work of Sechenov and Pavlov, is replete with references to the first (visual, nonverbal) and second (verbal) signal systems presumably developed through means of classical conditioning and grounded physiologically in the feedthrough components of the neuromuscular loops between the brain and speech musculature (Luria, 1966; Sokolov, 1969, 1972).

Though less consensus exists in the Western psychological literature regarding the role of speech muscle activity, many researchers would endorse a "moderate-centralist" perspective, in which speech EMG activity is thought to reflect, in some instances, the activation of central processes though the latter alone are functionally involved in covert information processing. Dissent from this perspective would primarily come from those who view speech EMG activity, when indexing silent or subvocal speech, as a major contributing mechanism for covert information processing (for reviews see Cacioppo & Petty, 1979b; McGuigan, 1978).

The empirical evidence to date is consistent with the notion that speech EMG is related to cognitive work, but the data are less clear regarding the validity and specificity of this hypothesized somatic-cognitive coupling. We now know that: (a) silently processing linguistic materials (e.g., reading) leads to greater EMG activity of the speech muscles (e.g., lips, tongue) than silently processing nonlinguistic materials (e.g., music), and both tasks usually result in elevated speech EMG activity relative to baseline measures (e.g., Edfeldt, 1960; McGuigan & Bailey, 1969); (b) activation of the speech muscles is specific—(i) a concomitant increase in EMG activity is not found indiscriminately or generally in nonoral muscle groups or in the galvanic skin response when silently processing linguistic materials (e.g., McGuigan & Tanner, 1971; Sokolov, 1967), and (ii) the *relative* activation of muscles *within* the speech musculature is contingent upon the phonetic characteristics of the material being processed (McGuigan & Winstead, 1974); (c) poor readers display greater speech EMG activity when reading than good readers, though both display increased speech EMG activity when silently reading diffi-

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cult rather than simple text (e.g., Edfeldt, 1960; Faaborg-Anderson, & Edfeldt, 1958); and (d) improving reading proficiency initially elevates the accompanying speech EMG activity (e.g., Sokolov, 1972).

Note, however, that the type of stimulus presented or the type of subject employed has been varied along with the extent of covert linguistic processing presumably manipulated. For instance, though poor readers show greater oral EMG activity while reading than good readers, we do not know whether this effect is caused by differences in the cognitive work involved in processing the material, the style in which the material is processed, attentional differences in the readers, the self-monitoring processes used by the readers, and/or differences in apprehension.

The instructional manipulations used commonly to study encoding operations offer an alternative procedure to study somatic patterns during covert information processing (cf. Cermak & Craik, 1978). The procedure, sometimes called the depth-of-processing paradigm, involves presenting target words (e.g., trait adjectives) to subjects while randomly varying the question pertaining to (and preceding) each target word (Craik & Tulving, 1975). In this paradigm, somatic responses attributable to subject and stimulus attributes per se are assigned to the error term. What generally remains is variance due to the instructional factor (cue-question), which serves as the operationalization, the predominant type of feature analysis operating in the encoding of the target word (i.e., covert information processing).

Since the introduction of the depth-of-processing model (Craik & Lockhart, 1972), research has focused on determining exactly what mental operations are affected when words are processed "deeply." Originally, processing depth referred to a hierarchy of mutually exclusive levels of feature analysis "ordered from those concerned with sensory, 'surface' qualities to those concerned with the abstract, symbolic properties of the event" (Craik, 1978, p. 457). Though the view of processing "levels" involving differing amounts of qualitatively distinct feature analysis has generally received support (cf. Cermak & Craik, 1978), qualifications have been introduced. Specifically, "deep" compared to "shallow" processing is now believed to result from analyzing a word more extensively or complexly along any single dimension (e.g., identifying more distinctive features and associations to the word), or from analyzing the word along a larger number of dimensions (e.g., phonetic, associative) either sequentially or simultaneously.

