Rapidly accumulating evidence indicates that motor commands in the nervous system are associated with neuronal discharges that alter activity in both sensory and motor pathways. These alterations permit monitoring of the commands themselves so that subsequent motor activity can be modified even before the effector event (muscle contraction) has occurred. They may act to inform sensory systems that the stimulation produced by movement is self-generated rather than environmentally produced. In this way these discharges are, at least in an abstract sense, crucial for the distinction of self and non-self.

Evidence for the existence of these corollary discharges has been found for both relatively simple, rigid systems (e.g., eye movements in fish, insects) and for complex, plastic motor behavior in man. Here I speculate on what consequences might be expected from the existence and disruption of similar mechanisms at the highest level of brain activity—the level of conscious thought. It may seem improper to attribute to the organ of consciousness some of the same sensorimotor mechanisms (however elegant) that serve nervous integration and control at lower levels. But I am not without distinguished precedent. Freud (1938) employed sensorimotor schema in much of his writing. Hughlings Jackson (1958) suggested that “The nervous states concomitant (correlative) with psychical states are, according to the doctrine of evolution, sensori-motor. The highest centres (popularly the ‘organ of mind’, ‘mental centres’, etc.) are, according to this doctrine, only the most complex, etc. and latest developed of a series of centres, every one of which represents impressions or movements, or both” (p. 367) and, more succinctly, “It being quite certain that the lower centres are sensori-motor, it is surely a legitimate hypothesis that the highest are so too” (p. 367). Equally legitimate, I believe, is the proposition that the successful mechanisms of corollary discharge, required for integration and control of movement at simple levels of Central Nervous System (CNS) function, would be retained throughout evolution and play a role in the motor phenomena of conscious thought. Before discussing the implications of this possibility, I will briefly review the evidence for corollary discharge in the control of movement. For this purpose, I draw heavily from the lucid review of Evarts (1971), of which what follows is an incomplete summary.

While the notion goes back to Von Helmholtz (1925), the modern concept of “corollary discharge” or “effference copy” was independently put forward in 1950 by Sperry and by von Holst and Mittelstaedt. Sperry found that rotation of the eye by 180° in fish was followed by circling behavior. He made the following suggestion:

[The] kinetic component may arise centrally as part of the excitation pattern of the overt movement. Thus, any excitation pattern that normally results in a movement that will cause a displacement of the visual image in the retina may have a corollary discharge into the visual centers to compensate for the retinal displacement. This implies an anticipatory adjustment in the visual centers specific for each move-
ment with regard to its direction and speed . . . with the retinal field rotated 180°, any such anticipatory adjustment would be in diametric disharmony with the retinal input, and would therefore cause accentuation rather than cancellation of the illusory movement. [Sperry 1950, p. 488]

Sperry went on to give the homely but non-trivial example frequently cited in discussions of corollary discharge. When one moves the eyes normally, the visual world is seen as stable, in spite of the succession of images that cross the retina. But when the eye is moved passively as by tapping the eyeball, the visual world seems to move. The difference, Sperry suggested, is due to the existence in normal eye movement of a discharge correlated with normal movement that "would provide a neural basis for what Helmholtz called the sensation of the 'intensity of the effort of will' " (p. 488). A related, clinically evident phenomenon occurs in normal extraocular muscle palsy (von Helmholtz 1925; Kornmüller 1966). In such cases, an attempt to move the eye results in the experience of a displacement of the visual world in the direction opposite to the intended movement. Thus, the motor command's corollary discharge to visual centers, finding no visual change to annul (because of the palsy), acts unopposed and produces the experience of visual displacement.

