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Consciousness and Self-Regulation

Advances in Research and Theory

VOLUME 4

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2 The Motor Theory of Voluntary Thinking

BARRY H. COHEN

The theory proposed in this chapter—the motor theory of voluntary thinking (MTVT)—is not exactly new; its basic elements can be found in the motor theories of Bain (1888), Maudsley (1889), Ribot (1889), Pillsbury (1908), and Washburn (1916) to name just a few. Many of the ideas expressed below were commonplace at the beginning of this century, and the interested reader is encouraged to explore the original sources referenced within this chapter, which frequently contain detailed, anecdotal descriptions and lengthy logical arguments in support of these ideas. To maintain the clarity of my exposition, I will quote only a few examples from the early literature; it is not my intention to present a history of the theoretical formulations concerning the relation between the motor system and attention or thought (a brief history can be found in Smith, 1969). Rather, my purpose in writing the present chapter is to present some of these old ideas in the context of a cohesive theory that is as clear, plausible, and useful as possible.

It is my opinion that the current lack of popularity of motor theories derives from the fact that these theories often contained unnecessarily restrictive or implausible provisions and were often tied to physiological notions based on the limited knowledge of their times. However, I feel that to reject these theories in their entirety is to disregard a host of potentially useful ideas, which appeal to one's common sense and may stand in close agreement with one's own introspections. The MTVT, as expressed herein, is far from complete and should certainly be considered as work in progress. Nonetheless, I feel it is useful to present the theory at this time, especially considering the current increased interest in facial muscle action (Ekman, Friesen, & Ellsworth, 1972; Fridlund & Izard, 1984), in order to encourage the notion that overt or covert

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changes in skeletal muscle activity may be more than just indicators of mental processes—these motoric activities may play an important mediational role.

I. Previous Motor Theories

Rather than discuss the details of the various motor theories proposed by particular psychologists, I will separate these theories into broad categories and then discuss issues common to the theories within each category.

A. *The Motor Theory of Consciousness*

In its simplest form, the motor theory of consciousness states that no perception, no image, no thought—in fact, no mental experience—is possible without the occurrence of some unique pattern of activation in the motor system; it is the particular motor activity pattern evoked directly by some external stimulus or associative process that determines which mental experience will occur.

The arguments in favor of the motor theory of consciousness can be quite convincing when applied to aspects of perception in which motor activity plays a critical role, such as discerning the shape of an object by scanning its boundaries visually and thus making appropriate eye movements (Sperry, 1952; Weimer, 1977). Accounting for mental imagery then becomes a simple matter: reproducing the pattern of motor activity that has been associated with a particular perception, even if covertly or only centrally, can, in the absence of the appropriate external object, evoke a pattern of cerebral activity similar to the cerebral activity accompanying the perception and thus produce a "faint" form of perception perceived as an image (in this case, a visual image). However, when one considers perceptual distinctions in which motor activity plays no obvious role, the motor theory of consciousness is far less convincing. For example, the perceptual quality that results from staring at a red wall is quite different from that which results from staring at a green wall, yet it is not obvious how the patterns of motor activity associated with each perception would consistently differ. Of course, if the motor theory of consciousness cannot explain the perceptual differences among colors, it also cannot explain the mental imagery of colors. In a relatively recent paper arguing in favor of a motor theory of consciousness, Weimer (1977) deals with the problem of sensory qualities in such a general manner as to offer no concrete explanation at all.

It is undoubtedly such weaknesses that explain the current unpopularity of the motor theory of consciousness. The motor theory of thinking is less encompassing than the motor theory of consciousness but may contain similar weaknesses, as will be discussed in the following section.

At this point it is appropriate to discuss an important issue that affects all types of motor theories: the necessity of peripheral motor feedback, that is, afferent feedback from the contraction of muscles. Theories that require peripheral feedback are susceptible to disconfirmation from studies in which the skeletal musculature of a human volunteer was paralyzed with curare (e.g., Leuba, Birch, & Appleton, 1968; Smith, Brown, Toman, & Goodman, 1947). In the Leuba *et al.* study, the subject was able to solve complex mental problems just as well when paralyzed as when not. Although McGuigan (1978) has amply criticized the curare studies (e.g., most curare studies have not used electrical recordings to establish that total paralysis had occurred), these studies have cast a great deal of suspicion on motor theories in general.

Actually, most proponents of motor theories have suggested that although peripheral feedback may be necessary in the initial stages of internalizing thought, such feedback becomes unnecessary when repeated associations result in "short-circuit" connections within the central nervous system. Dunlap (1927) suggested that this short-circuiting might occur "between cerebellum and cerebrum, with no muscular activity . . . involved" (p. 265). Although it is not likely that the cerebellum plays an indispensable role in cognition, the type of speculation offered by Dunlap does not seem entirely implausible in the light of more recent research on central efferent monitoring and corollary discharge (Evarts, 1971). Since it is unlikely that peripheral feedback is necessary for many types of overt motor acts, it seems even less likely that peripheral feedback would be necessary for thinking. A good example of the extreme central position is contained in the motor theory of consciousness proposed by Sperry (1952): "The core of the perceptual process is not itself a motor pattern. It is more pre-motor or better pre-premotor in nature owing to the hierarchical plan of neural organization" (p. 309).

Motor theories that are formulated exclusively in terms of central motor feedback are difficult to disprove experimentally and are therefore sometimes viewed with suspicion. But although central motor theories may not be easily disconfirmed, they can represent useful approaches to organizing our knowledge of cognitive processes and can suggest valuable experiments. The MTVT, described in subsequent sections, adopts this viewpoint in assuming that only central motor feedback is necessary when motor feedback is necessary at all, and that actual muscle contraction is never necessary for the motor system to influence mental experience.

B. *The Motor Theory of Thinking*

The motor theory of thinking, in its simplest conception, is just a subset of the motor theory of consciousness. The motor theory of thinking does not propose that motor activity is required for *all* mental experiences, but rather that motor activity is required for mental experience in the absence of external sensation—that is, for images and thoughts. From a commonsense point of view, the motor theory of thinking seems much more plausible than the motor theory of consciousness. Most perceptions do not seem to require motor activity necessarily, and certainly not specific and unique patterns of motor activity. On the other hand, the occurrence of mental images can seem somewhat mysterious—they are like perceptions in some respects, yet they have no obvious cause. The motor theory of thinking provides a reasonable explanation for the generation of mental images.

According to Washburn (1916), kinesthetic images are simply faint kinesthetic sensations: kinesthetic "images" are generated through slight, covert contraction of the appropriate muscles—the afferent feedback from these slight contractions is perceived as an image rather than a perception. It is quite reasonable to assume that one could make such slight contractions without being at all aware of making them and then regard the resulting faint kinesthetic sensation as a purely mental experience. That subjects do, indeed, produce slight muscle contractions when imagining muscular acts was confirmed by the early work of Jacobson (1932).

Jacobson pioneered the use of electromyography (EMG; the amplification and display of the tiny changes in electrical voltage associated with muscle contraction) to demonstrate that when a subject imagined bending one arm, slight contractions occurred in the biceps of that arm, but not the other arm. Moreover, the imaging of rhythmic activities, such as pumping a tire, were associated with a corresponding rhythm of slight muscle contraction and relaxation. Shaw (1938) partially replicated these results by exploring a wide range of motoric activities.

Washburn's explanation of kinesthetic imagery cannot, of course, be applied to other forms of imagery. Kinesthesia is the only modality in which sensations can be produced directly by voluntary action. Images in other modalities may be explained, however, through their association with kinesthetic sensations. The case of speech imagery (auditory images of one's own voice) or "inner speech" is by far the simplest to explain. Associations between one's own voice and kinesthetic sensations from one's speech musculature are very specific, consistent, and frequently repeated. It is a reasonable assumption that eventually the

kinesthetic sensations produced by slight contractions of the speech musculature can evoke auditory images of one's own voice, even when one is not aware of any kinesthetic sensations or images. As in the case of kinesthetic imagery, there is electromyographic evidence that covert muscle contractions occur in the appropriate area (i.e., the speech musculature) when subjects are asked to imagine speaking; in fact, the evidence is quite extensive (see McGuigan, 1978, for a comprehensive review). The specificity of this covert speech activity was convincingly demonstrated in an experiment by McGuigan and Winstead (1974), in which the EMG was recorded from both the tongue and the lips while subjects read and mentally rehearsed words containing either labial (requiring the lips for pronounciation) or lingual (requiring the tongue for pronounciation) phonemes. As expected, the lip EMG was significantly higher than the tongue EMG when subjects mentally processed the labial words, whereas the reverse was true for lingual words.

