Biological Psychology 9 (1979) 103–113

LIP AND NONPREFERRED FOREARM EMG ACTIVITY AS A FUNCTION OF ORIENTING TASK *

John T. CACIOPPO
University of Iowa, Iowa City, IA 52242, U.S.A.

and

Richard E. PETTY
University of Missouri, Columbia, MO 65211, U.S.A.

Accepted for publication 12 October 1979

Subjects performed orthographic or semantic orienting tasks while preparing an overt response (pressing one of two buttons). Electromyographic (EMG) activity of lip and nonpreferred forearm muscles and heart rate were monitored. Only lip EMG activity distinguished the extent of covert processing, evidencing greater activity during the semantic than sensory task. In contrast, increased nonpreferred forearm EMG and cardiac activity accompanied the behavioral response. It was concluded that general semantic and autonomic activity serve biological needs, but in addition, there are specific patterns of physiological response that are intrinsic to covert information processing.

1. Introduction

Electromyographic responses during covert information processing have been an active area of research since Golla's (1921) study of forearm tonicity and problem solving. Early studies concentrated primarily on changes in the arousal of the people performing mental tasks (e.g. Clites, 1936; Freeman, 1930). Then, Davis (1939), who measured multiple responses simultaneously and had subjects perform a variety of psychological tasks (e.g. mental arithmetic), found that each task was characterized by a bodily focus of muscular activity. Moreover, he found that the amplitude of somatic response decreased as the distance from the mental focus increased.

Research by Davis (1939), Jacobson (1929, 1930, 1931), Shaw (1940), and others suggests that these covert (problem-solving) responses emerge as minuscule

* Requests for reprints should be sent to John T. Cacioppo, Department of Psychology, University of Iowa, Iowa City, Iowa 52242, U.S.A. or to Richard E. Petty, Department of Psychology, University of Missouri, Columbia, Missouri 65211, U.S.A.

discharges along the efferent neuromuscular pathways that would be employed were the covert responses to become overt. This common theme is illustrated nicely by Shaw (1940). He found that the amplitude of preferred arm EMG increased linearly as the size of weights increased; this trend held during the actual lifting of the weights and more interestingly while imagining lifting the weights.

The last half century of research has continued to uncover electromyographic patterns that follow the theme of specificity during covert information processing. For instance: (a) silently reading or listening to prose leads to greater EMG activity of the lips and tongue than listening to music, though both tasks elevate oral EMG activity relative to basal levels (e.g. McGuigan and Bailey, 1969); (b) oral EMG activation during learning and problem solving is dissociated from nonoral muscle and electrodermal responses (cf. Sokolov, 1972); (c) poor readers display greater oral EMG activity when reading than good readers, and both display increased oral EMG when silently reading difficult rather than simple text (e.g. Edfeldt, 1960; Hardyck and Petrinovich, 1970); and (d) reducing the amplitude of the oral EMG response during reading initially impedes comprehension of the material (Hardyck, Petrinovich and Elsworth, 1966; but see McGuigan, 1971).

Of course, a wide variety of mental operations have been subsumed under the label 'covert information processing'. Problem solving, for example, might require sensory (e.g. are the letters in upper-case?) or semantic (e.g. does the word mean . . . ?) analyses; and the answer may be positive or negative. Moreover, the nature of these operations affects memory and subsequent mental operations (e.g. Eysenck, 1978; Kolers and Ostry, 1974; Treisman, 1978). Our major goal in the present study was to examine the effects on specific (task-relevant) and general (task-irrelevant) physiological activity of the type of problem solving analysis (sensory vs. semantic attributes) and decision (yes vs. no). Abstract words (trait adjectives) served as stimuli in the present study; we selected lip EMG as the measure of task-relevant somatic activity and nonpreferred forearm EMG as the measure of task-irrelevant somatic activity. Cardiac activity was also measured because of its previous association to cognitive performance (e.g. Cacioppo and Sandman, 1978; Lacey and Lacey, 1974), and its value as an index of general autonomic response (Lazarus, 1966).

