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A Neuromuscular Model of Mind With Clinical and Educational Applications

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This paper is a summary and extension of almost four decades of research directed toward an explication of the human mind. To achieve a precise, testable proposition that defines mind, I follow a historically rich tradition of materialism. First, an empirical basis is established wherein electropsychologically measured events from the brain, eyes, somatic and speech musculature occur almost simultaneously during a variety of cognitions. The inference is that these covert reactions form components of neuromuscular circuits governed by cybernetic principles. Conversely, when the striated musculature is totally inactive, cognitions are absent. The conclusion is that muscular components of the circuits are necessary for cognitions. An explication of the human mind emerges as the selective interaction of bodily systems to (1) generate contents of mind (cognitions) and (2) to program covert and overt behavior. Clinical and educational applications follow.

The history of the human mind is bewilderingly complex and sufficiently garbled that many scientists have avoided the area; some have devoted their energies elsewhere while others have asserted that mind constitutes a pseudoproblem. However, the concept of mind is so deeply ingrained in all human cultures that it cannot be ignored. Since psychology is the (empirical) science specialized for understanding mind, psychologists owe it to the society that provides their support to continue efforts for that purpose — psychologists did sign such a scientific contract in 1879. In this regard, it is reassuring to note that psychologists are few who have avoided the use of mentalistic terms — certainly the staunchest behaviorists Watson, Hunter, Hull, Tolman, Skinner have not, as I shall develop.

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My goal is to explicate, in Carnap's sense, the common sense notion of mind — to replace this ambiguous term from the vernacular with a precise, testable proposition. In approaching the problem, I join those of the past and present who follow the philosophical position of materialistic (physicalistic) monism. The thinkers who conceived of a functioning mind as having a physical (spatial/temporal) location in the body are sufficiently numerous that I can only sample a few, but that can serve to develop a proper contemporary perspective.

Physical ("materialistic") conceptions of mind. Aristotle referred to the seat of life as in the heart, the brain being a sort of "refrigerator" for the body. Egyptians localized thought in the heart but judgement was placed in the head or kidneys. Descartes established the notion of a conscious mind with the brain as its special organ, a position followed by Cabanis and Hartley. As Boring (1929) pointed out, however, it was Gall and his phrenology that established in everyday thinking the notion that the brain is *the* organ of mind. In contrast, the influential Alexander Bain espoused a holistic position that "the organ of the mind is not the brain by itself; it is the brain, nerves, muscles, and organs of sense . . ." (cited by Holt, 1937, pp. 38–39). Bain added that thought, reminiscence and emotions could not be sustained without communications between the brain and the rest of the body, the organs of sense and movement. Sechenov's (1863/1935) materialism advocated the objective study of mental activity as reflexes of the brain and muscle movement; the great Russian physiologists Pavlov, Bechterev and others elaborated Sechenov's conception. The early behaviorists followed in the Russian tradition such as in Watson's (1930) ascribing thought as an activity of the entire body wherein conditioning was important (it is often but erroneously thought that Watson defined thinking strictly as subvocal behavior and only of the larynx at that). Neobehaviorists such as Tolman and Hull continued the materialistic tradition as in Hull's (1962) long-term research objective to understand "the higher mental processes."

It is well here, then, to correct a common misconception that behaviorists ignored the mental concepts that psychology had inherited from philosophy and from the vernacular. What the behaviorists actually did was to materialistically redefine (translate) mentalistic concepts. For instance, Watson objectively redefined "consciousness" as the behavior of naming one's internal and external environments, a position that closely resembles Skinner's verbal concept of tacting. Watson's redefinition of thinking was a landmark accomplishment for several reasons. One was that verbal behavior became a physical phenomenon, no different in principle from other kinds of responses. More generally, as Bergmann (1956) pointed out, Watson's theory gave thought a behavioral existence — thinking and other mentalistic terms became physical phenomena; as a consequence, mental ghosts could be exorcised from psychology.

In his analysis of mind, Skinner held that "mind means little more than 'do.' . . . Cognitive processes are behavioral processes; they are things people do" (1989, p. 23). He added that cognitions are behavioral because they originate as behaviors, just as Osgood (Osgood and McGuigan, 1973) elaborately developed with his meaning reaction. Skinner thus did not really argue against mind, but against a nonphysical concept of mind espoused by some cognitive psychologists as a determiner of behavior. Eschewing dualism of a mental world different from a physical world, Skinner held that there is nothing under the skin but the organism itself. Skinner extensively considered mental phenomena as private events. His final (1990) publication entitled "Can Psychology be a Science of Mind?" is evidence of his long standing concern with the problem. Following the early behaviorists, Skinner offered response definitions of mentalistic terms such as that ". . . thought is simply behavior — verbal or non-verbal, covert or overt. It is not some mysterious process responsible for behavior but the very behavior itself. [A behavioral approach, he held, is] . . . most appropriate to the study of what has traditionally been called the human mind" (Skinner, 1957, in McGuigan, 1966, pp. 17–18).

In assessing these physicalistically oriented positions on mind, the dominant one (certainly dominant in lay thinking) is that the mind is in the brain, period! The alternative, so eloquently espoused by Bain and others is that mind is a function of the entire person, including the brain. Pythagoras implied such a holistic position when he said that the brain is the chief organ of mind.