The whole notion that kinesthetic feedback can, after frequent association, evoke a particular auditory image is rendered plausible by an experiment conducted by Hefferline and Perera (1963). In this experiment:

> When the subject occasionally emitted an invisibly small thumb twitch (detected electromyographically), he received a tone as a signal to press a key. After several conditioning sessions, the tone was progressively diminished to zero. The subject nevertheless continued to press the key whenever he emitted a thumb twitch, and he reported that he still heard the tone. (p. 835)

It is visual imagery that is the most difficult to explain in terms of motor activity or kinesthetic sensations, especially the imagery of different colors. Only in the case of visual objects that are extremely elongated in one direction or are moving does the possibility of a consistent association between eye movements and visual perception become realistic. In fact, in an early study by Jacobson (1930), eye movements (as indicated by the electrooculogram, or EOG) in the appropriate direction were found to accompany the visual imagination of elongated objects, such as the Eiffel Tower. This finding was confirmed by Totten (1935), who photographed a spot of light reflected off the cornea of her subjects. In the great majority of cases in which subjects formed a visual image of elongated objects, eye movements in the appropriate direction were clearly observable. Instances in which eye movements were not observed generally involved visual images which were "distant" or small. More recent studies have found an association between eye movements and visual images involving motion; these studies are discussed in a later section.

Hebb's (1968) theoretical notions would predict eye movements also in the case of forming a visual image of an object with well-defined boundaries. Hebb wrote:

> It is easy to form a clear image of a triangle or a circle when eye movement is made freely (not necessarily following the contours of the imagined figure), harder to do with fixation of gaze while imagining the eye movement, but impossible if one attempts to imagine the figure as being seen with fixation on one point. Though such informal evidence cannot carry great weight, it does agree with the idea that the motor accompaniments of imagery are not adventitious but essential. (p. 470)

It is not clear whether Hebb would expect eye movements to accompany an amorphous visual image, such as one of an empty blue sky. Hebb also leaves unclear the mechanism involved in imagining eye movements and the conditions under which an individual would be more likely to imagine making eye movements to form a visual image than actually to make them.

It is possible, as I have speculated previously (Cohen, 1978), that the visual imagery of static objects is associated with a characteristic pattern of muscle tension ordinarily associated with focused visual attention (e.g., squinting, including tension in the brows and around the eyes). But it seems unlikely that the motor activity accompanying the visual image of an orange on a table could be distinguished from the motor activity accompanying the visual image of an apple on a table. Therefore, it would appear that any motor theory of thinking which insists that visual images cannot occur without some unique pattern of motor activity or that the content of the visual images is completely determined by the accompanying motor activity must remain unconvincing. The motor theory of voluntary thinking, which I describe below, explicitly avoids this weakness.

C. *The Motor Theory of Attention*

The motor theory of attention does not assert that motor activity is necessary for the creating of mental experience but that motor activity plays a critical role in emphasizing one aspect of perception or thought over another. Among the earliest expressions of this theory was the view of Bain (1888) that "in selecting a quality out of a complex effect; in maintaining the attention upon one of several images that rise to the view; in a word, in all voluntary control of the thinking trains,—there is a muscular intervention" (p. 373). A distinction is invariably made between spontaneous attention and voluntary attention; the former is drawn automatically by its object with no concomitant sense of effort, whereas the latter is more abstractly motivated and requires the constant

application of effort and will. It is generally hypothesized that only voluntary acts of attention require activation of the motor system.

The motor theory of attention does not require specific patterns of motor activation to correspond to particular perceptions, images, or thoughts and thus avoids a major weakness of the motor theories described in the previous two sections. However, the motor theory of attention rests on there being some general relation between motor activity and the direction of attention. Pillsbury (1908) delineates three classes of motor activity related to attention: movements that adapt the sense organs for keener perception; general movements which depend on the nature of the stimulus; and "general overflow effects upon the voluntary muscles which do not depend upon the nature of the stimulus" (p. 12). James (1890/1950) describes motor activation of the first type as follows:

> In attending to either an idea or a sensation belonging to a particular sense-sphere, the movement is the adjustment of the sense-organ, felt as it occurs. I cannot think in visual terms, for example, without feeling a fluctuating play of pressures, convergences, divergences, and accommodations in my eyeballs. The direction in which the object is conceived to lie determines the character of these movements. (p. 300)

Fechner described a difference between attention to external objects and attention to mental images; as quoted by James (1890/1950), Fechner stated:

> I have, when I try to vividly recall a picture of memory or fancy, a feeling perfectly analogous to that which I experience when I seek to apprehend a thing keenly by eye or ear; and this analogous feeling is very differently localized. While in sharpest possible attention to real objects . . . the strain is plainly forwards, . . . the case is different in memory or fancy, for here the feeling withdraws entirely from the external sense-organs, and seems rather to take refuge in that part of the head which the brain fills; if I wish, for example, to recall a place or person it will arise before me with vividness, not according as I strain my attention forwards, but rather in proportion as I, so to speak, retract it backwards. (p. 435–6)

As an example of the second class of attention-related motor activities, Pillsbury refers to those subtle, automatic movements and changes in body posture which can allow a skilled "mind-reader" (or "muscle-reader," as Pillsbury contended) to discern the direction of an object upon which a person is concentrating. Generally, the person concentrating is unaware of performing these tell-tale motor activities, and the "mind-reader" may even be unaware of the source of his information.

The third class of motor activity is associated with all forms of attentional effort, regardless of its direction, and may account in large measure for the experience of effort. Pillsbury mentions the "wrinkled brow" as associated with mental effort. James associated tension in the brow and glottis to feelings of approval and disapproval but added: "in *effort* of any sort, contractions of the jaw muscles and of those of respiration are added to those of the brow and glottis" (p. 301, original emphasis). Ribot (1889), in describing the muscular reactions accompanying intense reflections, concluded that, in addition to more specific reactions, "in all persons and in every case there are modifications in the respiratory rhythm" (p. 27).

The theory I describe in the following section—the MTVT—combines elements from both the motor theory of thinking and the motor theory of attention. Many of the hypotheses I propose occurred to me independently of the works of the early psychologists cited above. However, the elegant writings of these pioneer investigators are helpful in providing rich examples of many of the phenomena to which I refer.

II. Defining the Motor Theory of Voluntary Thinking

The motor theory of voluntary thinking (MTVT) does *not* propose that a specific pattern of motor activity is necessary for the occurrence of each and every mental image or thought. According to the MTVT, any thought or image may occur as an association to a sensation or another thought or image. It seems reasonable that the cerebral processes involved in the experience of one mental image can stimulate the cerebral processes underlying another image without the mediation of any form of motor activity. However, the feedback from motor activity can also evoke thoughts or images according to principles of association. These motor associations can be highly specific, as in the case of inner speech, where the covert reproduction of a specific speech motor pattern can evoke the auditory image of a particular phoneme; or the associations can be much less specific, as will be discussed in a subsequent section. Furthermore, the MTVT does not merely suggest that motor feedback *can* evoke mental images and thoughts; it ascribes to the motor system a very important role in the ordinary thinking process. Patterns of covert motor activity can guide the direction of thought, sometimes very specifically, through the associations they generate. Moreover, it is proposed that motor activity is responsible for the experience of will or volition in thinking—for mental effort—as well as other important aspects of thought to be detailed below.

The basic premise of the MTVT is that all acts of will, or effort, involve activation of the motor system; that central motor activity is the only cerebral activity under direct voluntary control; and that the experience of voluntariness arises only from motor activity, even if only central and not peripherally expressed. Thus, the MTVT parsimoniously explains that the experience of volition that accompanies certain mental acts arises from the same source as the experience of volition accompanying physical acts.

A. The Experience of Volition

The MTVT explains quite simply why some mental images or thoughts are experienced as voluntary (e.g., rehearsing an unfamiliar phone number) and others not (e.g., suddenly experiencing visual memories upon perceiving a particular fragrance); the former images involve motor activation, whereas the latter do not. To be specific, rehearsing a phone number requires a speech motor pattern to be repeated covertly. However, memories can also occur spontaneously through association with other cerebral processes, which may arise in the form of perceptions or may themselves remain out of awareness.

It should be noted that the MTVT does not assert that motor activation must always lead to an experience of voluntariness. Even overt motor acts may become so habitual that they can be performed without any awareness and therefore with no sense of effort. It is possible in the case of some thought patterns that although they arise through association with motor feedback, the covert motor acts with which they are associated are performed automatically—that is, with no sense of effort. For instance, the persistent repetition of the auditory image of a popular song may be the result of a habitual covert motor pattern of which one is unaware, just as one may be unaware of habitually straightening an article of clothing or walking in the wrong direction while engrossed in conversation. Thus a thought may appear to be effortless because no motor activation is involved, or because the motor activity is of an automatic nature.

Whether a covert motor act associated with mental activity is perceived as voluntary or not would be determined by the same principles which determine the degree of voluntariness experienced during overt motor acts. In the preceding chapter, Norman and Shallice describe a theoretical motor mechanism, the "Supervisory Attentional System," the output of which is strongest when motor acts recruit the greatest exercise of attention, as when the motor act is particularly difficult, dangerous, novel, or unpleasant. Norman and Shallice then propose "that *will* be this direction of action by deliberate conscious control" and that "*will* corresponds to the output of the Supervisory Attentional System." The theory they propose is concerned primarily with external actions, but, as they say, "the same principles apply to internal actions—those that involve only the cognitive processing mechanisms." It is also worth noting that the concept of the Supervisory Attentional System is bolstered by the fact, pointed out by Normal and Shallice, that the functions proposed for this mechanism "correspond closely with those ascribed by Luria (1966) to prefrontal regions of the brain, thought by Luria to be required for the programming, regulation, and verification of activity."