A major problem in this area of research has been and continues to be the measurement of processing depth. According to the depth-of-processing formulation, deeper processing creates a more durable memory trace. Baddeley (1978) noted, however, that the measure of processing depth is memory performance. This circularity in logic seriously weakens the utility of the depth-of-processing formulation and can be overcome only by developing an independent measure of processing depth. Processing levels as described by Craik (1978, 1979) are constructs distinct from the memory traces they leave. "Deeper" processing results from more extensive and distinctive encoding operations and typically results in greater meaning (i.e., more lexical associates) attached to the encoded stimulus. The problem of measuring processing depth, then, might be overcome by monitoring the EMG activity of the speech musculature. As encoding operations are directed more toward meaning (i.e., exercise deeper analyses), higher intensity oral EMG activity should result.[1]

The purpose of the present study, then, was to determine the magnitude of oral and nonoral EMG response accompanying the performance of encoding tasks that differed in the extent to which mental operations were directed toward meaning (i.e., depth-of-processing—Craik & Lockhart, 1972; Craik & Tulving, 1975) while eliminating the variance due to stimuli and subjects per se from the treatment term. We used orienting tasks for which there is general agreement regarding their ordering along the depth-of-processing dimension (e.g., Nelson, 1977), and we expected the magnitude of oral EMG activity to reflect the processing depth elicited by these tasks. That is, the ordering of the changes in lip EMG activity should be ordered along the depth of processing dimension. Finally, cardiac activity was monitored to assess its relationship to the task requirements and somatic responses.

Method

Subjects and Design

Sixteen right-handed undergraduate men participated in a 2 (Experimental Replication) × 5 (Processing Task) × 12 (Task Replication) factorial. The Experimental Replication factor represented two concurrently conducted versions of the study, which were identical except for the use

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[1] Depth-of-processing effects have been found for pictorial stimuli as well (Mueller, Bailis, & Goldstein, 1979). These levels may not be reflected in oral EMG activity since the various levels may not differ in their linguistic distinctiveness or complexity. The instructions and target words employed here were selected to minimize the differential occurrence of pictorial processing across conditions and, indeed, its occurrence at all. We used abstract trait adjectives rather than concrete nouns (cf. Pavio, 1971).

of different random orderings of experimental stimuli. 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 we should suspect that some complicating factors are at work (e.g., carry-over effects). Collapsing across the factor provides a more conservative error term (and more assuredly successful randomization of treatments) for the subsequent tests than using a single random order of treatments (cf. Ronis, Baumgardner, Leippe, Cacioppo, & Greenwald, 1977).

Materials

The experimental stimuli (i.e., target adjectives) consisted of 60 words selected from Anderson's (1968) list of 555 personality traits. The words were selected to encompass a broad range of likability and affectivity to enhance the generalizability of the obtained results.

During the study, each target adjective was preceded by one of five cue-questions, which defined the processing task. The cue-questions (processing tasks) were (from shallow to deep—cf. Nelson, 1977; Rogers, Kuiper, & Kirker, 1977): (a) *Rhyme*—i.e., Does the following word rhyme with -----? (b) *Volume-discrimination*—i.e., Is the following word spoken louder than this question? (c) *Association*—i.e., Is the following word similar in meaning to -----? (d) *Evaluation*—i.e., Is the following word good (bad)? And (e) *Self-reference*—i.e., Is the following word self-descriptive?

The overt response required of the subject was a minimal finger pressing of one of two microswitches following the onset of the target adjective. One microswitch indicated that the subject's response to the preceding cue-question was "yes" and one indicated that the response was "no." Which switch denoted a yes and no response was counterbalanced between subjects within each experimental replication. Furthermore, which adjective served as the target for each cue-question and the ordering of the adjectives and cue-questions were determined randomly for each experimental replication. An audio tape was produced for each experimental replication and was used to present instructions and experimental stimuli.

Procedure

When subjects arrived at the laboratory, the experimental tasks were explained and electrodes were attached. Grass gold-plated cup electrodes were attached for: a) oral EMG—just below the apex of the lip at the right corner of the mouth, b) nonoral EMG—over the forearm flexor muscles of the nonpreferred arm, and c) heart rate—over the apex of the lower left rib and right collar bone; a plate electrode was attached to the subject's lower right calf as a ground.

Subjects next were seated in a comfortable chair, which was enclosed in a copper-mesh cage to shield electrical interference and was located in a sound-attenuated room. A 5-min adaptation period was followed by instructions to subjects to keep their eyes closed throughout the study, to breathe normally, and to refrain from unnecessary movements. The subjects were re-instructed on the nature of the experimental tasks and were given five practice trials, one for each type of task, to acquaint them with the experimental procedure.