Two physical models. In his classic textbook, Dashiell (1949) depicted these two models, historically labeled the central versus peripheral positions. Essentially, the central position holds that thought occurs exclusively in the brain while the peripheral position holds that interactions between the brain and the muscles generate thought. However, "peripheral" is a misnomer — "holistic" is a better term in that it connotes that systems other than peripheral ones (the central nervous system in particular) are also involved. The centralist position has been referred to as the Donovan's brain theory, based on the story of keeping only the brain of the business man Donovan alive to think and preside over his empire after his death. Each position has an extended history weaving throughout psychology, as in controversies about mechanisms of cognition and conditioning (McGuigan, 1978, 1994). One could therefore commence efforts to explicate mind through either a central or a holistic strategy and bring the relevant data to bear on the issue. For a central strategy, one would seek data relevant to the proposition that the mind is in the brain, and only in the brain. The alternative is to collect data on relevant functions of the brain and also contributions of other systems of the body. What are the consequences of these two strategies?

If one follows the brain-only position and it turns out to be the true one, explication would be achieved. An isolated brain by itself could think, as with Donovan's brain. However, if the brain-only position is false, we would fail to understand mind. On the other hand, by following the holistic strategy, one cannot fail to achieve truth. That is, if the brain-only position turns out to be true, the holistic strategy would find that out. But if the holistic position turns out to be true, only the holistic strategy would discover that.

In short, the optimal strategy is to seek mind wherever it might be within a person; the holistic strategy would thereby not be restricted a priori to studying but a single psychophysiological system, even if it is the magnificent brain. The optimal strategy is the one that is flexible and empirical, avoiding myopia. However, the growing field of neuroscience focuses on the brain, though some neuroscientists do pay lip service to a holistic position, maintaining somewhat of a perspective that the rest of the body interacts with the brain. One even held that "'mind' is an emergent property of the functioning of the brain (the latter being [bewilderingly] defined . . . to include the peripheral nervous system, organs and muscles)" [anonymous statement furnished in a personal communication from Cacioppo, May 16, 1996]. However, seldom in their research do neuroscientists actually include peripheral measures, especially of muscle activity, in conjunction with their study of brain events.

Electrical measurements of cognition. The most frequently used method for studying covert (versus overt, McGuigan, 1994) phenomena generated by systems that constitute the organism is to electrically measure them, a field that Ralph Hefferline termed "electropsychology." Hundreds of such empirical studies were summarized, analyzed, evaluated and classified in perhaps the most methodologically incisive and inclusive review of data covering about a century (McGuigan, 1978); they implicated covert speech, somatic, ocular, and brain reactions during a wide variety of cognitive activities. It was established that covert *speech* behavior occurs during subvocalization, auditory dreams, verbal mediation, auditory hallucinations, cursive writing, memory, learning, etc. Localized covert *somatic* responses were measured during such cognitive activities as problem solving, imagination, silent reading, speech perception, learning and nocturnal dreams. Electrical measurement of *eye* activity was intimately related to such cognitive activities as imagination, problem solving, answering questions, memory, hypnotic dreams, sensory deprivation and nocturnal dreams. Similarly, electrical measures of *brain* processes were recorded while performing mental arithmetic, learning, imagination, silent reading, speech perception and various thought tasks. With methodologically demanding criteria it was established that each electrically measured phenomenon (speech and somatic muscle, eye and brain events) was uniquely related to each particular cognitive event. For example, one criterion to establish these unique relationships was that control measures of events from elsewhere in the body were not modified during the specific cognitive activity. Thus, the uniquely implicated psychophysiological events were not simply components of general arousal activity. Instead, each brain, eye, speech and somatic muscle reaction must have intimately participated in the generation of the cognitive activity. An example is from McGuigan, Culver, and Kendler (1971), in which amplitude of tongue EMG significantly increased only for the group of subjects who solved a verbal mediation problem and the increase was significantly greater than for the other two (control) groups. Similarly, heightened arm activity (right versus left) occurred during the solution of a directional, non-verbal mediation problem by a nonoral mediation control group. Both mean tongue and arm responses were respectively large relative to each other and to a non-mediation control condition. Thus, during problem solving, we differentially use our striated muscles variously in the body, depending on the linguistic or non-linguistic demands of the problem.

While the data cited above indicate that all of the four categories of events occur selectively during any given cognitive activity, seldom have they all been measured in a single study. In one such study it was found that a number of disparate covert psychophysiological events during a specific thought occurred almost simultaneously, i.e., within but a few milliseconds of each other. While the subjects silently answered questions as yes or no, covert events were detected in the brain, non-active arm, lips, neck and eyes (McGuigan and Pavek, 1972). Rather than being independent, those events must have been related; consequently, they fit a model of components of complex neuromuscular circuits that reverberate during cognitive processing (McGuigan, 1978). Furthermore, a model was advanced holding that those circuits function according to cybernetic principles (McGuigan, 1994). But specifically, how do speech, eye and other muscles interact with circuits in the brain to generate cognitive activities? To answer this question I have given a priority to linguistic phenomena.

Speech muscle interactions with the brain. Some of our great thinkers have reasoned that covert speech responses act in concert with the brain to generate mental processes. For instance, Pavlov held that the "basic component of thought consists of kinesthetic impulses which pass from the speech apparatus into the cerebral cortex" (in Novikova, 1961, p. 210). Since the kinesthetic impulses originate in the speech apparatus, the information carried in them must be verbal in nature. But, what kind of verbal information is that?

