

add to this body of work by presenting a framework for the control of some innate movements. In doing so, they present the clearest account to date of Feldman's equilibrium-point hypothesis, and the paper is thus a welcome contribution for those of us for whom Feldman's Russian manuscripts are inaccessible. However, in spite of the clarity with which the λ hypothesis is described, Berkinblit et al.'s overall scheme for motor control has some apparent weaknesses. Because of space limitations I will restrict my comments to the topic of motor equivalence.

Motor equivalence. Equivalences are primarily selective. The use of the term usually implies that compared objects exhibit similarities in specific ways, not all ways. As originally used (Hebb 1949; Lashley 1942), motor equivalence referred to a goal-level equivalence, and it is this goal or task level that is essential to the understanding of both the generativity of skilled action and what we commonly consider to be motor equivalence.

Whereas the empirical study of movement often necessitates experiments that test single-joint movements, most natural activities involve multiple joints and articulators. It has become clear that the control of these multiarticulate movements involves more than the aggregation of single-joint gestures. For example, the independent control of the equilibrium points of each of the joints in the human arm may be able to model the final configuration and final end-point position of a natural prehension, but this simple aggregation of single-joint control does not produce the quasistraight-line trajectories characteristic of natural reaches (Delatizky 1982). The control of such movements thus requires that a goal-directed relation between joints and articulators be established.

No recent data have emphasized this requirement more strongly than the results of studies involving dynamic perturbations during limb movements (Marsden, Merton & Morton 1983) or during speech production (Gracco & Abbs, in press; Kelso, Tuller, V.-Bateson & Fowler 1984; Munhall & Kelso 1985). In the standard speech paradigm, one of the articulators is unexpectedly loaded while the subject is speaking. In all cases, the speech system almost immediately compensates for the perturbation by both autogenic and remote adjustments. It is the latter adjustments by other articulators that suggest that a coupling between articulators is one of the fundamentals of motor control. In the speech case, this interarticulator coupling is not a rigid framework for speaking in general, but rather a flexible, task-specific linkage that varies with phonetic goals. For example, if the jaw (Kelso et al. 1984) or lower lip (Munhall & Kelso 1985) is perturbed at various points during the production of the utterance /bæb/, the upper lip shows no immediate response when the perturbation occurs during the opening phase of movement but shows increased activity when the perturbation occurs during the closing phase of movement for the bilabial consonant (i.e., when the upcoming oral closure must be achieved). This compensatory behaviour of the upper lip shows not only that the articulators are coupled during speech production but that the coupling is one that adjusts to the evolving behavioural state of the system. Such behavior would not be produced by a control regime that specified individual equilibrium positions for articulators or joints, or by a control system that tried to achieve an exact final spatial configuration; in perturbed trials the lips will make contact in an absolute position different from the one adopted on trials without a perturbation.

What kind of specification of an overall motor goal can account for such articulatory coupling as well as other aspects of motor generativity? The answer to this question is still emerging but some general principles are apparent. Two requirements of a goal-level description seem to be necessary – that it encompass a relative geometry (Thom 1985) and that it characterize the organizational invariants of the class of movement to which the specific action belongs (see Fowler & Turvey 1978; Kugler & Turvey, in press; Saltzman & Kelso 1983); that is, the goal must

Motor equivalence and goal descriptors ⁵⁶⁹

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One of the most remarkable characteristics of skilled movement is its reproducibility across an infinite variety of initial conditions and contexts. Equally as remarkable is the fact that even relatively simple organisms display such generative capabilities and, as Berkinblit et al. demonstrate, even spinal preparations show complex compensatory adaptations. Clearly, the origin of this behavior is in something that is very basic to motor coordination. The universality of such adaptive behavior further suggests that it derives from a structure that is independent of the details of any particular instantiation; that is, a common functional organization must be producing adaptive behavior in what are physically quite different systems.

It is for reasons such as these that over the past few years the search for an adequate account of skilled movement has focused on the spring-like behaviour of muscles, joints, and articulators. Mass-spring systems are examples of systems that possess great inherent potential for adaptive behaviour and organisms may control themselves to advantage in an analogous manner. The similarity between the behaviour of certain types of oscillatory systems and motor control phenomena has been successfully demonstrated across a range of movements from single-joint limb movements (e.g., Cooke 1980; Kelso & Holt 1980) to the gestures of the articulators in speech production (Kelso, V.-Bateson, Saltzman & Kay 1985; Munhall, Ostry & Parush 1985; Ostry & Munhall 1985). In their target article, Berkinblit et al.

be specified in a language that is independent of the peripheral state or particular articulator contribution, and yet it must capture the movement's "kernel."

In the Saltzman and Kelso (1983) scheme, goals are characterized by their abstract dynamics. The class of discrete positioning tasks is thus described by point-attractor dynamics (Abraham & Shaw 1982). The appealing part of this approach is that the parameters that determine the abstract dynamics are just those that constrain the relevant articulator dynamics. Further, the task-space topology shapes the resulting effector trajectories.

No explicit description of a task space is apparent in Berkinblit et al.'s account, and thus their model is primarily a model of single-joint function. The continuous regulation of control parameters to which they allude is at least superficially akin to what goal-level organizations achieve. Unfortunately, Berkinblit et al. give little information about how this continuous regulation might occur.

The use of "sets of motor-equivalent programs" is more problematic. First, it does not explain generativity. Some unspecified process is required to organize the "reserve" motor-equivalent programs and to be capable of selecting just that program that would be appropriate in a particular context. Furthermore, a limited set of motor-equivalent programs cannot account for the dynamic perturbation results in which unexpected perturbations lead immediately to an appropriate reconfiguration of the articulators even on the first perturbed trial. The size of the set of equivalent programs that would be needed to account for such behaviours would be clearly unmanageable. What is missing in the Berkinblit et al. scheme and what would eliminate these problems is a task-level description that is independent of the articulator complex. Without such a description, neither the cooperativity of different effector systems nor the inherent serial order of the components of actions such as the wiping reflex can be accounted for.

A final word on terminology is warranted. Throughout the target article, the authors use vocabulary whose full or common meaning they either explicitly (see their note 1) or implicitly disavow (e.g., reflex, central pattern generator, motor program). Motor program, for example, has well-known, precise definitions (e.g., Keele 1968) to which the authors clearly do not subscribe. Keele's motor program accounted for controlled movement by having all the details of the movement stored as a script for the generation of later movements. This view, which attributes the form of movement solely to the program – a sort of "puppets in the puppet" view of action – is the antithesis of Berkinblit et al.'s approach. In recent years there has been a growing tendency to make motor program a generic term for organization in the motor system. Although I am not advocating a proliferation of new terminology, I would like to buck the tide of linguistic change and restrict terms such as motor program and reflex to their original referents. As such, they are milestones in our attempts to understand motor control, not constant companions on the journey.

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