The paradigm selected for this research was borrowed from research in cognitive psychology on encoding operations (Craik and Lockhard, 1972; Craik and Tulving, 1975). Briefly, a subject is instructed by a cue question to focus on a specific feature of a stimulus to solve a problem. Although various features of a stimulus are typically analyzed, sometimes simultaneously (Pavio, 1971; Rogers, 1977), the cued feature analysis generally dominates studies of encoding operations (Nelson, 1978). Further, the more distinctive, extensive, or semantic (i.e. meaningful) the cued analysis, the more durable the consequent memory trace (Craik, 1978, 1979); these effects are especially evident when semantic processes are cued at the time of encoding and retrieval (Morris, Bransford and Franks, 1977; Tulving, 1978). These data have been interpreted as indicating the existence of 'levels' of qualitatively different (though not mutually exclusive) encoding operations (cf. Cermak and Craik, 1978). Thus, cue questions that cause a person to orient on the structural rather than semantic referents of a stimulus are said to elicit 'shallow' rather than 'deep' central processing.

In the present study, we examined oral (lip) and background nonoral/nonlinguistic (nonpreferred forearm) somatic and autonomic (cardiac) activity as a function of processing 'depth'. We expected a semantic orienting task to lead to greater lip EMG activity than a structural task; no such effect was expected for general physiological activity.

2. Method

2.1. Subjects and materials

Deeper, more extensive levels of analysis are involved when determining whether a word describes oneself (a self-referencing task) than when determining whether the letters are printed in upper-case (Rogers et al., 1977). These two orienting tasks served as the experimental manipulations of covert processing. Eight men and eight women with ages ranging from 18 to 22 years served voluntarily in the experiment.

On the basis of pre-tests *, 40 adjectives were selected for use for each subject. Uniquely selected for each subject were 20 adjectives rated as highly self-descriptive and 20 rated as not at all self-descriptive. During the experiment, 10 of each type of adjective were presented in upper-case and 10 were presented in lower-case letters. Additionally, half of each of the four resulting groups of 10 adjectives each were preceded by a visual cue question instructing the subject to determine if the following word was printed in upper-case letters (i.e. shallow structural task), and half were preceded by a cue question instructing the subject to determine if the following word was self-descriptive (i.e. deep self-referencing task). The ordering of the 40 cue questions and target adjectives was determined randomly for each subject, and all stimuli were presented on 2 in. X 2 in. (5.08 cm X 5.08 cm) slides. Finally, the overt response required of the subject was a simple finger pressing of one of two buttons following the removal of each target adjective. One button indicated the subject's response was 'yes' and the other that the response was 'no'. Which button denoted a yes and no response was counter-balanced across subjects. Any observed differences in physiological response and encoding between the tasks would, therefore, seem to be attributable to the depth-of-processing of the stimulus rather than to subject characteristics; to the overt response selected; or to the physical, phonetic, or emotional attributes of the stimulus.

* 120 adjectives were selected from a list of 555 personality trait words that have been rated for likableness by Anderson (1968) to represent a broad spectrum of possible personality characteristics. Several days prior to their participation, each subject rated the self-descriptiveness of each of the 120 adjectives.