In the Osgood and McGuigan (1973, 1978) studies on what Osgood termed "The Gilbert and Sullivan Effect," heightened tongue electromyograms were recorded during perceptual clarification of auditorially unclear Gilbert and Sullivan operettas. The conclusion was that coding carried in neural feedback from the tongue while reading the words was responsible for the perceptual clarification. However, since the same conclusion was reached in the second experiment using Finnish Language that was meaningless to the subjects, the verbal coding from the tongue itself must be meaningless; still the coding could be responsible for determining meaning. Further research indicated that those conditions are satisfied by a phonetic code. In particular, McGuigan and Winstead (1974) found that there is a discriminative relationship between patterns of speech muscle behavior and the phonemic system during (thoughts that occur in) silent reading. For instance, electromyographically measured covert lip responding was relatively large when subjects silently read labial words like "Bob" and "Mom" (speech movements of the lips are primarily used when such labial words are overtly spoken). Similarly, the tongue was especially active when silently reading lingual alveolar ("tongue") words like "Dad" and "None." More particularly, mean lip responding significantly increased by 22.7 μv over resting baseline while reading bilabial prose but only increased by 2.2 μv (not significant) while reading lingual alveolar material. In contrast, tongue EMG increased significantly over baseline while reading lingual alveolar prose by 30.6 μv but while reading bilabial material a non-significant increase was only 8.5 μv. Covert responding of the preferred arm significantly increased during both kinds of reading. The fact that the nonpreferred arm and right leg did not significantly change, suggested that the preferred arm, as with the speech musculature, served a linguistic function (c.f., McGuigan and Bailey, 1969a). This discriminative relationship between locus of speech muscle responding and the phonemic system has been confirmed several times (Davenport, 1976; McGuigan, 1978; also see e.g., Locke and Fehr, 1971).

How might the speech muscles participate in the generation of a phonetic code? A model that I have followed (McGuigan, 1978) commences as in Figure 1, where the speech musculature is represented in three dimensions with a cell for each muscle fiber location. Since muscle fibers obey the all-or-none law, their status can be represented as on or off in binary arithmetic. The unique, momentary status of the composite of muscle fibers for the lips, for instance, may generate afferent volleys of neural impulses coded for that specific status at that instant in time. That information then reverberates extremely rapidly along neuromuscular circuits between these muscles and the linguistic regions of the brain. Such muscle and contingent neural events happen within but a few milliseconds of each other. This extremely complex processing involves billions of neural and muscle cells functioning in parallel channels that are presumed to follow negative feedback principles, e.g., the amount of information fed back from the muscles thereby controls the amount of mental activity (see McGuigan, 1994, pp. 20–21).

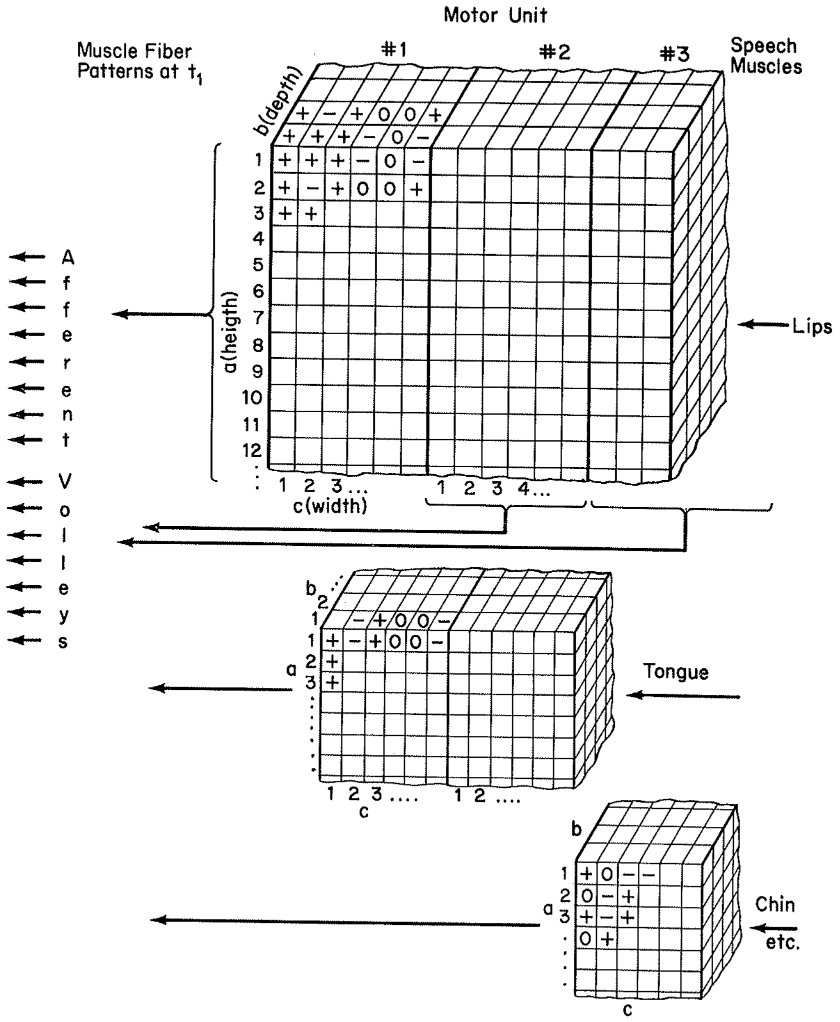

Figure 1: Speech muscle fibers are represented in binary coding as being contracted (plus) or relaxed (minus); O indicates absence of a functional cell in that location. Unique muscle fiber patterns generate linguistically coded afferent neural volleys as a function of time. From F.J. McGuigan, *Cognitive Psychophysiology: Principles of Covert Behavior*. Prentice Hall, 1978, Englewood Cliffs, New Jersey.

