Gyr and his colleagues (1979) would have us confront anew the evidence for assigning a critical role for motor activity in visual perception. While their discussion of "sensorimotor processes" suggests a tightly coupled relationship between perception and action systems, we believe that the authors present a potentially misleading picture of the relationship between efference and afference. The thrust of this article will be to lay out some of the logical problems associated with a theory that utilizes the concept of efference copy. By and large these are in addition to those already raised by a number of commentators on a paper by Roland (1978). The present position is that efference copy and its often synonymously used affiliates, corollary discharge and central monitoring of efference are, with perhaps a single exception, low on theoretical power. This is the general claim to be made here. In addition, we wish to point specifically to an alternative account for the type of data that Gyr et al. seek to explain. We focus on the concepts of information discordance and allocation of attention, which when allied, seem to provide an adequate explanation of much of the adaptation literature—without resorting to unique contributions from efference copy.

Gyr et al. present the classical data for the role of efference in visual perception. Many of the methodological problems in extending this approach to human behavior have been raised by Shebilske (1977) and will not be re-enumerated here. More damaging, however, is the elegant rationale by Turvey (1977a) that an explanation of visual perception relying on a comparison of efferent signals to eye muscles and the retinal input provided by vision, falls sadly short when we move beyond the situation of a simple eye movement in a stationary head on a stationary body. When one considers the complexity of the visual array when an individual performs locomotory activities, for example, a simple computational explanation no longer suffices.

It is clear that Gyr et al. wish to extend the efference copy notion to movement coordination in general. They are, of course, not alone in this enterprise in that the efference copy concept is often used to explain—among other things—(1) the superiority of active over passive movement perception (e.g., Kelso, 1977; Teuber, 1974); (2) subject's ability to make rapid error corrections in step tracking tasks well within the bounds of peripheral
feedback loop times (e.g., Higgins & Angel, 1970); and (3) the motor performance of deafferented animals (e.g., Taub, 1977). While such data require satisfactory explanation, we do not want to place our money on an all-encompassing efference copy-reafference relationship. As long ago pointed out by Bernstein (1967), there is an equivocality between motor commands and the effects they produce. Therefore, there can be no direct comparison between efference copy and reafference because such a one-to-one mapping between the two sources of information cannot exist.

More important for a theory of coordination is the issue of how the multiple degrees of freedom of the motor apparatus are regulated. Powerful arguments can be generated against a view that efferent commands specify the states of individual muscles. A consequence of such a view would be an extraordinarily detailed efference copy that fails to take advantage of the intrinsic organization of the nervous system (for details see Grillner, 1975). Rather we wish to view efference not in an executive role but as organizational, in which the entities regulated are coordinative structures (Easton, 1972; Turvey, 1977b); that is, functional groupings of muscles that are constrained to act as a single unit.

A specific operation of efference in this perspective is feedforward in nature such that the performer is prepared for the impending motor output and the afference arising from such activity. Thus various experiments have illustrated postural adjustments and descending biasing influences on the segmental machinery in preparation for particular types of activity such as lifting the arm or dorsiflexing the foot (see Kots, 1977). Note that efference does not necessarily carry a central, motor-to-sensory corollary discharge connotation (Teuber, 1974). Such a view, while placing the motor commands in a sensory 'code' readily available for comparison with reafference, is just as subject to the mapping invariance and degrees of freedom criticisms outlined above. Rather, efference may be viewed in terms of feedforward, which, because of its particular biasing or tuning operations on the spinal cord, constrains the performer to a limited set of activities (Fowler, 1977; Greene, 1972).

Gyr et al. resort to deafferentation research as evidence for autoregulation of behavior at a central level. In agreement with Pew (1974) we would have to say that the argument is a default one taking the following form: (1) peripheral feedback has been eliminated, (2) the animal can perform various motor activities, (3) therefore some internal monitoring mechanism is responsible. A variety of alternative conclusions have been offered (e.g., Adams, 1976; Schmidt, 1975). But it has never been clear in this formulation what is meant by monitoring, or the nature of the entity that is being monitored. Taub's more recent work on perinatal deafferentation (e.g., Taub, 1977 for review) can be interpreted to mean that residues of past experiences, efference copies and the like, are unsuitable candidates for the monitored representation. These are likely to be very impoverished indeed and hardly able, even if one could imagine them to do so, to contain all the details of the action patterns such as climbing, hanging and grasping, that have been observed. But the stronger criticism here is that posing the question: Is an efferent signal necessary or not for normal perception? is a conceptual error. The tight coupling between efference and afference demands that we not treat them as individual entities but rather seek to understand the nature of
their interaction. Some headway has already been made in this regard. There is neurophysiological evidence that prior to and during voluntary movements in cats, afferent information in the dorsal column medial lemniscus is modified (Ghez & Lenzi, 1971; Coulter, 1974). Similarly, anatomical evidence reveals that descending pyramidal fibers exert both pre- and post-synaptic influences on the transmission of sensory information in the spinal cord (Kostyuk & Vasilenko, 1968). Furthermore, human psychophysical experiments on the perception of vibratory stimuli show that the sensory threshold becomes elevated during voluntary movement (Dyhre-Poulson, 1975). This modulation is specific to the digit being moved and is not merely a general gating effect on sensory inputs. In sum, we have evidence from a variety of sources illustrating the efferent modulation of afference.

