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TRANSFER OF MOVEMENT CONTROL IN MOTOR SKILL LEARNING

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This chapter is concerned with transfer of learning in situations involving the kinds of responses that are defined primarily as motor behaviors. The authors focus on situations where movement control is learned and transferred to some other situation. Complimentary treatments of the motor and cognitive bases of transfer are offerred. Definitional and experimental design questions surrounding transfer are discussed as are a number of important principles of motor behavior and motor control which have emerged in the past few decades. Principles of movement control are also discussed

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in terms of understanding some of the phenomena seen in transfer of learning situations.

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Technical Review by

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Certainly one important concern for any examination of the phenomenon of human learning--and of the aspects of learning concerned with transfer discussed in this volume--is the area of skilled motor behavior and its acquisition. It is, of course, extremely difficult to provide a simple distinction between those aspects of human functioning that we would wish to term "motor" and "non-motor," and yet on a more superficial level these divisions of human responding are generally understood by most students of human learning. The difficulty is that every "motor" response (except perhaps for the most simple of laboratory reflexes) has components which are perceptual-cognitive in nature, with some degree of decision-making invariably being required. On the other side, even the most "cognitive" of tasks necessarily involves a movement of some sort in order that the subject convey a response to the experimenter (a button press, or verbal report).

Nevertheless, it still makes sense to consider a motor/non-motor dichotomy, if by it we can agree to mean that "motor" tasks are those for which the primary problem for the responder is to determine how to produce a given action which is clearly specified by instructions and/or stimulus materials, rather than to determine which of a number of previously learned actions is to be produced when a particular stimulus situation is encountered. This focus on "motor" behavior emphasizes how the performer controls his/her limbs in particular ways that we term skilled (piano playing, pole vaulting, etc.), where the precise patterning of muscle forces and their timing are the primary determinants of success, and where decision making and the choice among patterns of activity are minimized. Thus, motor behavior involves situations in which the learner's problem is "how to do it" rather than "what to do" (Schmidt, 1982).

This chapter is concerned with transfer of learning in situations

involving the kinds of responses that we have defined here as primarily motor behaviors. Specifically, we have focused on situations where movement control is learned and transferred to some other situation, where such evidence often gives insight into the nature of the representations that were learned and transferred. We have deliberately deemphasized literature and ideas that are concerned with the transfer of perceptual, cognitive, or information-processing capabilities, as these are emphasized beautifully by Cormier (this volume). Our two chapters here can be seen as providing complimentary treatments of the motor and cognitive bases of transfer (see also Lintern, 1985).

After a treatment of some important definitional and experimental design questions surrounding transfer, we turn to a discussion of a number of important principles of motor behavior and motor control which have emerged in the past few decades, and which have been generated in experimental settings where transfer of learning has not been the primary focus. In later sections of the chapter, we discuss how some of these principles of movement control can perhaps help us to understand some of the phenomena seen in transfer of learning situations. Earlier analyses of transfer in motor situations has not had the benefit of these newer insights into movement control, and adding them here appears to contribute considerably (although tentatively) to our understanding of transfer.

Transfer: Some Definitional Issues

Transfer of learning is usually defined as the gain (or loss) in the capability for responding in one task (termed the criterion task) as a function of practice or experience on some other task(s) (the transfer tasks). As such, transfer becomes involved when we want to understand how tasks contribute to, or interact with, each other in training situations, and it forms the basis of understanding such situations as those involving the use of simulators for learning some complex and expensive criterion

task (e.g., piloting a 747), the use of various training strategies (e.g., lead-up activities), and the intelligent design of effective environments for maximizing learning. Here, the focus is on how learning one task affects the performance capability of another task.