As further developed by McGuigan (1978), the changing status of the three dimensional matrix in Figure 1 representing each of the speech muscles can generate distinctive features (Jacobson and Halle, 1971) as a function of time in a language recipient (see Figure 2). For instance, the distinctive feature #7 of being tense (+) or lax (–) in Figure 2 determines whether the instance of a phoneme is perceived as /p/ or /b/. Thus, if the lip muscles generate coding that carries the distinctive features for tense, /p/ is coded. If /p/ is followed by distinctive features that are responsible for the instances /i/ and /t/, the word "pit" is comprehended. However, if the lax feature is coded to yield /b/, the word "bit" is processed. This model well fits the requirements specified by the "Gilbert and Sullivan" and the McGuigan and Winstead (1974) studies. That is, the speech muscles can thereby function in the generation of a phonetic code that is meaningless but still can determine meaning, such as whether one perceives "pit" or "bit."

To specifically test this model, subjects were asked to silently read in randomized order tachistoscopically presented slides of the letter "T" and the letter "P" as instances of the phonemes /t/ and /p/ (McGuigan and Dollins,

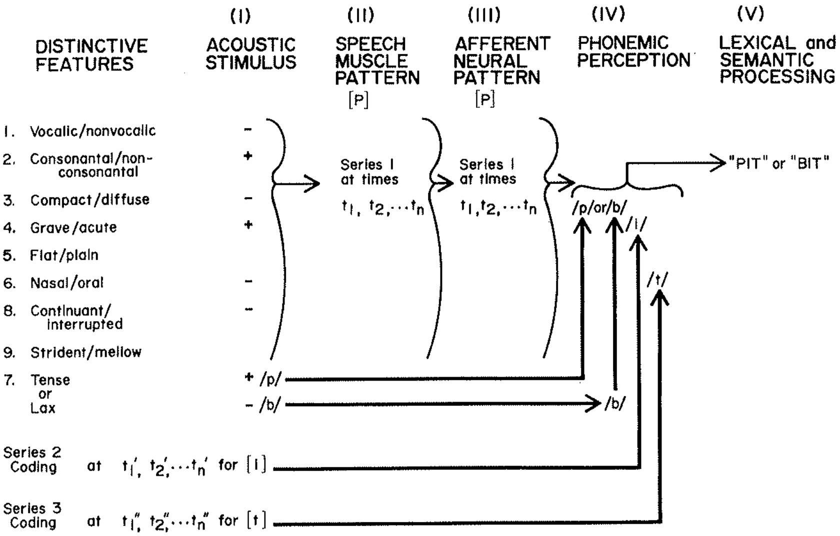

Figure 2: Distinctive features matrix to indicate coding processes within a listener or reader as a series of acoustic language stimuli impinge. Jacobson and Halle (1971) showed how acoustic stimuli may be coded according to the 9 distinctive features identified to the left. Extending their model to the recipient, the coded stimulus that impinges evokes a speech muscle pattern with that information. Within the recipient, that afferant neural information interacts with the linguistic regions of the brain, leading to phonemic perception and then lexical and semantic perception (see Figure 3). From F.J. McGuigan, *Cognitive Psychophysiology: Principles of Covert Behavior*. Prentice Hall, 1978, Englewood Cliffs, New Jersey.

1989). Consonant with the results of McGuigan and Winstead (1974), it was found that the speech muscles also discriminatively respond during the processing of individual letters that represent instances of phonemes. In particular, mean total power measures of covert responding of the lips was significantly greater during the silent reading of "P" relative to silently reading "T" or viewing a control slide; however lip responding did not significantly change when reading the letter "T." Similarly, the tongue was significantly more active during the silent reading of the letter "T" relative to reading "P" or a control slide and the tongue was not significantly active while reading "P."

In short, the speech muscles discriminatively respond to both words and letters, and extremely rapidly too — in my laboratory, Davis (1983) measured covert response latencies to tachistoscopically presented words of 44 ms and 85 ms at the lips and tongue respectively. Note that there is covert speech prior to the generally accepted perceptual latency for about 200 ms, again implicating that activity as part of the semantic process. Such highly differentiated activity of the speech musculature suggests that the generation of phonetic coding is the result of transducing incoming visual linguistic information. Coding for incoming speech need not be transduced. In either case, the afferently carried code interacts, by the model in Figure 3, with the linguistic regions of the brain and the speech (and other) muscles within the numerous neuromuscular circuits. As this enormous amount of information is processed extremely rapidly, we comprehend what is being read or spoken (McGuigan, 1978, 1994; McGuigan and Dollins, 1989). Other circuits are simultaneously activated such that the arms, for instance, are engaged in cognitive processing as cited in several studies herein.

Is striated muscle actually capable of generating linguistic codes? Linguistic components of thought, we have held, depend on the generation and transmission of a refined phonetic code to and from the brain. But a critical question is whether the speech (and other) muscles are anatomically and physiologically capable of such highly differentiated functioning as depicted in Figure 1. That is, some muscle fibers need to contract as other nearby ones simultaneously lengthen while yet other close-by muscle fibers are contracting. Various combinations of highly differentiated contractions and lengthening, like the actions of a myriad of keys on a gigantic piano, are required to send precisely coded feedback information to and from the language regions of the brain. Can the speech musculature really do that?