Following another 5-min adaptation period, the experimental trials were initiated. Each trial consisted of: 1) a 10–20 sec variable intertrial interval (ITI), which served also as the prestimulus interval; b) a 5-sec cue-question; c) a variable length target-adjective interval, which was initiated by a voice-activating switch when the target word was announced and was terminated when the subject pressed one of the microswitches; and d) a 1-sec recovery interval, which was included to isolate potential movement artifacts from the prestimulus interval. The length of the target-adjective interval was recorded by a PDP-8I minicomputer and served as the measure of reaction time.

After completing the experimental trials, subjects rated their recognition (on 5-point confidence-rating scales) of 100 words in which the 60 experimental stimuli were embedded.

Data Reduction

The EMG data were amplified by Physiograph wide-band ac-dc preamplifiers, individually rectified, and summed by an EMG integrator with a time constant of 0.2 sec. The integrated EMG data were displayed on the physiograph as a resetting ramp function with a full-scale pen deflection of 40 mm (1 mm = 5 μV), and were transmitted on-line to a PDP-8I minicomputer, sampled 10 times per second, and recorded. Cardiac activity was recorded on FM tape and subsequently reduced beat-by-beat (in msec) using a Grass cardiotachometer adjusted to detect the R-spike of the cardiac cycle. All electrophysiological measures were monitored visually throughout the study on 3 channels of an 8-channel oscilloscope.

Mean activity for each EMG measure and for heart rate was calculated for each interval and subject. The value of each measure displayed during the ITI was then subtracted from the value obtained during the remaining trial intervals (i.e., cue-question, target-adjective, and recovery intervals). Nonparametric analyses were performed for these measures since the data were not normally distributed (see Cacioppo & Petty, 1979a).[2]

Results[3]

Recognition Confidence and Reaction Time

Analyses of variance were conducted for the ratings of recognition confidence and for reaction time. These analyses confirmed that the processing tasks employed here differed with respect to their cognitive requirements. The overall test of Processing Task for recognition yielded a highly significant effect, $F(4/56) = 15.82$, $MS_e = 2.64$. Pairwise comparisons using the Duncan Multiple Range Test re-

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[2] The data collection process was controlled by a laboratory computer, which was programmed to delete obvious movement artifacts. The number of such edits did not differ as a function of condition.

[3] An alpha level of $p < .05$ was employed in all analyses except where stated otherwise.

vealed the means to be ordered as follows: a) Self-referencing, $\bar{X} = 4.31$; b) Evaluating, $\bar{X} = 3.97$; c) Associating, $\bar{X} = 3.62$; d) Rhyming, $\bar{X} = 3.27$; and e) Discriminating-volume, $\bar{X} = 3.21$. All means except the last two differed significantly from one another. The mean recognition confidence for the 40 words that were not presented was 2.74, indicating that each task increased somewhat the recognition of the words.

Reaction time was affected similarly by processing task, $F(4/56) = 31.01$, $MS_e = 721.5$ Pairwise comparison intimated that the rhyming task elicited the fastest responses ($\bar{X} = 125.24$ msec) whereas the self-referencing task evoked the slowest responses ($\bar{X} = 220.95$ msec). Reaction times for the other tasks fell within these bounds and were approximately equal ($ps > .05$). No other reliable effects were obtained.

Electrophysiological Measures

Friedman nonparametric analyses of variance were used to assess treatment effects, and the Sign Test was used for pairwise comparisons (all tests are two-tailed). Table 1 displays the median change from the ITI for lip and nonpreferred forearm EMG activity as a function of processing task and interval.

Lip EMG Activity

As evident from inspecting Table 1, both the processing task and the interval affected lip EMG activity (χ^2 (4) = 18.79): Lip EMG during the target-adjective (i.e., processing) interval varied significantly as a function of task with the direction and magnitude of the changes mirroring the semantic-feature analyses inherent in the various tasks. There also was a nearly significant overall decrement in lip EMG activity across trial intervals (χ^2 (2) = 5.28, $p < .07$), an effect that was most dramatic for the relatively shallow tasks up to the recovery interval (see Table 1).

Nonpreferred Forearm EMG Activity

Analyses of nonpreferred forearm EMG activity revealed that, in sharp contrast to lip EMG activity, it *increased* across intervals (χ^2 (2) = 14.17). Inspection of Table 1 indicates that all tasks exhibited equal elevations of forearm EMG activity, and that the largest increases were obtained during the recovery interval.