B. *Specific Motor Associations*

The chief assertion of the MTVT is that without the motor system there could be sensation, perception, and even mental images—but no voluntary thought. The critical aspect of this theory is the delineation of the mechanisms by which covert motor activity can explain all aspects of voluntary thinking. One important principle is that the more specific the associations are between patterns of motor activity and the contents of mental experience in a particular modality, the more closely mental experience in that modality can be determined through voluntary motor control. In the case of kinesthetic imagery and inner speech, the associations are simple and direct, as described above in the motor theory of thinking, and therefore these types of imagery should be easy to control. To recall how it feels kinesthetically to row a boat, one need only to activate covertly the appropriate pattern of motor activity. To imagine how it might feel to perform some new motor activity, one would only have to activate covertly the pattern of motor activity that one believes would be necessary, just as one would activate the new pattern overtly if trying the activity for the first time.

1. *Inner Speech*

In order to rehearse a telephone number one would simply "speak" the numbers covertly—that is, activate the appropriate speech motor patterns, but too slightly to produce audible speech. To take the case of rehearsing a telephone number a step further, consider that the person is being distracted by loud music. Because the music would be competing for his attention, he would have to increase the amplitude of his rehearsal by increasing the speech motor activity, perhaps to the point of making actual lip and tongue movements. Were the music loud enough he might have to speak the numbers aloud so that the numbers would capture enough of his awareness to remain in his short-term memory. McGuigan and Rodier (1968) did indeed find increased speech motor activity (as measured by EMG) in subjects who read during auditory distraction (e.g., white noise, "reverse" speech) as compared to reading in silence.

The person rehearsing the telephone number might also be distracted by his own thoughts or images. For instance, he might be facing an important deadline and find his awareness flooded with verbal thoughts about activities which must be performed as soon as possible. Although it is conceivable that these distracting thoughts could arise spontaneously without accompanying motor activity, it seems more likely that these distracting thoughts would themselves be based on covert speech activity that occurs rapidly and automatically in response to an awareness of the impending deadline. Increasing the speech motor activation associated with the telephone number can probably diminish the distraction of competing thoughts in two ways. First, the telephone number captures an increasing amount of awareness (this would work against any distractor, whether music or thought). Second, to the extent that the distracting thoughts require activation of the speech motor system in their own service, attempting to monopolize the speech system with the telephone number allows less access to the distracting thoughts. At this point it should be considered that thoughts are not likely to require full speech motor patterns to reach awareness. Partial patterns can probably be activated very rapidly, intertwining two or more thoughts in such a way that they seem virtually simultaneous. However, it also seems clear that the strong and rapid repetition of one particular thought can greatly diminish the expression of competing thoughts. Rehearsing a telephone number is just the type of thinking that is very likely to require voluntary thinking in every case and, therefore, speech motor activity, against an inevitable background of distracting thoughts and images.

2. *Visual Imagery*

The case of voluntary visual imagery is less straightforward than the case of inner speech, but its explanation presents no great problem for the MTVT. Visual imagery represents the case in which the relation between motor activity and mental content is not highly specific, yet some degree of voluntary control is still possible. First, it must be made clear that the MTVT does not posit a one-to-one correspondence between patterns of motor activity and the contents of visual images. Consequently, it cannot be contended that specific visual images are evoked by activating the appropriate motor pattern. However, even if visual images cannot be directly evoked by motor activity, they can to some extent be suppressed, enhanced, or moved by the appropriate motor pattern. In the case of visual imagery, the appropriate motor activity very likely involves the extraocular muscles, which control the movements of the eye, and the musculature which surrounds the eye, including the muscles which draw down the brow to aid in squinting.

Eye movements seem to play an important role in supplying motion to visual images. Antrobus, Antrobus, and Singer (1964) found that subjects exhibited significantly more eye movements when forming visual images involving motion (e.g., a tennis match) than when forming static images (e.g., an orange on a table). Several experiments have confirmed that most subjects produce noticeable, rhythmic horizontal eye movements when visually imagining a moving pendulum (Brown, 1968; Deckert, 1964; Lenox, Lange, & Graham, 1970). Those subjects not producing measurable eye movements may yet have been producing the same central oculomotor activity, but at a level insufficient to move the eye.

It should be noted at this point that the lack of useful proprioception from the extraocular muscles, which has been convincingly demonstrated (e.g., Matin, Pearce, Matin, & Kibler, 1966), does not weaken this part of the MTVT. Central feedback from motor activity plays an important role in visual perception and may play an important role in visual imagery as well. To those who are skeptical of the involvement of eye movements or oculomotor commands in the motion of visual images, the following demonstration is recommended:

> Imagine that you are standing on the roof of a tall building and looking across the street at a building that is even twice as tall. On the roof of the opposite building, just near the edge, is a colorful beach ball (you must look upward to see it). At this point in the demonstration, the reader must actually move his eyes upwards as high as it is physically possible, without inducing pain (obviously, the reader will have to read the demonstration through once before actually trying it, unless it is being read to him). Then, while maintaining your eyes in this upward position as firmly as possible, imagine that a slight breeze has caused the beach ball to fall off the edge of the opposing roof. Without allowing your eyes to move down even slightly from their extreme upward position, imagine the beach ball falling slowly downward. You must actually "see" the beach ball as a visual image, as vividly as you can. The beach ball begins its descent above you, but it is soon level with your position, as it continues to fall. Remembering not to allow your eyes to lower even slightly, continue to "see" the beach ball fall downwards until it bounces on the street below you.

When this demonstration was read to a group of more than 30 experimental psychologists and graduate students, the majority felt a strong tendency to move their eyes along with the visual image and felt that the image was marred if they did not succumb to this tendency. Many felt they simply could not "see" the beach ball fall without moving their eyes. I devised this demonstration as a visual analog of a demonstration described by James (1890/1950) and attributed to Stricker. In the Stricker demonstration the subject must imagine hearing a word such as *bubble*, while keeping his mouth partly open. Some people find their auditory images disturbed, at least initially, because of the incompatibility between the feedback from a partially opened mouth and the feedback that would occur in pronouncing the word.

If eye movements can be effective in "moving" a visual image, they can, perhaps, play a role in suppressing unwanted visual images by "moving" them to the periphery, or even past the boundaries of the mental visual field. Consistent with this hypothesis is the finding by Singer and Antrobus (1965) that eye movements were significantly greater when a subject was trying to suppress rather than maintain an image, whether the subject's eyes were open or covered with a translucent surface.

To increase the vividness of visual images, some individuals may activate the motor pattern that produces squinting, as this is the motor activity most closely associated with trying to enhance visual perception. In my own research, I have obtained some evidence which suggests that subjects who generate greater corrugator (brow) tension relative to lip or arm tension experience more vivid visual imagery than subjects whose brow tension is less prominent. After performing two different cognitive tasks, all subjects rated the vividness of their visual imagery and inner speech for each task. Only 7 out of the 22 subjects gave higher ratings generally for their use of visual, as compared to speech, imagery. These subjects were considered a separate "group" in an ANOVA which included muscle area as a within-subject factor. The interaction between imagery group and muscle area was on the borderline of significance, $F(1.63, 32.53) = 3.37$, $p < .06$ (the degrees of freedom were adjusted according to the method of Geisser and Greenhouse [1958] to account for the lack of homogeneity of covariance). As can be seen in Figure 1, the two groups do not differ in total muscle tension during cognitive performance, but rather in the way that the tension is distributed.