2.2. Equipment and procedure

When subjects arrived at the laboratory, they were seated in a comfortable chair that was enclosed in a copper-mesh cage to shield electrical interference. The subject was located in a sound-attenuated room separate from, though adjacent to, the room containing the polygraph. Grass gold-cup (surface) electrodes were attached: (a) just below the apex of the lower lip at each corner of the mouth to measure the EMG activity of the lips and surrounding (speech-related) muscles; (b) over the forearm flexor muscles of the nonpreferred arm to measure the EMG activity of the forearm and surrounding (nonspeech-related) muscles; and (c) over the apex of the lower left rib and right collar bone to measure cardiac activity; a Grass ear-clip electrode was attached to the lobe of the right ear as a ground. The EMG activity was amplified by Physiograph wide-band dc–ac preamplifiers (E & M Instruments Co., Inc.), individually rectified, and summed by an EMG integrator with a time constant of 0.2 sec. The integrated EMG was displayed on the physiograph as a resetting ramp function with a full-scale pen deflection of 40 mm (1 mm = 5 μV) and was transmitted on-line to a laboratory computer, sampled 10 times/sec, and recorded. Cardiac activity was measured beat-by-beat (in msec) with a cardiotachometer (E & M Instruments Co., Inc.) adjusted to detect the R-spike of the cardiac cycle. Finally, each electrophysiological measure was displayed on a Physiograph-Six and was monitored visually throughout the experiment. Data accompanied by gross movements were deleted from the analyses. (The number of such edits did not vary across conditions.)

Following a 5-min adaptation period, subjects responded to eight practice and 40 experimental trials. Each trial consisted of: (a) a cue-question interval – the presentation of a cue question for a variable interval ranging from approximately 5–15 sec (a variable interval was employed to reduce the incidence of the preparatory physiological responses which accompany fixed-interval foreperiods); (b) a 760-msec interval that was initiated by the first R-spike after the preceding interval and during which time the slide changed to the target adjective (data for this interval were not recorded); and (c) a target-adjective interval – the presentation of the target adjective, which was displayed until the onset of the second R-spike in this interval. (The mean duration of exposure of the target adjective – i.e., the two heart beats after slide onset – was 1.67 sec and did not differ as a function of condition.) The subject replied 'yes' or 'no' by pressing one of two buttons during the slide-change for the presentation of the next cue question. During the experimental trials the presentation and timing of the slides and the data-collection process were controlled automatically by a laboratory computer.

Following the 40 experimental trials, the subject was given 2 min to list all of the adjectives that he or she could recall.

2.3. Data reduction

A measure of mean basal EMG activity (in μV) for the lips and forearm was determined for the 10 sec immediately preceding the onset of the first experimental trial. The basal value for each EMG measure was then subtracted from each subsequent mean value of EMG activity displayed during the presentation of the cue question. The decision to subtract the initial basal score from each of the subsequent responses has no effect on the statistical analyses since all comparisons are within-subjects. The adjustment was made, however, to better highlight the size of the responses observed as a function of condition.

Nonparametric analyses were conducted for the electrophysiological data. Overall treatment effects were assessed using the Friedman test, whereas pairwise comparisons were conducted using the Sign Test. A significance level of $p < 0.05$ (two-tailed) was used for each test.

3. Results

3.1. Performance

Examination of the recall data provided support for the notion that when a person sees a word, that word is more likely to be remembered when the person covertly processes its meaning, associations, and personal relevance than when the person focuses primarily on its structural features. Subjects recalled more of the words presented during the self-referencing ($M = 3.66$) than during the structural ($M = 1.39$) task [$F(1, 14) = 50.75$], replicating previous research in the depth-of-processing paradigm (e.g. Rogers et al., 1977). No other effect or interaction was statistically reliable.

3.2. Electromyographic activation

3.2.1. Effects on lip EMG activity of task and interval

Fig. 1 displays the median change from baseline of lip and nonpreferred forearm EMG activity as a function of orienting task and interval. As is evident in Fig. 1, the self-referencing task elicited greater lip EMG activity than the structural task in both the cue question (57.2%) and target adjective (57.6%) intervals ($p < 0.05$ by the Sign Test). Pairwise comparisons (using the Sign Test) among the scores displayed in the top panel of fig. 1 indicated that there was significantly greater lip EMG activity present when covert processing was directed toward the meaning of the stimulus (i.e. cue-questions or self-referencing target-adjective task) than when it was focused on the sensory features of the stimulus. Moreover, this activation was greatest in response to the cue-question for the self-referencing task (all ps < 0.05).