The evidence suggests an affirmative answer, as in the previously cited "Gilbert and Sullivan" studies. Furthermore, Sussman (1972), in an article appropriately entitled "What the Tongue Tells the Brain," considered the nature of the information carried by the afferent pathways from the tongue. He concluded that "Not only can the higher brain centers be kept informed

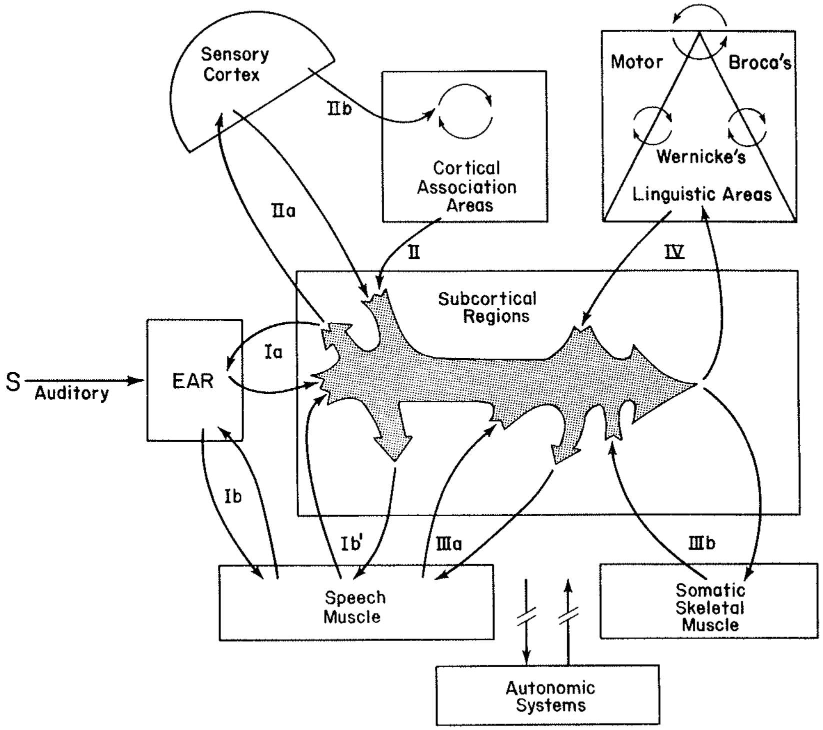

Figure 3: Hypothesized neuromuscular circuit classes that reverberate as visual and auditory linguistic stimuli are internally processed. The immediate point is that the speech musculature generates a phonetic code that interacts by circuit classes IIIa and IV with the linguistic regions of the brain to generate meaning. Interactions of other circuits are developed in J.F. McGuigan, *Cognitive Psychophysiology: Principles of Covert Behavior.* Prentice Hall, 1978, Englewood Cliffs, New Jersey.

as to the *initiation* of a high-speed consonantal gesture of the tongue but also as to the *attainment* and subsequent *release* of that gesture . . . . The neuromuscular system of the tongue has been shown to be a built-in feedback system that can signal the length and rate of movement of a muscle" (p.266). Consequently ". . . it is logical to assume that the *afferent discharge pattern emanating from the tongue should contain high-level distinctive information*. Such discriminative information can be provided by the differential frequency discharge patterning of the muscle spindles due to the orientation of the extrafusal fibers relative to the direction of movement" (p. 267, italics mine).

Other striated muscle is also capable of highly differentiated responding. The eye musculature, so important in the generation of visual imagery (McGuigan, 1992), is a case in point. In Figure 4 we can note how the eye differentially responds when subjects silently answer questions as "yes" or

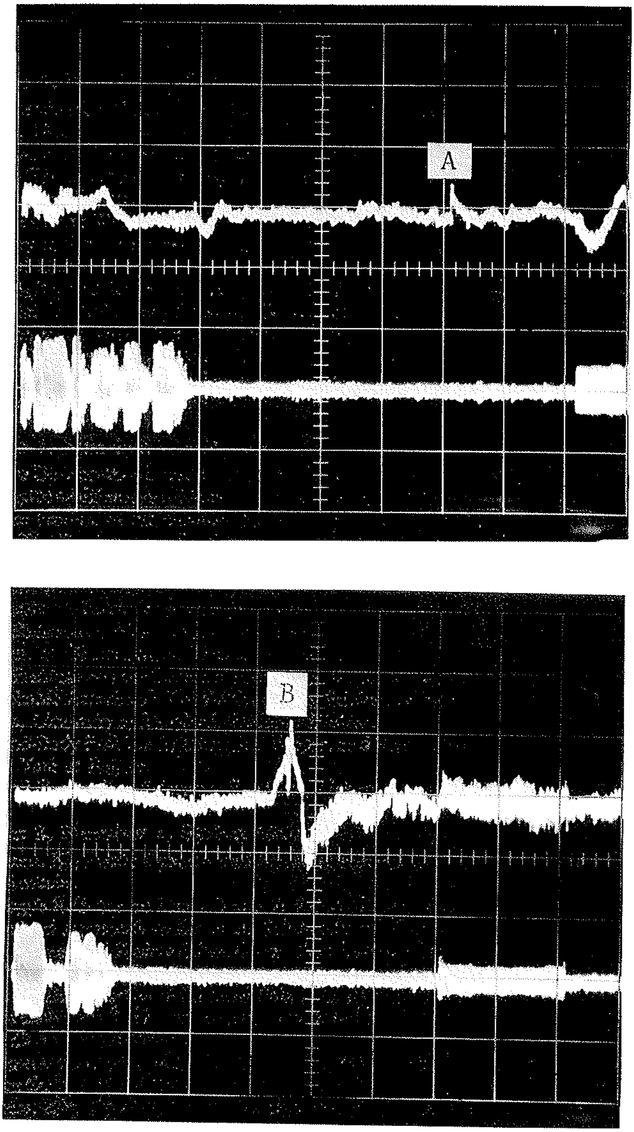

Figure 4: Illustrations of highly differentiated responding of the eyes. The covert response labeled A is an instance of a significantly shorter duration when the subjects silently thought "no" than when the subjects silently thought "yes" (B). In the time lines at the bottom, transduced sound at the left is when a subject was asked a question and a silent answer period followed until the event marker to the right that indicated the subject's answer. From McGuigan, F.J., and Pavek, G.V. (1972). On the psychophysiological identification of covert nonoral language procesesses. *Journal of Experimental Psychology*, 92, 237–245.