Problems in Defining a "Task"

But the field of transfer has a definitional problem, as can be readily seen when one tries to define precisely what is meant by saying that a given task is different from some other task. Consider pairs of activities such as (a) throwing a ball 20 m versus 25 m, or (b) skiing in bright sunlight versus in dark clouds. Do these pairs represent different tasks, or merely variations of the "same" task? We can (and often do) arbitrarily define two "tasks" by altering relatively minor goal requirements (distance thrown) or the conditions under which the tasks are performed (lighting conditions). But, it should also be clear that one can progressively change these conditions along various continua so that, beyond some point, we would all readily agree that there have indeed been two "tasks" formed by such alterations (e.g., throwing 2 m versus throwing 100 m).

We can carry this extension somewhat further. If it can be argued that minor variations in an activity (e.g., distance thrown) produce two different tasks, then the same can be said for variations in behavior which occur "naturally" in the course of learning to throw an object, say, exactly 30 m. Because of our inevitable variability in such actions, some of the throws will be too long, others too short, and we must according to this argument consider each of these throws as examples of "different" tasks. And, it is well known that the structure of the underlying abilities shifts somewhat with practice (e.g., Fleishman & Hempel, 1955; Schmidt, 1982), which makes it possible to say that the task is "different" (in terms of its factorial structure) in early practice than it is in late practice. If so, then a performance of a given Trial n of some motor task is dependent on the

transfer from Trial n-1 and all previous trials.

Implications for Understanding Learning

This realization, for us at least, carries with it important implications for the study of learning and transfer. If this analysis is correct, then many earlier approaches in which the transfer of learning was considered as a particular category of learning, with its own laws, experimental designs, and spaces alloted in textbooks, is not particularly defensible. Rather, our view implies that transfer and learning are, in the final analysis, essentially indistinguishable, and that we should be careful about searching for the principles of transfer as if they were in some way distinct from those of learning. Later, we will present a number of examples which should make this issue more clear.

The Learning-Performance Distinction

These ideas about the similarity of learning and transfer have strong implications for how transfer (and hence learning) is studied. First, recall that transfer was defined as the gain (or loss) in the capability for responding in the criterion task as a result of practice or experience on some other task(s). The emphasis here on the capability for responding is exactly parallel to the emphasis in the study of learning, in which the old distinction (e.g., Hull, 1943; Guthrie, 1952) between learning and performance figures heavily (see also Schmidt, 1982). Here, the notion is that many variables influnece performance only temporarily (e.g., fatigue, drugs, "moods," and so on), the effects disappearing as soon as the variable is removed, these influences should probably not be thought of as learning. As a result, often elaborate designs are employed, in which subjects who performed under different levels of an independent variable in the acquisition phase are switched after a rest to the same "task," but with a common level of the independent variable. On such a test, the temporary performance effects should disappear, leaving behind the relatively

permanent effects that we wish to attribute to learning.

The same concern can be applied to studies of transfer. Many variations of transfer tasks can influence the performance on a criterion task, some of which are temporary and others "relatively permanent." As a result, many of the same concerns for the learning versus performance effects of independent variables are also present in traditional transfer situations, and the same cautions should be raised about the interpretations of the results, especially when one wants to understand the transfer of the underlying capabilities for performance. This issue further highlights the difficulties in distinguishing transfer from learning.

Some Fundamental Principles of Motor Behavior and Control

Consistent with the idea that the goal of transfer research is to understand the nature of what is learned and transferred, we have found it useful to try to bring some of the recent findings and thinking in the area of movement control and learning--which recently has focused on the underlying representations for actions--to bear on the problems of movement transfer. In the next few sections, we turn to a discussion of some of these ideas and principles which have emerged from the literature on movement control. Following this, we turn to a discussion of how these concepts might help us to understand some of the common transfer findings for movement situations.