Cardiac Activity

Analyses of variance were conducted for mean heart rate for each interval. These tests indicated that heart rate was unaffected by the processing tasks. A second analysis using range-corrected scores (Lykken, 1972) yielded the same results. When changes across intervals were inspected using the Duncan procedure, we found that heart rate increased significantly during the instructional (cue-question) interval ($\bar{X} = 1.09$ bpm), remained raised, though not significantly, during the target-adjective interval ($\bar{X} = 0.46$ bpm), and dipped slightly below the basal level during the recovery interval ($\bar{X} = -0.25$ bpm). These changes are similar to those obtained for general somatic activity and may primarily serve the general biologic needs created, for instance, by the motoric response.

Discussion

Increasing the covert requirements for elaborating upon an abstract linguistic stimulus resulted in increased oral EMG activity, but changed neither cardiac nor nonoral EMG activity. This somatic specificity is consistent with previous research showing distinct patterns of muscular activation in cognition and affect (e.g., Izard, 1971; McGuigan & Winstead, 1974), but was obtained here while controlling for the effects of stimulus and subject differences. In the present procedure, the variance accountable by subject (e.g., good vs bad readers), stimulus (e.g., affectivity), and overt response attributes were equated across processing tasks.

TABLE 1

Median change from prestimulus levels for EMG activity from the lip and nonpreferred forearm as a function of task and interval

Tasks	Median Changes From Prestimulus Levels (µV)					
	Lip EMG Activity			Nonpreferred Forearm EMG Activity		
	Cue-Question Interval	Target Adjective Interval	Recovery Interval	Cue-Question Interval	Target Adjective Interval	Recovery Interval
Self-reference	0.6	3.3	−4.4	1.0	2.2	2.7
Evaluation	0.6	5.3	1.3	1.0	5.3	6.3
Association	0.7	− 4.0	−5.0	3.7	2.6	4.2
Rhyme	−3.5	− 9.8	−6.7	2.6	3.7	2.1
Volume-discrimination	−6.5	−10.0	−4.4	0.0	−4.5	−4.4

Nevertheless, the lip EMG data for the processing interval approximately rank-order along the depth-of-processing dimension. This ordering is difficult to explain with alternative accounts as evidenced by the difficulty in finding variables that reflect processing depth (Baddeley, 1978). Encoding operations aimed primarily at determining the meaning or personal significance of a stimulus produced the most durable memory traces and the largest elevations of oral EMG activity, whereas encoding operations focused on sensory features produced the opposite effects. That is, the magnitude of the oral EMG response decreased as the instructed encoding operations directed mental operations toward sensorial rather than semantic feature analyses. Moreover, temporal specificity in somatic response was obtained: The nature of the instructed encoding operation altered oral EMG activity only during the processing interval. Collectively, these data suggest that output from an efferent component of the neuromuscular circuits between the brain and speech muscles mirrors depth-of-processing by indexing covert linguistic (semantic) processing.[4]

These observations notwithstanding, one might wonder why what appears to be covert speech behavior is displayed concomitant with environmental demands on processing capacity. "Simple conversation requires such an intricate meshing of breath, chest muscles, larynx, tongue, palate, lips, and words that it's a wonder anyone ever says anything" (Fry, 1979, p. 38). Several explanations might be offered. First, the changes in the magnitude of oral EMG activity may simply be the result of efferent overflows from the activated central processes of the brain. If this is the case, then the present results intimate that oral EMG may be a useful index of these hard-to-measure central processes (cf. Baddeley, 1978).

It seems possible too that the proprioceptive feedback from the speech muscles provides a nonmeaningful but redundant phonetic code that aids information processing, particularly when the stimulus-response connections are not yet well learned and semantic processing is involved (cf. McGuigan, 1978, Ch. 9; Sokolov, 1969). For instance, Kleiman (1975) found that disrupting subvocalization interfered with the normal reading process; he suggested that the feedback from the speech muscles served as a temporary storage for information that might be of importance to an overloaded central processing system. In this case too, oral EMG activity may prove to be useful in studying the operation of the central processing system.

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[4] This is not to suggest that skeletomuscular patterning reflects *only* depth-of-processing (see Cacioppo & Petty, 1981). For instance, research is presently underway to determine whether cognitive depth and effort (Tyler, Hertel, McCallum, & Ellis, 1979) can be discriminated in terms of somato-visceral patterns.

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