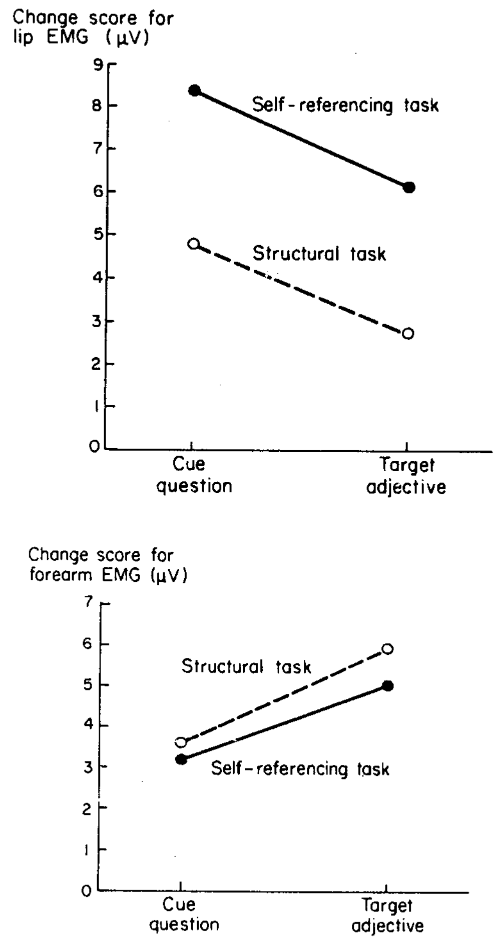

Fig. 1. Median change from baseline for EMG activity from the lip (top panel) and nonpreferred forearm (bottom panel) as a function of orienting task and interval.

3.2.2. Effects on nonpreferred forearm EMG activity of task and interval

In the lower panel of fig. 1, we have displayed the median EMG activity of the nonpreferred forearm as a function of task and interval. The most striking evidence for specificity of EMG activity is immediately apparent upon inspecting fig. 1: lip and nonpreferred forearm EMG responses were affected very differently across the intervals by the orienting tasks. Several previous studies have found a slight inhibition of the EMG activity of irrelevant muscle-groups preparatory to the reception and processing of a stimulus (McGuigan and Boness, 1975; Obrist, Webb, Sutterer and Howard, 1970). Similarly, inspection of fig. 1 shows a nonsignificantly lower level of nonoral/nonlinguistic EMG activity preparatory to the presentation of the target adjective. Finally, both statistical analyses and inspections of fig. 1 indicate that the nature of the orienting task had absolutely no effect on nonpreferred forearm EMG activity.

3.2.3. The additional and interactive effects of decision on lip and nonpreferred forearm EMG activity

The effects of the decision (yes vs. no) and type of orienting task on the median changes for lip and nonpreferred forearm EMG activity during the processing interval are displayed in the left and right panels of fig. 2. As can be seen in the left panel of fig. 2, deciding that the target adjective was not self-descriptive elevated lip EMG activity relative to each of the structural decisions ($p < 0.02$ for the structural task – 'yes' response: $p < 0.005$ for the structural task – 'no' response; all comparisons by the Sign Test). Deciding that the target adjective was self-descriptive enhanced slightly, though not significantly, the lip EMG activity compared to each of the structural decisions. Comparable analyses of nonpreferred forearm EMG activity revealed no such pattern of activation. As suggested by the right panel of fig. 2, none of the pairwise comparisons was statistically significant.

3.3. Cardiac activity

Mean heart rate for the two beats preceding through the end of the target-adjective interval is displayed in fig. 3. An analysis of variance revealed that heart rate changed across beats [$F(4, 56) = 4.98$]. No other effects or interactions were statistically significant.