Motor Programs

One of the most important ideas in motor control for the past 70 years or so has been the idea that (at least some) movements are controlled primarily open-loop, with a centrally "stored" structure (a motor program) responsible for the grading, timing, and coordination of the muscular activities needed to produce skilled movement behavior. The motor-program idea has had many forms, each with its own share of critics, and it is difficult to characterize in a simple way all of the various

notions that come under this banner But there are a few features which serve to define these kinds of ideas reasonably well. Three lines of evidence compel us to take the notion of motor programs seriously

First, very old (Lashley, 1917) and more recent (Taub & Berman, 1968) evidence on deafferentation has shown that movements are certainly possible without sensory information from the responding limb. Some movements, such as climbing, swinging, and grooming behaviors in monkeys tend to be controlled rather well without this feedback, whereas others such as fine finger movements show rather serious disruptions But the major point is not how much they are disrupted; rather, the important finding is that some movement can occur at all. If so, then a large class of models emphasizing chaining of responses to feedback produced from a prior part of the chain (e.g., James, 1890), or strictly closed-loop models based on error-nulling (Adams, 1971), are weakened considerably. At the same time, these findings support the notion that some central representation, not absolutely dependent on response-produced feedback, is responsible for the action.

A second line of evidence is that sensory information processing has been considered to be too slow to be an effective basis for controlling the moment-to-moment phenomena seen in at least rapid movement control. Systems which use response-produced feedback are very sensitive to feedback delays, and will oscillate uncontrollably if the feedback delays are too long (particularly if the gain of the feedback loop is large) As such, while response-produced sensory information undoubtedly plays a role in slower, ongoing movements (e g , steering a car), is is unlikely that quick responses can be controlled in this way Considerable evidence shows that, when the subject is suddenly and unexpectedly asked to change a movement in progress (Henry & Harrison, 1961), or to abort it completely (Logan, 1982, Slater-Hammel, 1960), approximately 200 ms can elapse before any

changes can be seen in the movement. Presumably, the movement is being controlled by some motor program in the mean time.

Such a concept is further strengthened by the findings of Wadman, Denier van der Gon, Geuze, and Mol (1979; Shapiro & Walter, 1982) with quick limb movements. In Figure 1 are EMG records from one of their experiments in which the subject made a quick elbow-shoulder extension movement to a new position some 15 cm away. The trace labeled Normal shows the patterning of EMGs during the normal conduct of this action, revealing a distinct temporal structure in which the agonist is active for about 100 ms, followed by the antagonist activity, with the agonist acting again near the end of the movement. A feedback-based view of control of such actions argues that this patterning is determined by the sensory information from the responding limb switching the muscles off and on[1]. But Wadman et al. also used a condition in which the limb was unexpectedly mechanically blocked, so that no movement could occur, and the EMGs for these trials are shown as the trace labeled Blocked. Here, we see that the EMG patterns are essentially identical for the first 100 ms or so, and then begin to be modified (presumably reflexively) during the later portion of the action. The important point here, in our view, is that the antagonist muscle is switched on at the proper time, even though the feedback from the "responding" limb must have been massively disrupted. This suggests that the patterning of the EMGs was structured before the action, and was carried out open-loop, at least for a while until the reflexive activities could begin to have an influence.

Figure 1 about here

A third line of evidence comes from a reaction-time (RT) analysis of movements begun by Henry and Rogers (1960). Here, the RT for a movement depends on the "complexity" of the response that is to be made. Since the RT measurement begins when the stimulus appears, and ends when the

movement begins, it was difficult to understand how RT (which occurs before the movement) could be affected by something that occurred later (i.e., movement complexity). This result is generally understood by assuming that the motor system is organized (during a response programming substage of RT) to produce the movement, and that more "complex" movements require more time for such processes to occur.