So far I have described how motor activity may modify a visual image that already exists in awareness. However, there are times when one voluntarily produces visual images in order, for example, to recall a previous vacation or to imagine a future one. If, according to the MTVT, visual images do not directly correspond to patterns of motor activity, it must be explained how they can be voluntarily evoked. The explanation is that they are evoked only indirectly by association, but

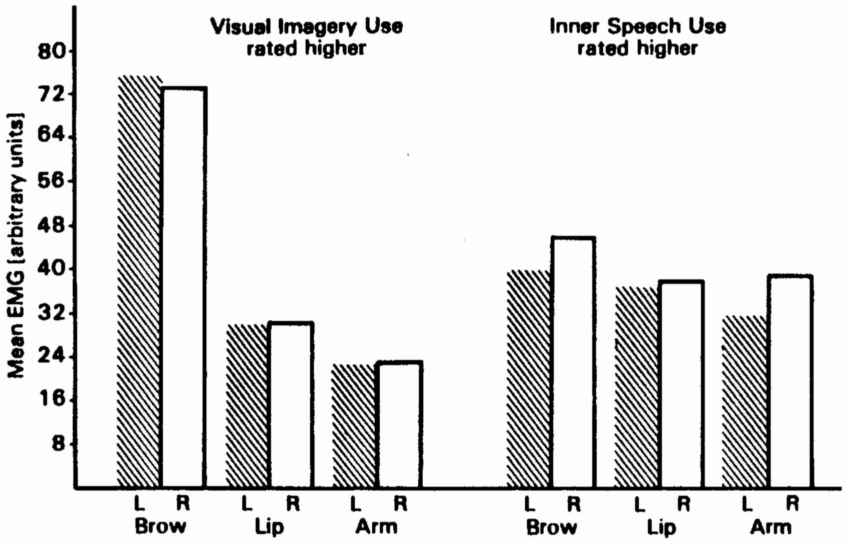


FIGURE 1. Mean EMG amplitude in left and right areas of the brow, lips, and forearms during cognitive performance for two subgroups of subjects differing in reported imagery use (see text).

that some of these associations are under direct, voluntary control. The strong association between words and visual images should be apparent to anyone who has read a novel, especially one in which visual aspects of the setting played an important role. If one closes one's eyes and thinks the word *elephant*, it is difficult not to get some visual impression of a bulky animal with a trunk, etc. To voluntarily produce a visual image, then, one need only name the object in question or describe it with inner speech (in fact, there are extreme visualizers who cannot think any word, even an abstract one, without immediately experiencing some kind of image), which in turn requires the activation of speech motor patterns. Some individuals must close their eyes to experience a clear image, whereas others tend also to squint. Still others claim that they never experience clear visual images. The MTVT does not attempt to explain these differences in visual imagery ability; the theory simply asserts that all visual images are evoked by association (not necessarily to inner speech; perhaps kinesthetic images or sensations can evoke visual images, for instance), more easily for some than for others.

It should be noted that the MTVT does not propose that eye movements are necessary to form vivid, static images or nonelongated images. In fact, it may be helpful to suppress large eye movements in order to minimize disruptive movement of the image. This principle may explain

the results of Ehrlichman and Barrett (1983) who recorded fewer eye movements when subjects solved spatial problems (presumably using some visual imagery) than when they solved verbal problems, whether in a dark or lighted environment. These investigators were somewhat puzzled by their results because they expected imagery disruption to be a factor only in a lighted environment due to movements of the external visual field; they did not consider movements of the images *per se*. It should be mentioned that Stoy (1930), who used very different spatial problems, obtained the opposite results. Whether imagery *movement* helps or hinders the solving of a spatial problem may depend on the details of the particular problem.

An experiment by Marks (1973) suggests yet another role for eye movements during visual imagery: scanning for detail. In Marks' study, two groups of subjects were selected on the basis of the subjective ratings they had given to the vividness and clarity of visual images called for by a questionnaire. Eye movement rates were measured for both the "vivid" and "poor" visualizers while they viewed complex visual stimuli and while they attempted to answer questions concerning the visual details of what they had seen several seconds before. Marks found that the vivid visualizers not only recalled more visual details but also exhibited fewer eye movements during recall than did the poor visualizers. This result might be difficult to explain for a theory that requires eye movements for all visual imagery, but it is consistent with the MTVT. The vivid visualizer is such because visual images appear to him more quickly and completely when he thinks about the image. The poor visualizer, in an attempt to answer questions about details he could not easily visualize, may have needed to scan repeatedly his vague and incomplete image. The vivid visualizer, on the other hand, had all the details he needed at once before his mind's eye.

Cuthbert and Lang (1984) obtained a result seemingly inconsistent with the findings of Marks. They found that subjects whose imagery was below average on vividness as reported on a questionnaire were less likely than the remaining subjects to exhibit eye movements during recall of a moving visual display. However, both results are consistent with a theory which posits specific functions for eye movements during visual imagery but does not contend that eye movements are necessary to create a vivid visual image. Subjects with a vivid image in the Cuthbert and Lang study could be expected to use eye movements to set the image in motion (the MTVT posits that even the best visualizer cannot voluntarily visualize objects in motion without producing eye movements), whereas subjects with a poor image would not be able to produce a noticeable effect on their image with eye movements. Quite likely it is hard to notice a clear pattern of motion when one's image is hazy and unstable to start with. Because changes in visual imagery due to eye movements would not be clear, such movements would not be reinforced. Cuthbert and Lang's result replicates a similar finding by Brown (1968) who used a moving pendulum. In summary, it is suggested that subjects with vivid visual imagery, as compared to those reporting poor imagery, would be more likely to produce eye movements when imaging a moving object but would produce fewer eye movements in searching for details because the details would be more easily and quickly noticed.

The notion that visual images can be controlled only indirectly is not a weakness of the MTVT. On the contrary, this principle can explain some important differences between visual imagery and inner speech. First, it should be noted that nearly all undergraduate respondents to a questionnaire reported clear experiences of inner speech, whereas experience with visual imagery varied widely (Cohen & Jonas, 1978). Second, for most individuals, visual imagery is harder to control than inner speech; it is relatively easy to compose a novel sentence, but for some individuals it is quite difficult to combine diverse visual elements into a novel visual image. Third, when associations occur spontaneously as during daydreams or night dreams, visual images are likely to exhibit combinations that are more bizarre and less logically structured than verbal imagery; the visual images are combining according only to the laws of association, whereas verbal images tend to retain the structure of language.

3. *Other Modalities*

Other modalities of imagery (e.g., smells, tastes) can be accounted for in a manner similar to the explanation of visual imagery. To form the image of a taste, one might think the appropriate words, while covertly activating tongue or jaw movements. For an olfactory image, some form of covert sniffing would likely accompany an internal verbal description. Auditory images other than the sound of one's own voice represent an interesting case that has been surprisingly neglected. From my own introspection, I find that to imagine the sound of a musical instrument I subvocally mimic the sound of the instrument and "sing" or "hum" the tune mentally, while my memory fleshes out the sound. As in the case of visual imagery, these other modalities are under less direct control than inner speech and rely principally on a combination of inner speech and the appropriate sensory memories.

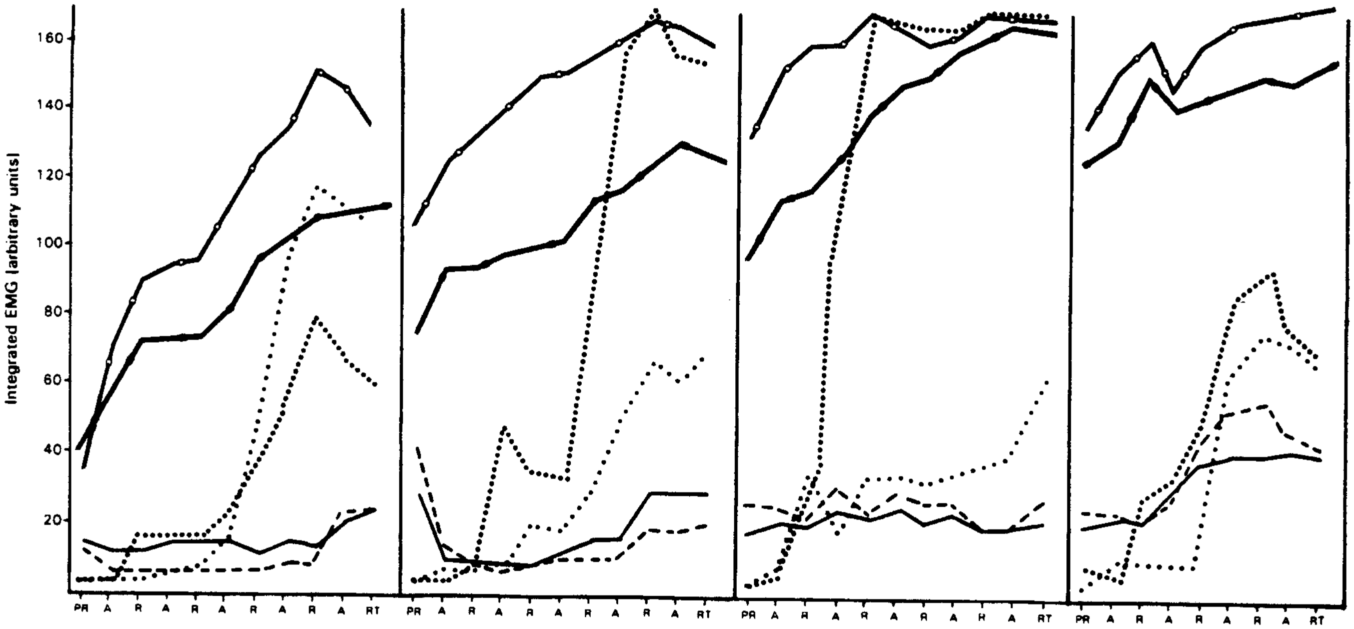
C. *General Motor Associations*

In addition to evoking specific thoughts and images, and their immediate associations, covert motor activity may play a more general role

in the deployment of attention. There is a great deal of research demonstrating that experimentally induced muscle tension can, up to some optimal tension level, improve performance on a variety of mental tasks (see Cohen, 1983, Appendix B, for a recent review). There is also suggestive evidence that the mental performance increments associated with induced tension are due to the increased cortical arousal produced (e.g., Pinneo, 1961). That proprioceptive stimuli can be highly effective in producing cortical arousal was shown directly in cats and monkeys by Bernhaut, Gellhorn, and Rasmussen (1953). In addition, Gellhorn (1958) found the reverse effects in cats; muscle relaxation produced by curare paralysis was accompanied by a marked reduction in cortical arousal and responsiveness to painful stimulation. Thus it may be supposed that individuals increase the tension in their muscles globally, or according to idiosyncratic patterns, in order to increase their level of arousal and thus improve their mental performance. This response, however, can become maladaptive if the individual is already aroused above his optimal level for the mental task in question.