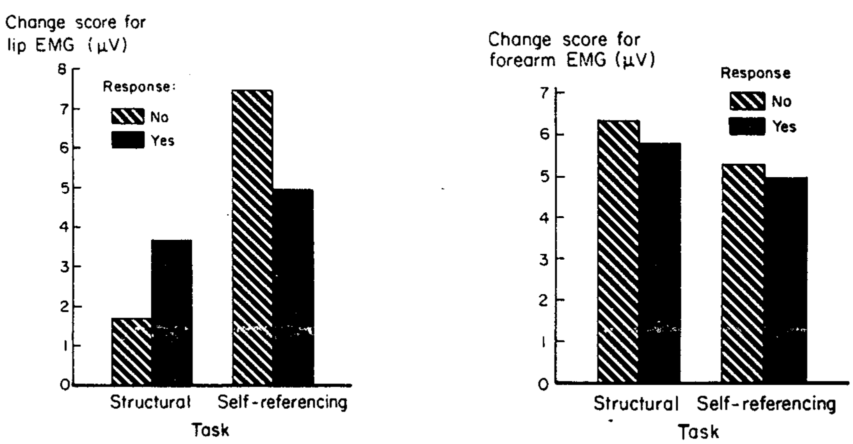

Fig. 2. Median change from baseline for EMG activity from the lip (right panel) and nonpreferred forearm (left panel) as a function of orienting task and decision.

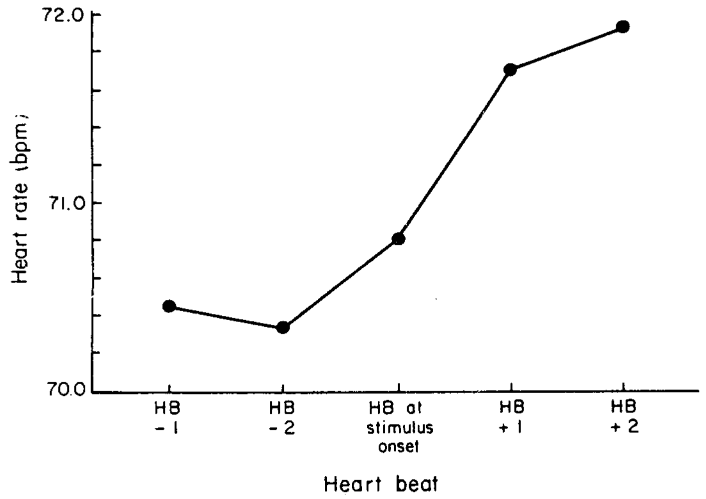

Fig. 3. Mean heart rate for the two beats preceding onset through termination of the target-adjective interval.

4. Discussion

The orienting tasks of self-reference and orthographic structure predictably altered the subsequent retention of the target words: More deeply processed words yielded more durable memory traces. Additionally, we found that when subjects were cued to focus on the meaning and personal significance of a word they emitted higher amplitude somatic activity from the speech musculature than when they were cued to orient on visual features of the word.

Importantly, the responses from the general musculature monitored over the nonpreferred forearm and from the autonomic system indexed by mean beat-by-beat heart rate were clearly dissimilar to those observed for speech-related somatic activity (see figs. 1 and 3). Increased nonpreferred forearm EMG and cardiac activity were greatest when subjects behaviorally expressed their decision, but these responses were neither differentiated by the depth-of-processing stimulated by the tasks nor were they indicative of the nature of the decision. At least for the intellective tasks employed here, changes in general somatic and cardiac activity appear to have served the biological needs created by motoric responses (Obrist et al., 1970) rather than subtle differences in encoding processes (e.g. Cacioppo and Sandman, 1978). Hence, as data from Davis (1939), Shaw (1940) and McGuigan (1978) suggest, there appear to be both: (a) subtle and specific modulations of task-relevant physiological activity that reflect covert operations of the central information processor; and (b) general adjustments of comprehensive physiological systems to maintain homeostatic biologic conditions.