Just as interesting is the rather direct influence of afferent information on efferent activity. At a neurophysiological level, Easton (1972) has shown that stretch of the vertical eye muscles leads to facilitation and inhibition of cat forelimb flexor and extensor muscles. A downward directed gaze resulted in facilitated forelimb extension while upward gaze facilitated flexion. More recently, Thoden, Dichgans, and Savidis (1977) have produced evidence that hindlimb flexor and extensor activity can be modulated by both vestibular and visual stimulation. Of particular note is the finding that direction-specific reflex excitability in extensor and flexor motoneurons could be induced by rotating a visual display about the cat's line of sight. Thus counterclockwise rotation, indicating displacement to the right, led to an enhancement of extensor motoneuronal activity and a depression in flexor motoneurons, while clockwise rotation had an equal but opposite effect. Analogous findings are available from the elegant "swinging room" experiments of Lee and his colleagues (see Lee, 1978). Even though the subject is supplied with veridical information from kinesthetic receptors that the floor is stable, posture and balance are shown to be under visual control as evident in the excessive sway observed when the room is moved. Indeed body sway can be visually driven by oscillations as small as 6 mm without the subject's being aware of it. All this points to a tight coupling, a specification as it were, of efference by afference.

The general claim here, then, is that the efference copy construct cannot handle the vagaries of the motor system nor does it provide a particularly useful explanatory device for visual perception. Neither do we want to approach the issue of adaptation via a framework that promotes a dichotomy between efference and afference as Gyr et al. have done. In actuality, there is no need to revert to a recorrelation formulation for an explanation of perceptual adaptation. It is now well-documented, for example, that adaptation can occur without movement (Howard, Craske, & Templeton, 1965), in passive conditions (Melamed, Halay, & Gildow, 1973), and in conditions where passive movement is induced by vibration (Mather & Lackner, 1975). All that is needed for adaptation to occur is a discordance between two or more sources of information that are normally congruent with each other. The performer's attempt to nullify this discordance, and hence return the inputs to their previous correspondence, is seen to be representative of the adaptive process. Numerous studies support this viewpoint (see Kornheiser, 1976, for a review) by showing that the degree to which adaptation takes place is a function of the information available to the subject regarding the altered state of the system.
While the notion of discordance is plausible as an account for the occurrence of adaptive change, it lacks predictive power with regard to the exact form that such change will take. The additional concept of attentional allocation provides a potential solution to this problem in that the outcome of any noncorrespondence between two sources of information (say proprioceptive information detected visually and proprioceptive information detected by joint, muscle and tendon receptors) can be predicted on the basis of the attentional demands of each input. Thus Canon (1970), Kelso, Cook, Olson, and Epstein (1975) and more recently, Warren and Schmitt (1978), have all shown that adaptation takes place in the modality that is not used during the exposure period. When allocation of attention is left uncontrolled, the dominant modality (in most cases, vision) will remain stable while the paired source of information will undergo an adaptive shift.

We are left then to explain, within this formulation, the consistent finding that self-produced movement facilitates the adaptive process more than passive movement. Viewed from the informational account, we would argue that under active conditions the subject is sensitized to pay attention to the discordance between the seen and felt positions of the limb, while under passive conditions, attention is more evenly distributed between the two sources of information. Given the dominance of vision and the subjects' inherent bias to attend to it (Posner, Nissen, & Klein, 1976), we would then expect greater adaptation under self-produced movement conditions. What matters then for the adaptive process is information about discordance, which, when combined with attentional factors, seems adequate to explain the findings attributed to motor-sensory mechanisms.

In the present view, therefore, there is no urgent need to reopen this issue based on Gyr et al.'s failure to replicate Held and Rekosh. Many of Held's predictions have been tested over and over again in an area already burgeoning with empirical data (e.g., Kornheiser, 1976; Welch, 1974, for reviews). The real need, therefore, is not for more experimentation but rather for more understanding of the nature of the adaptive process, with particular reference to the interaction of efference and afference.

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