Covert motor activity may also serve in a general way to focus attention. There may be some motor patterns that are activated whenever the individual expends mental effort, regardless of the type of imagery or thought engaged in, or the nature of its content. Each individual may have his own idiosyncratic tension pattern that he activates whenever he concentrates (i.e., focuses his attention). However, some motor elements may have nearly universal association with mental concentration. In particular, brow contraction appears to be closely related to the process of focusing attention.

Rather than being mere by-products of mental effort, these general tension patterns may serve an important short-term mnemonic function that aids the individual in maintaining the direction of his attention. If a certain motor pattern has often been associated with mental effort in a particular individual, feedback from that motor activity could serve to remind the individual that he is presently involved in some attentive act from which he has become distracted. Although the feedback would not tell the individual where his attention should be, it would cause him to search his immediate memory. This mechanism could act as a mental "string around the finger" in the following manner. Suppose an individual is concentrating on some mental problem while tensing his muscles in a characteristic pattern. His attention wanders off the problem, but within seconds he becomes aware of motor feedback from his "concentration" activity. He then quickly searches his immediate memory to recall the particular problem he had been working on. This shifting of attention back and forth could occur very quickly and frequently, especially if the problem were not intrinsically interesting.



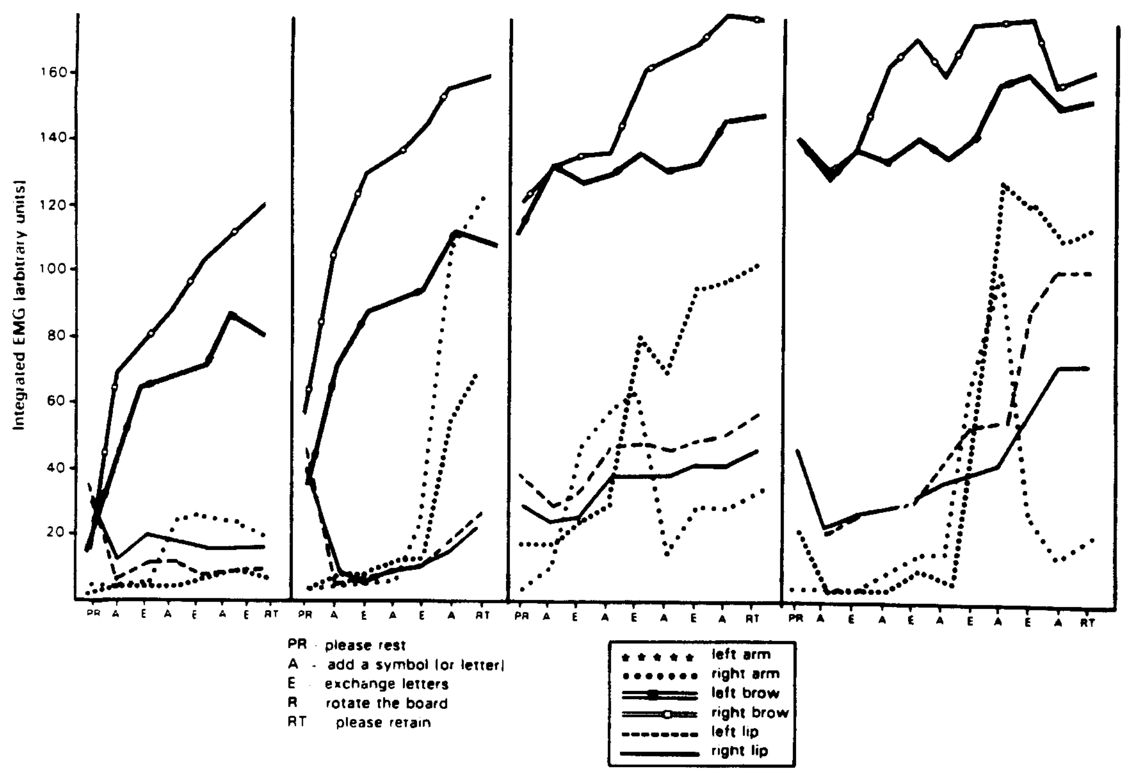


FIGURE 2. Integrated EMG from left and right areas of the brow, lips, and forearms for one subject during four trials of a mental rotation task followed, after a brief rest break, by four trials of a letter transformation task.

It could be suggested that the individual would soon adapt to the constant feedback from his concentration activity, which would then be rendered ineffective. One solution to this problem of adaptation would be for the individual to increase continuously the intensity of his concentration activity during the period of focused attention. This increasing motor activity could be expected to produce a rising tension gradient in at least some of the individual's muscles. Such tension gradients have indeed been found during experiments involving continuous attention (Bartoshuk, 1956; Wallerstein, 1954). In my own research (Cohen, 1983), I observed that for some subjects brow tension did not decrease appreciably within or between trials but would rise higher with each succeeding trial until a rest period was given (after each block of four trials). These gradients were much less pronounced and considerably more variable in the lip and forearm areas. Trials consisted of a series of aurally presented instructions describing progressively more difficult mental rotations or transformations of a string of letters. These instructions were cumulative within a trial and the subject did not respond until the end of a trial. Figure 2 presents data for two blocks of trials for one subject who exhibited prominent brow tension gradients.

III. The Role of Covert Motor Activity in External Attention

A. *Voluntary Attention*

Mental effort accompanies not only the focusing of attention upon purely mental experiences such as images or thoughts; a sense of mental effort can also be experienced in attending to one of several competing external stimuli. The classic example is the "cocktail party phenomenon", in which the listener is bombarded with several simultaneous conversations and must attend to one of them, at least long enough to understand its meaning. Moreover, the conversation selected need not be the loudest. An explanation consistent with the MTVT is that the listener would "shadow" the selected conversation (i.e., repeat it covertly) to keep his attention oriented toward it. However, covert motor activity may aid in selective attention by an additional mechanism in this case, and this additional mechanism may account, in part, for the sense of effort and volition involved in selectively attending to one of many external stimuli. This additional mechanism consists of producing a pattern of covert motor activity to represent symbolically one of the competing inputs. For example, if one conversation originates from the listener's left and the other from his right, to select the leftmost conversation the listener may produce a bodily posture subtly oriented toward the left. This posture may be expressed solely in tensional adjustments without producing any actual body movements. In the case of several conversations originating from diverse locations, the tensional adjustments would likely be less specific and less helpful, but nonetheless could aid in the listener's spatial orientation. This mechanism could be applied analogously for other perceptual modalities. The MTVT asserts that the experience of effort that sometimes arises during external attention is due entirely to motor activation, whether in the form of postural adjustments, sensory organ adjustments, or inner speech. Symbolic postural adjustments may also play a role in directing attention to one thought or image as opposed to another, but in the case of internal attention, spatial orientation is less likely to be a useful factor, and inner speech probably assumes the major burden in determining direction.

B. *Spontaneous Attention*

James (1980/1950) described two forms of "sensorial attention": one that is "active and voluntary" (as described in the previous section) and one that is "passive, reflex, non-voluntary, effortless" (p. 416). The latter form of attention, which I prefer to call *spontaneous*, may be *immediate*, drawn to stimuli by virtue of their force or intrinsic interest, or *derived*, that is, drawn to stimuli by virtue of their association with objects of immediate attention. In psychophysiological research, the type of attention described by James as "passive immediate sensorial" has been evoked experimentally by visual stimuli depicting, for instance, attractive nudes or repulsive accident scenes; passive derived sensorial attention has been evoked by presenting warning signals for trials involving aversive events, or fast reaction. Both types of passive sensorial attention have been associated with significant decreases in heart rate, usually associated with lowered arousal; other arousal indicators simultaneously changed in the direction of heightened arousal (e.g., Libby, Lacey, & Lacey, 1973; Obrist, Webb, & Sutterer, 1969). This paradoxical divergence of arousal indicators has been called *directional fractionation* (Lacey, 1967).