The latter conclusion has been amply documented in previous research (cf. Obrist et al., 1974). Perhaps the most interesting finding of the present study, then, is the former inference. Evidence for it from this study is displayed in the top panel of fig. 1, which graphically represents the intensity of lip EMG mirroring the extent to which semantic features were involved in encoding operations. Further evidence for this cognitive-somatic coupling was obtained in the analyses of lip EMG activity as a function of response (i.e. yes vs. no). Recent evidence reviewed by Craik (1979) suggests that determining yes–no responses requires a series of contingent analytic operations. Blatantly inaccurate information can be signalled quickly with little associative branching and processing, but detecting less obviously inaccurate information requires extensive associative analysis. In terms of the present study, the stimuli for the structural questions (i.e. determining if the word is printed in upper-case letters) produced obvious cues and could be rejected or accepted quickly since each letter of the word was either capitalized or not. On the other hand, stimuli for the self-referencing questions (i.e. determining if the word was self-descriptive) required more extensive analysis, since all of the stimuli were common trait adjectives used to describe personal characteristics and dispositions. Further, negative responses to this semantic task require the additional cognitive effort of either ruling out a number of traits or translating the stimulus trait into its opposite and searching for this derived trait. Accordingly, we found that lip EMG amplitude was essentially equal for no and yes responses for the structural task, but it was slightly greater for no, compared to yes responses for the self-referencing task. This pattern of effects appears attributable to the extent rather than duration of somatic involvement since target-adjective presentations and response times were not significantly different across the yes–no conditions.

In sum, maximal nonpreferred forearm EMG and cardiac activity accompanied subjects' motoric response, whereas lip EMG activity was maximal preparatory to the self-referencing orienting task; moreover, only lip EMG activity differentiated the depth-of-processing of the orienting tasks. These results are consistent with the notion that covert (information processing) responses recruit abbreviated efferent discharges along the neuromuscular circuits that would necessarily be involved were the covert responses to become overt.

Acknowledgements

We owe thanks to Charles W. Snyder for his valuable technical assistance, and to Mary K. Braccio and Maria Calibresse for serving as experimenters. This work was supported by National Science Foundation Grant Number BNS 78-18667 to the first author.

References

Anderson, N. (1968). Likableness ratings of 555 personality-trait words. Journal of Personality and Social Psychology, 9, 272–279.