"no." The covert responses were differentially detected by a computer when the subjects silently thought "no" vs. "yes" and were not observable by the naked eye.

Three classes of cognitive neuromuscular circuits. While linguistic components of cognition have been our priority, cognitive processes obviously have other components too. The class that we have considered so far involves the speech musculature as it interacts principally with the linguistic regions of the brain. As neural impulses carrying phonetic coding reverberate within the circuits, we experience the linguistic components of our thoughts (cognitions, etc.). This cognitive activity has been referred to as speech imagery (Jacobson 1938; McGuigan, 1994). Similar circuits reverberate between the eyes and eye musculature in conjunction with visual and other regions of the brain to generate visual aspects of our cognitions (visual imagery), as in Figure 4. Differential reactions throughout the striated musculature function in neuromuscular circuits with somasthetic and other regions of the brain to generate experiences of activity of localized regions of our bodies (somatic imagery), as for instance in the previously cited mediation study of McGuigan et al. (1971). I am here limiting considerations of cognitions to these classes of neuromuscular circuits, the muscular covert response components of which have been objectively recorded. A complete explication of mental activity may well include other components such as circuits coded for emotional and evaluative phenomena (McGuigan, 1978).

To illustrate objectively recordable psychophysiological response patterns, consider a thought that one would have about a football. This would involve circuits between the brain and: (A) speech muscles (for speech imagery) as one covertly subvocalizes "football"; (B) the eyes (to generate a visual football image); and (C) [leg] muscles for somatic imagery as one covertly kicks the football. In short, the contents of our cognitive activities include the relative contributions of these three kinds of imagery and the specific cerebral engrams retrieved as these three classes of circuits reverberate. While all three kinds of imagery are usually present in cognitive activities, sometimes we only process information in one or two of these categories; congenitally blind and/or deaf individuals are always thereby restricted.

When can we be conscious of cognitions? One possibility is that awareness of mental processes occurs when circuits that engage the speech muscles are activated so that the linguistic information thereby generated can allow verbalization about such cognitions (McGuigan, 1994). As Skinner (1989) held, all cognitions are unconscious — they only become conscious on proper demand, which is when we can talk about them. But what about visual and somatic cognitions that lack circuits involving the speech muscles? Presumably one can have visual and somatic cognitive experiences on which one cannot report, which is how Watson defined the unconscious. So, there may be two classes of unconscious cognitions: those that we can "demand" into consciousness to verbalize them and those that we cannot. Only in the former can we invoke circuits that involve covert speech behavior. Yet, all private events (cognitions) can in principle become public through the methods of psychophysiology. Perhaps even subjective experiences of a dog's dreams could be made public by feeding relevant psychophysiological signals into a readout system, as developed by McGuigan (1978, see Chapter 10).

Systematic Manipulation of the Striated Musculature

1. *Clinical applications*. Numerous therapeutic applications follow from a neuromuscular model of mind, as abundantly developed by Edmund Jacobson in his seven decades of clinical practice and scientific research. With regard to mental processes, his extensive research led him to conclude:

> All the subjects and patients who attained high skill in progressive relaxation spontaneously arrived at, and agreed in, their conclusions regarding psychological activities. With visual imagery there is . . . tenseness in the muscles of the ocular region . . . . With complete ocular relaxation, the image disappears . . . . Motor or kinesthetic imagery likewise may be relaxed away. "Inner speech," for instance, ceases with progressive relaxation of the muscles of the lips, tongue, larynx and throat . . . . With the relaxation . . . the auditory image is absent . . . . With progressive muscular relaxation — not alone imagery, but also attention — recollection, thought-processes and emotion gradually diminish . . . . [After he reached those conclusions he stated that] reports have been secured more or less independently from about one hundred additional patients. The conclusions stated above have to this extent been repeatedly confirmed. (1938, pp. 188–189)

Note that these are instances of the covert response patterns that have been electromyographically recorded, as summarized earlier.

There is also enormous evidence that by decreasing the amplitude of covert response patterns (i.e., muscle tension levels) through relaxation procedures, numerous kinds of mental activities involved in psychiatric disorders can be treated. For instance, by relaxing principally the eye and speech muscles in conjunction with relaxation throughout the somatic musculature, phobic, obsessive, depressive, etc., forms of mental activity have been eliminated or alleviated (see especially Jacobson, 1938, 1970; McGuigan, 1992; Wolpe, 1990). Such elimination of muscle tensions have been electromyographically confirmed.

For the control of emotional behavior, Jacobson also established that while a person is well relaxed there is no subjective experience of emotions. A study in my laboratory provided an illustration in that Spielberger et al.'s (1988) Anger–Out and Anger–Expression scores were significantly reduced for subjects who had completed a course in Progressive Relaxation (Workman, 1994). The extensive work of Wolpe (e.g., 1990), using his method of systematic desensitization based on Jacobson's progressive relaxation, has been especially successful for phobias. A model for the generation and control of these disorders is presented in Figure 5. In summary, not only does a neuromuscular model of mind have important clinical applications, but when we manipulate the striated muscles to relax them, cognitive processes can be diminished or eliminated.