On the basis of a series of experiments which demonstrated that heart rate reductions to warning stimuli were accompanied by reductions in various aspects of somatic activity (e.g., chin tension, respiration, eyeblinks), Obrist, Webb, Sutterer, and Howard (1970) proposed that both the cardiac and somatic activity reductions are due to a global inhibition of bodily activity in order to reduce neural noise which might otherwise compete with the perception of the external stimulus. Thus, it appears that spontaneous external attention may involve increased activation in specific cortical areas (which may correlate with observed increases in, for example, electrodermal activity), coupled with an active inhibition of somatic activity. This phenomenon is easily understood within the context of the MTVT. Ordinarily, the perception of external stimuli would stimulate associations, which would lead to a series of covert motor responses and their accompanying mental images, as this is how normal thinking is posited to proceed. However, if it is important to maintain attention to the environment, it would be best to minimize thinking, and motor inhibition would serve this purpose (in addition to reducing the distraction of extraneous bodily activity *per se*). Because mental effort is not required for this type of attention—both perception and cortical activation are stimulated directly by the environmental and cognitive situation—motor activity is not required (and can actually be a hindrance). However, I suspect that in spontaneous attention, although there is a global reduction in bodily activity, including muscle tension, there may be increased activity in certain muscle areas, especially the brow. Tension in selected regions, not sufficient to offset the global reduction in bodily activity, may be activated automatically to aid in the focusing of attention. Considering the nature of spontaneous attention, any muscle tension that accompanies this state would probably remain in a fixed pattern and at an unusually steady level.

The two types of attention, described in the previous two sections as voluntary and spontaneous, correspond to some degree with the processes of controlled search and automatic detection, respectively, as postulated by Shiffrin and Schneider (1977). The former requires mental effort, often in the form of covert verbal rehearsal, and should therefore be accompanied by significantly more muscle tension than the latter, which may benefit from motor inhibition. (Automatic detection, as described by Shiffrin and Schneider, more specifically corresponds to James's definition of passive derived sensorial attention since it must be learned.) Moreover, the amount of muscle tension generated during controlled search would likely be a function of the "load" as defined in the Shiffrin and Schneider paradigm.

IV. REGULATING THE STREAM OF THOUGHT

A. *Ordinary States*

In Volume Two of this series, Pope and Singer (1978) presented a paper entitled "Regulation of the Stream of Consciousness" in which they described the major factors that determine the contents of one's

daily mental experience. Among their excellent descriptions of different styles of consciousness regulation, Pope and Singer include a hypothetical case of a person who pushes away distracting thoughts while reading a book about mathematics but indulges in free association while reading poetry. This example was chosen by Pope and Singer to illustrate that "we are able . . . to adopt temporary, situation-specific 'plans' for mental processing" (p. 126). These investigators, however, do not describe any mechanism by which such plans could be enacted.

The MTVT, not surprisingly, can describe a mechanism which can account for this important aspect of consciousness regulation. According to the MTVT, the person pushes away distracting thoughts while reading by increasing the covert speech motor activity which he uses to represent the words he is reading. He may also increase tension in the muscles associated with visual perception and the control of eye movements, including the extraocular muscles, and the muscles of the brow and neck. Finally, he may increase the tension in his skeletal musculature generally, but especially in those muscles with which he associates the act of concentrating. On the other hand, to allow the ideas evoked by his reading to distract him from the reading process, he need only relax his motor activity somewhat and refrain from engaging in the types of motor activity which would direct his attention to his primary task.

In such a manner as described above, the MTVT can explain a very salient experiential dimension of ordinary consciousness—the feeling of voluntariness with respect to mental activity. These are times during the course of ordinary daily activities when we seem to be struggling with our thoughts—trying to push unwanted thoughts from our mind, or perhaps repeating particular thoughts in the attempt to find some elusive solution to a problem. There are other times, for instance, sitting idly on a bus or train, when our thoughts seem to flow quite by themselves, and we feel more that we are observing them than creating them. According to the MTVT, the feeling of effort and will associated with some instances of thinking is due to the deliberate engagement of the motor system during such instances in the service of guiding or controlling the direction of thought. When thoughts seem to flow effortlessly, it is because the motor system has not been voluntarily enlisted in the thinking process. A state in which one is absorbed by an exciting train of thought can be described as spontaneous internal attention. Any motor activity (overt or covert) occurring during such a state would be of an automatic nature, not involving the highest cortical control.

B. *Natural Relaxation*

An obvious prediction from the MTVT is that states of global motor quiescence should be accompanied by free-flowing, nonvolitional mentation. This prediction does not apply to states in which muscular relaxation is induced pharmacologically, as with curare, because there would still be the possibility of considerable central motor activity. Nor does it apply to the case of spontaneous external attention during which the decrease in motor activation appears to be the result of an active inhibition coupled with high cortical arousal. It is when reduced motor activation occurs due to fatigue, and the environment does not draw attention, that attention is likely to turn inward. However, this state differs from spontaneous internal attention because cortical arousal is likely to be lower than normal. It is more a state of reduced attention. During such drowsy states, the MTVT predicts that images would flow more according to principles of free association than logical requirements because of the reduction in motor control. Even when the individual is not drowsy, a natural reduction in motor activity should allow ideas to flow more freely by association. This principle can account for the finding of psychoanalysts that lying on the couch tends to encourage free association.

Antrobus *et al.* (1964) interrupted subjects during periods of naturally occurring ocular motility or relative quiescence. The subjects rated their mental content as it was just preceding the interruption. Ocular quiescence tended to be associated with more reports of daydreamlike mentation than did ocular motility. If ocular quiescence is indicative of reduced motor activation, this finding fits well with the predictions of the MTVT. Singer (1975) reported the results of personal, introspective experiments involving interruptions of his own stream of thought: "The impression I gained . . . was that under relaxed, slightly drowsy conditions, one's brain is not geared to producing an orderly sequence of thought. Personalized visual imagery intruded upon me quite regularly" (p. 44). From the viewpoint of the MTVT, spontaneous bursts of visual imagery during relaxed states are quite understandable. As Singer notes, such imagery is likely to involve a memory sequence which flows according to well-worn associations. Much less likely in such a state would be to "hear" an auditory image of one's own voice composing a complex essay.

States of profound relaxation, such as occur just prior to the onset of sleep, are often accompanied by increasingly bizarre combinations of thoughts and images. If, as the MTVT implies, motor activity is required for organizing images and thought into analytical and logical progressions, then it is not surprising to find images evoking other images according to primitive principles of association when the motor system is inactive. It is, perhaps, no coincidence that the state of normal consciousness most closely associated with bizarre, illogical mentation is

the state accompanied by the most profound facial motor inhibition—namely, rapid eye movement (REM) sleep.

Creative thinking often involves a stage of free-flowing mentation during which ideas can combine in new ways that may even seem illogical during ordinary states of thinking. Often a creative episode is preceded by a period of ordinary mental effort during which some problem is considered along with proposed logical solutions. However, the novel, creative solution to the problem often occurs when the individual has stopped thinking about the problem and has relaxed his motor activity. It is in such a state that ideas are more likely to flow by free association.

C. *Progressive Relaxation and Meditation*

The MTVT allows that thoughts can arise either by association with sensations or previous thoughts, or by association with the feedback from motor activity. At this point, I would like to propose tentatively that without sustained motor activity any train of associations would quickly fade away, that it is only the maintenance of motor activity that can prolong a train of thought indefinitely. In this regard, it should be recalled that, according to the MTVT, thoughts may arise through association with spontaneous or habitual motor activity. Together, these two notions—that some motor activity is necessary for sustained thought and that spontaneous motor activity is sufficient for thought—have some interesting implications. One implication is that very deep relaxation of the entire motor system should result in the cessation of thought, but not necessarily of consciousness. Another implication is that the cessation of thought is impossible without the relaxation of all thought-evoking motor activity.

The above hypotheses explain why most people find it impossible to stop their flow of thoughts for more than a very few seconds. Some of the motor activity which is capable of evoking thoughts occurs habitually and may be motivated by the same relentless forces that maintain various nervous habits, such as nail biting. In order to eliminate a habit, one must first be made aware of performing the habitual act. But unlike nail biting, habitual covert motor activity may have no readily observable consequences other than the thoughts it produces. Still, in principle, it should be possible to gain voluntary control over any particular pattern of motor activity; the results of EMG biofeedback experimentation lend much support to this principle (Basmajian, 1979). The possibility of using EMG biofeedback to gain control of specific thought patterns seems remote at present. However, two global procedures offer some promise towards the goal of reducing or even eliminating habitual thought. Jacobson (1938) observed that many individuals exhibited a good deal of residual muscle tension of which they were unaware when they were lying down and supposedly relaxing. Typically, a person asked to relax further would "try" to do so and thus increase, rather than decrease, his tension. Through his experimentation, Jacobson discovered that subjects could relax residual tension in a particular muscle more completely when they became aware of the proprioceptive sensations arising from tension in that muscle. To improve his subjects' ability to perceive muscle tension and thus relax it, Jacobson devised the technique of progressive relaxation. In this technique, a subject systematically tenses and relaxes all of the major muscles, noting the feeling of tension in each, and the feeling of relaxation, of "letting go." Subjects are encouraged to continue letting go even after the point at which they believe the muscle has been completely relaxed. Particular attention is paid to the muscles most closely associated with thought, those involved with speech and control of visual perception. Remarkably, Jacobson found that well-trained subjects could attain a state of muscular relaxation so profound that all images and thoughts would cease, leaving the subject awake and alert but with his consciousness devoid of any particular object. Thus, Jacobson believed that his technique could eliminate habitual thinking, at least temporarily, during total relaxation. He also believed that the effects of progressive relaxation would generalize to daily life and minimize excessive rumination or worrying.