Cacioppo, J.T. and Sandman, C.A. (1978). Physiological differentiation of sensory and cognitive tasks as a function of warning, processing demands, and reported unpleasantness. Journal of Biological Psychology, 6, 181–192.
Cermak, L.S. and Craik, F.I.M. (Eds) (1978). Levels of Processing in Human Memory. Erlbaum: Hillsdale, N.J.
Clites, M.S. (1936). Certain somatic activities in relation to successful and unsuccessful problem solving. Part III. Journal of Experimental Psychology, 19, 172–192.
Craik, F.I.M. (1978). Levels of processing: Overview and closing comments. In: Cermak, L.S. and Craik, F.I.M. (Eds). Levels of Processing in Human Memory. Erlbaum: Hillsdale, N.J.
Craik, F.I.M. (1979). Human memory. In: Rosenzweig, M.P. and Porter, L.W., (Eds), Annual Review of Psychology Vol. 30. Annual Reviews, Inc: Palo Alto, Calif.
Craik, F.I.M. and Lockhart, R.S. (1972). Levels of processing: A framework for memory research. Journal of Verbal Learning and Verbal Behavior, 11, 671–684.
Craik, F.I.M. and Tulving, E. (1975). Depth of processing and the retention of words in episodic memory. Journal of Experimental Psychology: General, 104, 268–294.
Davis, R.C. (1939). Patterns of muscular activity during 'mental work' and their constancy. Journal of Experimental Psychology, 24, 451–465.
Edfeldt, A.W. (1960). Silent Speech and Silent Reading. University of Chicago Press: Chicago.
Eysenck, M.W. (1978). Depth, elaboration, and distinctiveness. In: Cermak, L.S. and Craik, F.I.M. (Eds). Levels of Processing in Human Memory. Erlbaum: Hillsdale, NJ, 89–118.
Freeman, G.L. (1930). Changes in tonus during completed and interrupted mental work. Journal of General Psychology, 4, 309–334.
Golla, F.L. (1921). The objective study of neurosis. Lancet, 2, 115–122.
Hardyck, C.D. and Petrinovich, L.F. (1970). Subvocal speech and comprehension level as a function of the difficulty level of reading material. Journal of Verbal Learning and Verbal Behavior, 9, 647–652.
Hardyck, C., Petrinovich, L. and Elsworth, D. (1966). Feedback of speech muscle activity during silent reading: Rapid extinction. Science, 154, 1467–1468.
Jacobson, E. (1929). Progressive Relaxation. University of Chicago Press: Chicago.
Jacobson, E. (1930). Electrical measurements of neuromuscular states during mental activities, I: Imagination of movements involving skeletal muscle. American Journal of Physiology, 91, 567–608.
Jacobson, E. (1931). Variation of specific muscles contracting during imagination. American Journal of Physiology, 96, 115–121.
Kolers, P.A. and Ostry, D.J. (1974). Time course of loss of information regarding pattern analyzing operations. Journal of Verbal Learning and Verbal Behavior, 13, 599–612.
Lacey, J.I. and Lacey, B.C. (1974). On heart rate responses and behavior: A reply to Elliott. Journal of Personality and Social Psychology, 30, 1–18.
Lazarus, R.S. (1966). Psychological Stress and the Coping Process. McGraw Hill: New York.
McGuigan, F.J. (1971). External auditory feedback from covert oral behavior during silent reading. Psychonomic Science, 25, 212–214.
McGuigan, F.J. (1978). Cognitive Psychophysiology: Principles of Covert Behavior. Prentice-Hall: Englewood Cliffs, NJ.
McGuigan, F.J. and Bailey, S.C. (1969). Covert response patterns during the processing of language stimuli. Interamerican Journal of Psychology, 3, 289–299.
McGuigan, F.J. Boness, D.J. (1975). What happens between an external stimulus and an overt response? A study of covert responses. Pavlovian Journal of Biological Science, 10, 112–119.
Morris, C.D., Bransford, J.D. and Franks, J.J. (1977). Levels of processing versus transfer appropriate processing. Journal of Verbal Learning and Verbal Behavior, 16, 519–533.
Nelson, D.C. (1978). Remembering pictures and words: Appearance, significance, and name.

In: Cermak, L.S. and Craik, F.I.M. (Eds). Levels of Processing in Human Memory. Erlbaum: Hillsdale, NJ, 45–76.

Nelson, T.O. (1977). Repetition and depth of processing. Journal of Verbal Learning and Verbal Behavior, 16, 151–171.

Obrist, P.A., Black, A.H., Brener, J. and DiCara, L.V. (1974). Cardiovascular Psychophysiology. Aldine: Chicago.

Obrist, P.A., Webb, R.A., Sutterer, J.R. and Howard, J.L. (1970). Cardiac deceleration and reaction time: An evaluation of two hypotheses. Psychophysiology, 6, 693–706.

Rogers, T.B. (1977). Self-reference in memory: Recognition of personality items. Journal of Research in Personality, 11, 295–305.

Rogers, T.B., Kuiper, N.A. and Kirker, W.S. (1977). Self-reference and the encoding of personal information. Journal of Personality and Social Psychology, 35, 677–688.

Shaw, W.A. (1949). The relation of muscular action potentials to imaginal weight lifting. Archives of Psychology, 35, 50.

Sokolov, A.N. (1972). Inner Speech and Thought. Plenum Press; New York.

Triesman, A. (1978). The psychological reality of levels of processing. In: Cermak, L.S. and Craik, F.I.M. (Eds). Levels of Processing in Human Memory. Erlbaum: Hillsdale, NJ, 301–330.

Tulving, E. (1978). Relation between encoding specificity and levels of processing. In: Cermak, L.S. and Craik, F.I.M. (Eds). Levels of Processing in Human Memory. Erlbaum: Hillsdale, NJ, 405–428.