In 1950, the same year that Sperry published his theory, von Holst and Mittelstaedt put forward a similar hypothesis. They had rotated the head of an insect 180° so that, so far as the rest of the nervous system was concerned, the two eyes were interchanged. Such insects, once they began to move, would spin rapidly to the right or left (testifying to the folk wisdom which states that it is important "to have one's head screwed on right"). Von Holst (1954) suggested:

. . . the efference leaves "an image" of itself somewhere in the CNS, to which the re-afference of this movement compares as the negative of a photograph compares to the print; so that, when superimposed, the image disappears. A motor impulse, a "command" from a higher centre causes a specific activation in a lower centre, which is the stimulus-situation giving rise to a specific efference to the effector (i.e., a muscle, a joint, or the whole organism). This central stimulus situation, the "image of the efference" may be called "efference copy." The effector, activated by the efference, produces a re-afference, which returns to the lower centre, nullifying the efference copy by superposition. [p. 91]

MacKay (1966) suggested that the cancellation theory proposed by von Holst and Mittelstaedt was quantitatively inadequate for perceptual behavior more complex than sensorimotor coordination in fish and insects. He introduced the concept of "feed-forward" control, in which motor commands are monitored and evaluated as they occur, before the effectors have been actuated. This "feed-forward" phenomenon is perhaps more appropriately described as "internal feedback" (Evarts 1951), since it arises from structures within the nervous system.

Internal feedback of this nature can affect both ongoing motor activity and sensory systems. While it is not necessary here to consider the neurophysiological mechanisms involved, it is pertinent to note that a large part of the brain is dedicated to such activity. Thus, Evarts has emphasized that the prominence of internal feedback loops increases with the size and complexity of the nervous system. He cites "Hassler's (1966) comments on the evolutionary changes in thalamic function, in which it is pointed out that only one-eighth of the human thalamus serves as a part of somatosensory systems, with the remaining seven-eighths serving as relay stations for other systems" (p. 97). The clinical importance of these internal feedback loops is, incidentally, demonstrated by the efficacy of pharmacological and neurosurgical treatments in human movement disorders; these treatments appear to interrupt disturbed feedback loops.

Let us now consider what consequences might ensue if conscious thought shared some properties of simpler motor acts, including internal feedback or corollary discharge. Ignorance of the effector systems of these highest motor processes must be admitted at the outset. Indeed, as Jackson pointed out, the " . . . highest motor centres . . . can act without producing peripheral reactions upon the environment" (p. 375). But it could be argued that their discharges may, by internal feedback, affect the highest sensory centers, each unit of which "repre-
sent[s] the whole organism in most complex ways” (p. 372).

Whereas the internal feedback associated with simpler motor acts is below the level of consciousness, one might postulate that the corollary discharges accompanying conscious thought are themselves conscious. If so, the subjective experience of these discharges should correspond to nothing less than the experience of will or intention. That this notion need not be totally fanciful is suggested by the experiments of Penfield (1974). He found that upon stimulation of the motor cortex of conscious subjects with sufficient intensity to provoke say, arm movement, they would state not that “I have moved my arm” but that “You (Penfield) caused my arm to move.” Moreover, this effect was not limited to motor acts. When stimulation of the temporal lobe brought memories into consciousness, the patient would report “You caused me to think that.” Thus, Penfield’s studies point to the existence of a mechanism analogous to internal feedback in the experience of conscious thought. By-passing this mechanism, even at cortical levels, bypasses the subjective experience of will or choice. To be sure, one ought not to make too strong a case on responses to such grossly unphysiological stimuli. But Penfield’s observations are at least consistent with the possibilities we are entertaining.

Let us consider now the clinical phenomena of schizophrenia in the light of this discussion. If thought is a motor process heavily dependent upon internal feedback, derangement of such feedback might account for many of the puzzling psychopathological features of the “psychosis of thinking.”

One obvious application of these concepts lies in the area of delusions, especially the so-called “autochthonous” delusion. In this situation, the patient is seized by a belief which he recognizes as unsupported by external evidence but which he feels compelled to accept. This symptom might directly reflect the absence of appropriate corollary discharge. Moreover, other common delusional experiences such as mind control by television sets or supernatural agencies might simply represent culturally determined interpretations of an experience in which thoughts seem to arise independently. “Independently” is, of course, not quite the right word; normally, many if not most of our thoughts emerge spontaneously into consciousness. We may simply lack a consensual language for the experiences patients describe as mind control—experiences hypothesized to result from failure or derangement of corollary discharge mechanisms.