The state Jacobson described, in which a subject's mind was alert but "blank," is similar to the state of "pure awareness" or "pure consciousness" that is said to be the goal of many forms of meditation. Meditative techniques can be divided into two types depending on whether they involve active or passive forms of concentration (Naranjo & Ornstein, 1971). This active-passive distinction is similar to the one drawn by James in discussing attention. In active concentration, mental effort is used to direct the focus of attention; in passive concentration, the attention is left free to be drawn by any mental object, though usually some focal object, such as the act of breathing or a mantra (a Sanskrit word that is usually easy to articulate but may have no meaning to the user), is used as a point of departure. It can be shown, within the context of the MTVT, how passive mantra meditation can lead, by a complementary route, to the same state of thought-free alertness described by Jacobson.

According to the technique of transcendental meditation (TM), a form of passive mantra meditation popularized by Maharishi Mahesh Yogi (Bloomfield, Cain, & Jaffe, 1975), one is to return one's attention to the mantra whenever one becomes aware that his attention has wandered, but one is not to use mental effort to maintain the mantra in awareness. The effect of "trying" to think of the mantra without expending effort is that one becomes increasingly aware of the effort exerted in producing any thought. According to the MTVT, the effort involved in producing a thought is nothing more than the effort exerted to create the motor activity that evokes the thought. By becoming increasingly aware of producing very subtle motor activity, the individual may gain the ability to relax such motor activity, including the motor activity responsible for habitual thinking. Thus, it may be possible through both passive mantra meditation and progressive relaxation to become aware of and relax away the spontaneous covert motor activity underlying habitual thought.

The alleged benefits of progressive relaxation (Jacobson, 1964) and transcendental meditation (Bloomfield *et al.* 1975) with respect to reduced anxiety and increased energy and efficiency may be due in large part to the reduction of habitual thinking that may be produced by both techniques. Habitual thinking may be harmful not only as a consistent waste of energy but as a mediator of stress reactions.

V. CONCLUSIONS

A. *Summary*

The central assertion of the MTVT is that the experience of acting voluntarily arises solely from activity in the motor system, whether the voluntary act is physical or purely mental. However, not all activity in the motor system produces an experience of volition; only activity that requires deliberate conscious control produces this experience. Because the ordinary perception of one's environment does not appear to require any volitional act or to give rise to any sense of effort, the MTVT, unlike the motor theory of consciousness, does not posit the necessity of motor activity for the emergence of conscious perceptions. Similarly, some mental images seem to arise spontaneously by association with a perception or another image. The MTVT does not posit that these mental experiences require motor activity either, although the possibility is raised that images which seem to arise spontaneously may actually be associated with habitual or automatic motor activity.

The MTVT does assert that all images and thought produced or guided in a voluntary manner are associated with motor activity. Deliberately imagined kinesthetic imagery is evoked by covert motor activity directly corresponding to the imagined activity. Similarly, all deliberate inner speech is based on the appropriate covert activity in the speech musculature. Visual imagery, however, cannot be controlled so closely or directly because there is no one-to-one correspondence between visual perception and motor patterns. Similarly, imagery in the other modalities is not directly controlled, nor are shifts in external attention.

The MTVT asserts that all mental acts which involve the experience of voluntariness must be accompanied by some distinct pattern of motor activity. But it is conceded that it is not presently possible to state for all modalities the exact types of motor activation involved, nor can the possibility of significant individual differences be ignored. However, reasonable speculations can be offered. Inner speech appears to play a major role in evoking and controlling imagery in other modalities. Inner speech may be accompanied by motor patterns associated with perception as appropriate for each modality. Thus, visual imagery may be accompanied by squinting and, if the images require motion or scanning, eye movements in the appropriate direction. The voluntary imaging of tastes or smells may be accompanied by covert oral or nasal adjustments. Attending to some types of imagery or some aspects of the external environment may be aided by directional adjustments in bodily posture. In the most general case, overall increases in bodily tension or, just in certain idiosyncratically preferred muscles, may aid any form of mental effort. On the other hand, motor activity may be deliberately inhibited during states of spontaneous attention, in order to reduce internal distractions. In such states, only a few muscles may be contracted, and these contractions would be maintained steadily.

Conversely, during the marked reduction of motor activity produced by fatigue, the organizing effects of motor activity upon thought would decrease, and the stream of thought would tend to flow more by free association than according to logically structured, purposeful plans. Finally, spontaneous thinking, which may seem virtually impossible to eliminate voluntarily, may be the result of habitual covert motor activity. Both progressive relaxation and certain forms of meditation hold the promise of allowing the individual to gain greater awareness of the habitual motor activity that produces incessant thoughts and thereby to gain greater control of his consciousness.

B. *Implications for Experimental Research*

1. *The Issue of Necessity*

In its present form, the MTVT would not be easy to prove or disprove experimentally. Because the MTVT posits that only central motor

activity is actually necessary to produce the experience of volition during mental activity, attempts to block muscle contraction peripherally are irrelevant. Even if data were collected showing that for at least a few subjects no measurable EMG changes could be found during a period when the subjects were expending great mental effort and not receiving any paralytic drugs, it could be argued that these subjects were producing tension in idiosyncratic muscle areas not measured. Alternatively, it could be argued that these subjects were generating motor activity sufficient to generate useful central feedback, but not sufficient to produce measurable changes in muscle contraction.

To block central motor activity by artificial means is not possible at the present stage of neurophysiology, and considering the difficulty of defining motor activity as opposed to other forms of neural activity within the central nervous system, this means of disconfirming the MTVT may never be possible. However, there are nonpharmacological methods for reducing central motor activity that can be considered. For instance, if biofeedback procedures are employed to ensure that a subject maintains a state of relaxation in a certain muscle region, it can be assumed that this relaxation is the result of a reduction in central motor commands directed at that region. This was the approach adopted by Hardyck and Petrinovich (1970); these investigators found that subjects who kept their laryngeal region relaxed while reading a difficult essay exhibited worse comprehension than subjects who kept their forearms relaxed, or nonrelaxed control subjects. The group that maintained relaxation in their forearms was included to control for the distracting effects of trying to keep the EMG biofeedback signal off (i.e., keeping the EMG amplitude below some threshold value). The effectiveness of this control procedure can be questioned. The tendency for forearm tension to rise while reading is far less than the tendency for laryngeal tension to rise (this was even confirmed within the Hardyck and Petrinovich study, for the nonrelaxation group), so keeping forearm tension at baseline levels is probably the easier and less distracting condition. Therefore, distraction cannot be ruled out as an explanation for the impaired reading comprehension in the laryngeal relaxation group.

The optimal design for using the biofeedback-relaxation strategy is to select two different mental tasks which are associated with muscle tension in two different areas; four conditions are employed such that in two conditions subjects are relaxing "necessary" muscles and in the remaining two conditions relaxing "irrelevant" muscles. Unfortunately, demonstrating that the relaxation of necessary muscles impairs mental task performance significantly more than the relaxation of irrelevant muscles would still not prove the necessity of motor activity for mental performance. It could always be argued that the tendency to produce tension in one muscle region as opposed to others is invariably greater for a particular task, even though that tension is not necessary or even helpful. Because the degree of distraction associated with keeping a muscle relaxed is likely to increase with the tendency to activate the muscle during a particular task, distraction could never be ruled out as the sole cause for the relevant performance decrements. One would strongly prove the association between motor activation *tendencies* and particular mental tasks, but not the absolute necessity of motor activation. However, the stronger and more reliable these motor tendencies are proven to be, the more useful and important it becomes to delineate the exact relation between mental content and motor pattern, as will be discussed further below.

On the other hand, Cole and Young (1975), using the laryngeal biofeedback-relaxation technique, claimed to have demonstrated that subvocalization (i.e., covert speech motor activity) is not necessary for nonsense syllable memorization. Subjects receiving EMG feedback were compared to a control group which had no relaxation requirement at all. Although feedback subjects produced significantly more errors than the control group, Cole and Young attributed this impairment entirely to the effects of distraction. These investigators argued that the occurrence and type of errors in each group was unaffected by the presence or absence of subvocalization on any given trial. However, a serious flaw in Cole and Young's experimental design greatly weakens the force of their arguments. The EMG was recorded only from the laryngeal area, and this was the only area that subjects were ever required to relax. The larynx, though, is not the only area that is activated during audible speech or covert speech motor activity; according to McGuigan (1978) the tongue and lips, in that order, are the most sensitive indicators of inner speech. In fact, the bulk of speech information is encoded in the form of lip, tongue, and mouth movements; lip readers lose rather little information even without perceiving the speaker's laryngeal activity. It is quite possible that feedback subjects quickly learned to "mouth" covertly the nonsense syllables while suppressing laryngeal activity. Indeed, subjects may actually have compensated for laryngeal suppression with an increase in covert tongue and lip activity. Cole and Young's conclusions would have been far more compelling had they ruled out the above objection by additionally recording the EMG from the tongue and/or lips and including a group of subjects required to maintain relaxation in several speech areas simultaneously.