2. *Educational applications*. The principles developed here have applications for understanding how the body processes information to generate comprehension (meaning) as in the processes of reading, writing and thinking in general. For instance, silent reading is an important cognitive activity that

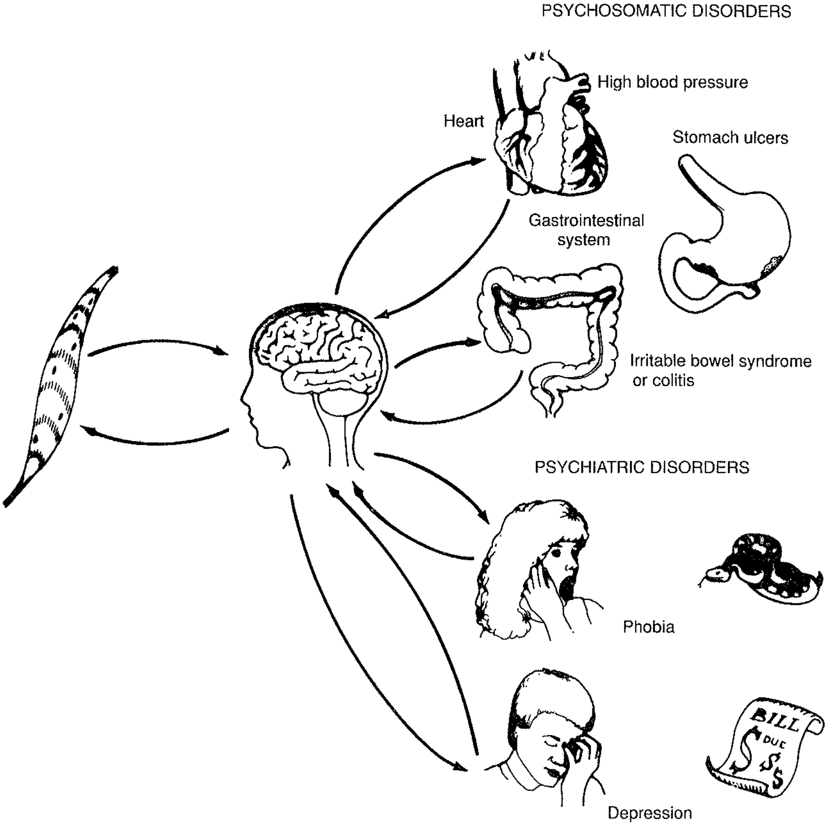

Figure 5: Clinical Progressive Relaxation has been successfully applied for a variety of psychiatric and psychosomatic (somatoform) disorders. The principle is that chronic over-tension contributes to the development of such disorders. Consequently, an appropriate therapy is to reverse the process and relax the striated musculature. From F.J. McGuigan, *Biological Psycholoy: A Cybernetic Science*. © Prentice Hall, 1994, Englewood Cliffs, New Jersey.

has a particular advantage for the researcher — the reader's thought processes are controlled by the words being read. Consequently, the researcher knows what the reader is thinking about. Covert speech behavior (subvocalization) has been well documented in silent reading (McGuigan, 1970a) and in silent writing (McGuigan, 1970b). The fingers of deaf children are covertly active during thought since their language is dactylic (Max, 1937; McGuigan, 1971). While covert speech behavior is frequent in children, it naturally decreases as they mature. Still, it stabilizes significantly above zero at a level typical of adults (McGuigan and Bailey, 1969b). But what happens to the amplitude of covert speech behavior in elderly subjects? My student Livesay (1989) found, in two independent studies, that lip EMG significantly increased in amplitude during silent reading for elderly subjects relative to that for middle-aged and young adults.

As we increase reading rate, covert speech behavior also increases (McGuigan and Pinckney, 1973). As the eye moves to the end of a line of prose, return eye movements occur, providing an independent measure of reading rate. Thus by both psychometric and psychophysiological measures, as one reads faster, one covertly subvocalizes to a greater extent.

A remedial reading course using Grace Fernald's (1943) effective kinesthetic method resulted in both increased reading proficiency and increased amplitude of covert speech behavior (McGuigan and Shepperson, 1971). Edfeldt (1960) concluded that there are larger amplitudes of covert speech behavior (silent speech) during silent reading for poor than for good readers, while reading blurry versus clear text, and for difficult versus easy text.

It has been widely assumed that subvocalization is detrimental to the reading process such that subvocalization should be eliminated or interfered with. "Speed reading" courses, for instance, have attempted to "short-circuit" the speech musculature in order to increase reading rates to amazing values such as of 25,000 words per minute. My students and I studied four classical techniques and a novel one in attempts to decrease or eliminate covert speech behavior during silent reading. The results for the following techniques were summarized in McGuigan (1978): 1. distraction, 2. mechanical interference or restraint, 3. anesthetization, 4. voluntary (conscious) control and, 5. biofeedback from the speech musculature.

In *distraction*, the reader engages in some irrelevant and presumably interfering behavior such as counting aloud while silently reading. McGuigan and Rodier (1968) had subjects read under conditions of silence, non-matching auditory prose, prose played backwards, and white noise. Reading while listening to prose and separately to backward prose significantly increased amplitude of covert speech behavior, though white noise did not have that effect. One conclusion was that increased speech behavior facilitates the silent reading process in the presence of linguistic auditory interference because one must exaggerate covert speech behavior then for comprehension. The general conclusion from several studies on distraction is that the method does not eliminate or reduce subvocalization during reading (McGuigan, 1978).