Delusions, as Bleuler (1950) pointed out, represent wishes, fears, or some combination of both. Thus, it may be presumed that they are heavily influenced by the lower, appetitive brain centers. Recent evidence in invertebrates shows that corollary discharge from lower as well as from higher command centers is required for integration of both. For example, in the mollusk Pleurobranchae, corollary discharge from the buccal ganglion to the brain serves to coordinate the feeding rhythms that occur in both structures (Davis, Siegler, and Mpitsos 1973).

Disturbances of the organization of thinking (formal thought disorder) would be another consequence of impaired internal feedback, for such feedback would be crucial for the hierarchical programming of thought processes. Clinical experience suggests that delusional behavior and degree of formal thought disorder are not highly correlated. The mechanisms postulated here could account for this lack of correlation, since the particular symptoms produced would depend upon the locus of the deranged feedback loops (appetitive-cortical as opposed to intracortical, for example).

Auditory hallucinations are perhaps the most common symptom in schizophrenia. They often seem more cognitive than sensory (Feinberg 1962), and frequently have a strong affective tone. Impaired corollary discharge of the sort described above would be consistent with these phenomena as well.

Even more complex behavioral disturbances might be produced by disordered internal feedback. Thus, if corollary discharge, in permitting the distinction of self-generated from environmental movement, thereby contributes to the distinction of self and other, its impairment might produce the extraordinary distortions of body boundaries reported by schizophrenic patients. If, as suggested above, the corollary
Discharges accompanying conscious thought are themselves consciously experienced as the sensation of will, the subjective as well as the objective disorders of volition emphasized by Kraepelin (1919) in his original description of dementia praecox could be accounted for by the disturbances postulated here.

Thus far, I have emphasized the motor or efferent aspects of thought. However, schizophrenic patients often report sensory experiences consistent with ideas of being poisoned or persecuted, for example. Such apparent afferent disturbances might simply reflect a normal perception of an abnormal motor state. Alternatively, they may directly result from disordered internal feedback to the highest sensory centers, those which Jackson (1958) postulated must represent, in the most complex way, the entire organism, or self.

Finally, it may be less than coincidental that all drugs that ameliorate schizophrenic symptoms are capable of producing motor disorders. These extrapyramidal syndromes presumably result from alterations of internal feedback in striatal pathways. Perhaps antischizophrenia drugs alter the feedback systems of thought as well, opening disordered feedback loops and in this way alleviating psychotic symptoms.

The notion that disordered feedback circuits cause psychosis is hardly original, being at least as old as the first application of the concept of feedback to CNS function. Perhaps a partial justification for these new speculations is that they direct the attention of psychiatrists to recent discoveries of mechanisms of motor control which, on their own level, have profound implications for mechanisms of CNS integration. They also suggest a new, albeit hypothetical locus for the failure of neural integration thought to be present in schizophrenia: the corollary discharges associated with the motor acts of thought.

**Summary**

Many motor commands in the nervous system are associated with corollary discharges which alter the excitability in both sensory and motor systems. These discharges may assist in the distinction between self-generated and externally produced movements; they also allow (or represent) monitoring of the motor commands before the effector response has occurred. Here, I hypothesize that this mechanism of control and integration is also present in thinking, which as Hughlings Jackson pointed out, may be considered the highest and most complex form of motor activity. I speculate that if corollary discharges are normally part of the motor mechanisms of thought, their derangement could produce many of the symptoms of schizophrenia.

**References**


Acknowledgment

The author is grateful to Dr. E.V. Evarts, Chief, Laboratory of Neurophysiology, NIMH, and Professors L. Ganz and B. Libet, of Stanford University and University of California, San Francisco, for encouragement and suggestions.

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psychotherapy of schizophrenia conference

The Department of Psychiatry of the Yale University School of Medicine will sponsor a conference on the "Psychotherapy of Schizophrenia: Current Status and New Directions" to be held April 9 and 10, 1979. This conference, in honor of Theodore Lidz, M.D., will bring together some of the major contributors to the field of treatment for schizophrenia. The participants, representing a variety of orientations, will focus on the state of practice and research, suggesting new directions for treatment and study. Participants are listed below:

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