To prove that a pattern of motor activity is necessary for a particular mental event to occur, one must show not only that the motor pattern is exhibited whenever the mental event occurs but also that preventing the motor pattern's occurrence also prevents the occurrence of the particular mental event. It seems safe to state that, at present, the necessity of motor activity has not been proven with respect to any class of mental events. Moreover, for the reasons discussed above, it does not seem likely that the necessity of motor activity will be proven in the near future. However, although proving the necessity of motor activity for certain mental experiences would be of enormous theoretical interest, failing to prove necessity does not render worthless the vast wealth of data demonstrating the association between motor manifestations and various mental contents.

2. *Applications of Research in Covert Motor Activity*

There are at least two important reasons for studying the motor correlates of mental states even if those motor correlates are totally unnecessary. First, if patterns of motor activity are correlated in a highly specific and reliable way with certain aspects of mental experience, the motor patterns may serve as useful indicators of the type of mental content. These motor patterns, which can be measured through the use of several simultaneous EMG recordings, can provide clues concerning a subject's cognitive strategy at times when verbal report may be inconvenient, distracting, unreliable, or simply unavailable (e.g., aphasic patients). Second, the motor activity accompanying mental effort, whether helpful or not, can have psychological and physiological consequences that are of practical importance. In extreme cases, the muscle tension generated during mental concentration may produce a debilitating degree of discomfort.

In regard to the use of EMG patterns as indicators of cognitive strategy, the recent work of Cacioppo and Petty (1981) should be noted. These researchers monitored lip EMG during several cognitive tasks which differed in their expected demand on the use of inner speech. The relative amounts of lip tension generated by the different tasks conformed well with theoretical predictions. The EMG was also recorded from the left forearm to rule out the possibility that changes in general arousal, rather than inner speech, could account for the task differences in lip tension. Forearm EMG did not differ significantly between conditions, confirming the specificity of the observed changes in lip tension. The Cacioppo and Petty experiment represents an excellent example of the way measurements of covert motor activity can be measured and used as a tool to explore cognitive processes. However, one improvement should be mentioned. By using forearm EMG as a comparison to control for the effects of general arousal, Cacioppo and Petty implicitly assumed that the forearm would be as responsive—or at least nearly so—as the lips to changes in general arousal. This need not be so. It is quite possible, as has been argued before (Cohen, 1983), that some muscles, such as the orbicularis oris (which manipulates the lips), or the corrugator (which pulls down the brow), are far more responsive than other muscles to changes in general arousal. The use of additional simultaneous EMG recordings to measure more comprehensively the tension patterns that accompany the performance of cognitive tasks would expand the usefulness and render more conclusive the results obtained by Cacioppo and Petty.

The design of the Cacioppo and Petty experiment was based on the great volume of research (a large portion of which was conducted by McGuigan and his associates) which has established the reliable and specific relation between the use of inner speech and the covert activation of the speech musculature. Further research involving the motor correlates of other types of mental activity is needed to expand the usefulness of covert motor activity as an indicator of cognitive strategy. For example, the motor correlates of visual imagery should be studied more thoroughly, using EMG recordings from several facial areas, particularly around the eyes, in addition to the EOG for measuring eye movements. The visual imagery tasks used in these experiments should be designed so as to control more carefully various aspects of the images subjects are expected to form, such as the size of the image and the direction of any required motion or scanning. Research involving imagery in other modalities, though less useful in the exploration of higher cognitive processes, would be of considerable theoretical importance, as the results could refine and clarify our conception of the MTVT.

Much research effort has recently been directed towards the classification of facial expressions associated with distinct emotions, and the use of facial EMG as an indicator of specific affect (Fridlund and Izard, 1983). The bulk of this research has focused on affective states that are typically regarded as highly emotional; little attention has been paid to the affective state known as "interest." However, because interest often accompanies and blends with various emotions, and because for many individuals interest may be present by itself more frequently than any other affective state, it would seem worthwhile to explore the motor correlates of mental states involving relatively pure interest. It should be noted, however, that these motor correlates may vary according to the general direction in which the interest is deployed. For instance, interest stimulated by the environment may be associated with a somewhat different facial expression (and other motor manifestations) from interest in one's own mental imagery. Moreover, interest involving audition may differ motorically from interest in the visual field. During the early phases of research into the motor correlates of interest, investigators should be careful to note the exact conditions by which the state of interest was evoked and to record from as wide a representation of muscle areas as possible.

It would be very helpful if the motor correlates of specific types of attention proved to be universal, exhibiting similar motor patterns from one individual to the next; assumptions could then be made about individuals whose motor patterns had not yet been observed in controlled circumstances. However, it would also be useful if individuals fell into well-defined categories based on their motor patterns during mental work; these categories might then be found to represent important and consistent individual differences with respect to cognitive style. But even if the motor correlates of mental activity were highly idiosyncratic—differing considerably between any two individuals—as long as these patterns were consistent within each individual over time, they could still be useful. One form of attention, the motor correlates of which could be expected to be rather idiosyncratic, is attention which is directed to one of several similar-sounding auditory stimuli distributed widely in space. Different individuals may employ a different set of motor patterns to aid their efforts in directing attention to a particular spatial location. One individual might control his attention in this situation by the position of his eyes, whereas a second individual might adjust the position of his jaw. (In the initial stages of this experimentation, many channels of simultaneous EMG recordings, as well as EOG and visual observation, would have to be employed to cover the many possible motor strategies that could arise.) If an individual maintained such a motor strategy consistently throughout an experiment, this information could be useful in subsequent experimental sessions with the same individual, in which the individual might be induced, for instance, to switch his attention rapidly between two inputs the spatial location and separation of which could be systematically varied. Just to observe the different motoric strategies of several experimental subjects as they switch the direction of their attention could be a useful first step in this research program.

The second reason mentioned above for studying the motor activity accompanying mental work involves the consequences of such motor activity. Regardless of whether such motor activity serves any useful function, it can result in high levels of muscle tension. There is evidence that muscle tension in some bodily areas, particularly the forehead, can rise continuously during sustained mental performance. More research is needed to determine whether the tension in these areas can eventually produce enough discomfort to interfere with mental performance. It is likely that individuals who are prone to having tension headaches would show steeper forehead tension gradients during mental work. Other individuals may show similar gradients in other muscles, perhaps in the jaw or neck. Even among those who rarely experience pain from muscular tension headaches, tension levels may reach high enough levels to produce distraction and diminish mental concentration. The possibility ought to be explored that individuals could be trained to increase their span for concentration by learning to relax certain muscles during mental performance. This was the hope of Jacobson (1938) in devising the concept of differential relaxation.

Finally, the possibility of reducing or eliminating extraneous and even debilitating thoughts through refined techniques of relaxation is too intriguing to be ignored. The potential benefits of such relaxation for mental health are enormous. Although numerous studies have been conducted using EMG biofeedback and abbreviated forms of progressive relaxation, such studies have not focussed on the relation between covert motor activity and the intensity of concurrent mental activity. Perhaps mental devices for relaxation can be validated and refined through the use of multichannel EMG measurement. Such experimentation could be capable of combining the benefits of ancient wisdom concerning meditation practices with modern technology in order to approach the highest goal of self-control: control of consciousness itself.

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3 Cardiac Afferent Influences on Consciousness

CURT A. SANDMAN

I. INTRODUCTION

The separation of reality from our experience of it has intrigued, confused, and consumed the greatest thinkers of our civilization. Philosophical treatises have been devoted to its analysis, dualistic religions have deified it, and theoretical physics has become its current harbinger. Although it is inviting to plunge impulsively into debate of the issue, instead a framework or paradigm will be erected (or resurrected) for merging mentalistic with psychobiological constructs. Within this framework the separation of reality from its experience had its most obvious expression in the posthumous "debates" of Walter Cannon and William James. The focus of these debates was the necessary ingredients of experience.

In the analysis developed by Cannon (1929), sensory input triggered a predetermined pattern of action or experience. The output of the system (effector system) was graded in terms of its magnitude or level of arousal (the "bang" theory of emotion) and was controlled solely by the central nervous system. Larger responses were assumed to relate to more intense stimuli (experiences), but qualitative differences in consciousness were not accommodated. This reflexive theory still guides most modern-day physiological studies of consciousness.

A radically different view was proposed by James (1892). He suggested that the experience of reality was a product of visceral and autonomic communication with the brain. Perception (or the experience of reality) gained meaning in the context (apperception) in which it was experienced. The peripheral nervous system, coupled with the environment, provided this context. Thus, the viscera, the muscles, and the

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