In the method of *mechanical restraint* the experimenter attempts to minimize covert speech behavior during silent reading by restricting action of the speech musculature. Methods used here have been to tape the mouth closed, have the child read with marbles in the mouth, with a stick that depresses the tongue by inserting it across the mouth between the teeth, or holding the tongue between the teeth. However, instead of reducing covert speech muscle behavior, baseline tongue electromyograms increased in amplitude (McGuigan, 1978). Additional increases then occurred when silent reading commenced. Furthermore, other measures indicated that cognitive processing continued despite attempts to restrain or interfere with covert speech.

Another approach was to attempt to deaden the tongue and lips by the application of a 5% lidocaine solution. However, the speech muscles continued to function during silent reading and rehearsal of linguistic material (McGuigan, 1978), as they do for voluntary control.

The last strategy was to transduce electromyographic signals from the speech musculature during silent reading so that their external representation could be used to monitor amplitude of covert speech behavior. The effort was to use these signals to reduce covert speech behavior and study effects on reading proficiency (this procedure was later called "biofeedback"). However, while subjects were able to reduce covert speech behavior during silent reading by means of the auditory speech muscle feedback, the effect was not permanent. That is, when the signal was removed, the amplitude of covert speech behavior returned to baseline level (McGuigan, 1971). In this connection Hardyck, Petrinovich, and Ellsworth (1966) erroneously reported that heightened speech muscle activity during silent reading could be permanently eliminated with five minutes of "treatment" (sic) — (see McGuigan, 1967). By using the word "treatment," the authors assumed that subvocalization was a disorder that retarded the reading process — as developed herein, such covert speech behavior is not detrimental and actually facilitates understanding of the text. Apparently, the only successful behavioral way to eliminate covert responding is to totally relax the speech muscles — Jacobson (1938) showed that individuals who are well-trained in progressive relaxation and are instructed to silently read while they totally relax their speech muscles do not comprehend the meaning of words from a book even though the words impinge on their retinas.

The general conclusion for methods intended to eliminate, reduce or interfere with covert speech behavior is that they are ineffective; covert speech behavior continues during the silent reading of prose under the above conditions. Covert muscle activity also continues under other conditions when it is in fact thought to be eliminated as in a state of curarization, or as in quadraplegics (McGuigan, 1994).

In summary, covert speech behavior during silent reading is of larger amplitude in readers with low proficiency, in the young and the elderly. It also increases as textual and environmental demands increase, and as reading rate with comprehension is experimentally increased. The following picture emerges. During silent reading, one orally reproduces the words read so that as one speaks words overtly or covertly, one "hears" them as auditory images and thus understands them. In this way, visual information is transferred to the auditory mode (McGuigan, 1984). Thus, one covertly says what one sees and then hears what one says (McGuigan, 1979). Apparently, covert speech responses are made as part of the process of interpreting (decoding) the text being read. In first learning to read, the child necessarily makes large articulatory movements while pronouncing words. As proficiency increases, the gross amount of speech muscle activity is reduced and efficiency increases so that initial large scale and erratic movements become woven into smooth, highly coordinated response chains. In reading, these response chains are most efficiently run off at the covert level. Hence, the covert speech response persists in the adult and continues to function during reading, be it overt or silent. During silent reading, when necessary for comprehension, amplitude of speech behavior increases. Thus, the poor, young and elderly readers and those reading under demanding conditions exaggerate the amplitude of covert speech behavior to enhance reading comprehension. Consistent with a principle of behavioral efficiency, during easy reading a minimal amount of afferently carried verbal information is generated in the speech system. But when required, a greater amount of verbal information, perhaps a redundancy of information, is sent to the brain. The educational implication, therefore, is that one should not tamper with a child's subvocalization — it is likely that the child needs to subvocalize while reading and, in any event, the subvocalization naturally reduces in time. The scientific implication is that the cognitive processes involved in reading depend on the generation of phonetic coding by neuromuscular circuits involving the speech muscles.

Defining mind. In general summary of this paper, first, extensive research has ascertained that covert muscular movements electromyographically measured are present during cognitive activities, even when efforts are made to eliminate them. Second, it has been well established that with progressive relaxation, cognitive events are eliminated in a thoroughly relaxed body. Since muscle movements are present during cognitive activities and absent when cognitive activities are eliminated, by Mill's methods we conclude that the striated musculature is an intimate component of cognitive activities. As

Edmund Jacobson once put it, it might be naive to say that we think with our muscles, but it would be inaccurate to say that we think without them. The muscles are components of circuits that interact with the brain, circuits that are governed by cybernetic principles. The selective interaction of those circuits generates cognitive activities. A major clinical application of our physicalistic model of mind is that mental events can be directly controlled by programming the *voluntary* (striated) muscles. An educational application is that thought, such as occurs in silent reading, requires covert speech behavior ("subvocalization") which should not be tampered with.

Our efforts to explicate the common sense notion of mind is based on the concept of neuromuscular circuits that are governed by cybernetic principles of feedforward, feedback, and adaptive control mechanisms (McGuigan, 1994). We thus arrive at the following proposition: *the human mind is the functioning only of systems of the body. As those systems selectively interact through neuromuscular circuits according to cybernetic principles, they (1) generate cognitive processes (the contents of mind, some of which we can verbally report) and (2) program behavior, both overt and covert, to accomplish our purposes.* Generation of cognitive events and programming of behavior is primarily controlled by circuits that include the eye and speech musculature (McGuigan, 1992).

The next problem is to establish principles by which the body's circuits selectively interact to generate mind. The interactions between the speech muscles and the linguistic regions of the brain by means of phonetic coding provide but a start. We need to bring together all of the possible methods of measuring these interactions, at present including electrical, chemical, magnetic, thermal and various scanning systems. A grand combination of the read-outs from these systems should advance us well toward a precise specification of mind that has both scientific and technological consequences.

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