Feedback involvement. Original statements of the program view (e.g., Lashley, 1917), and even more recent ones (e.g., Keele, 1968), have been too strong in insisting that the movement control be strictly open-loop, with essentially no involvement from peripheral feedback. Evidence has always favored feedback control in slower movements, and more recent evidence suggests considerable feedback involvement in movement control even in quicker actions. For example, there is now strong evidence of spindle contributions to the fine details of an ongoing response, and that these activities may be responsible for such important features as compensations for unexpected loads (Dewhurst, 1967) or the maintenance of important mechanical (spring-like) properties of muscle (Crago, Houk, & Hasan, 1976). Recent work also suggests that vision can operate far more quickly than we had believed earlier (Zelaznik, Hawkins, & Kisselburgh, 1983). And, Forssberg, Grillner, and Rossignol (1975) found that a given stimulus presented during locomotion (e.g., a tap on the top of a cat's foot) leads to a completely different response depending on the phase of the step cycle in which the stimulus is delivered. Analogous findings have been found recently in speech motor control by Abbs (1984) and Kelso, Tuller, Vatikoitis-Bateson, and Fowler (1984). These so-called "reflex reversals" can be interpreted to mean that the program, in addition to controlling commands to musculature, is also involved in the "choice" of various reflex pathways. Presumably, this ensures that particular subgoals of the action during that phase are carried out faithfully if the limb is perturbed.

But it should also be pointed out that these results do not detract in any important way from the idea that some central representation of the action is the basis for action, and that feedback can interact with this central structure in a variety of ways. Under consistent movement situations, where the peripheral influences are presumably predictable or absent, the central representation could assume a particularly dominant role in movement production. Understanding the relationship between these central and peripheral influences in movement control has become one of the most important goals of motor control work recently.

Summary. Overall, the dominant idea is that at least quick movements are orgainized in advance, with some central representation defining the muscular activities that are to occur, and then this action is initiated and carried out aided by slight involvement from response-produced feedback. Current thinking is that some oscillator-like neural network (motor program, coordinative structure, central pattern generator, etc.) is activated, and that the ryhthmic properties of this structure are responsible for the timing of the various phases of the movement, with this control lasting for perhaps 1 s, or longer (Shapiro, 1978).

Generalized Motor Programs

Recent concerns about movement control focused on the fact that the motor program idea seemed to require that each movement that is to be made have a separate motor program to control it. This leads to logical problems concerning where so many programs could be stored, and how individuals could ever produce a novel movement (Schmidt, 1975, 1976, 1982). Various attempts to save the attractive features of movement programs discussed above, while addressing these storage and novelty problems, resulted in various ways of considering programs as generalized across a particular class of movements.

Rate parameters. For many of us, the first suggestion of this idea came

from Armstrong's (1970) experiment in which the subject learned a complex pattern of arm movement defined in both space and time, as most movements are. In Figure 2, the goal pattern is shown as the solid line, and a movement that happened to end too early is shown as the dotted trace. Armstrong's observation was that, when this movement occurred too quickly, the whole movement tended to be sped up as a unit. Notice that the dotted trace leads the solid one by only 90 ms at the first peak, by 230 ms at the trough (downward "peak"), and by 620 ms at the third peak. This was consistent with the idea that the entire movement was sped up essentially proportionally. More importantly, it suggested that the movement might be represented as some abstract temporal structure, but that it could be produced on any particular trial by selecting a rate parameter to define the particular movement time, the temporal structure remaining invariant.

Figure 2 about here.

Relative timing. Important to this idea was the identification of some invariant feature of the action--a feature which remained essentially constant while other features (e.g., overall movement time) were changing markedly (Schmidt, 1985a). One such feature has been termed relative timing, which is a measure of the overall temporal structure of the action. Invariant relative timing means that the proportion of the movement time devoted to some segment of the movement (e.g., the time from the first peak until the second) remains constant while the movement time changes. To a rough approximation, this invariance seem to be present, as this value is (2.94-.75)/3.59=.61 for the solid trace, and (2.28-.66)/2.90=.56 for the dotted trace. The invariance is not perfect in this example, but it suggests that some underlying timing structure might be operating here, prompting additional searches for these or similar invariants.

Initially, these and later findings in rapid limb movements (Shapiro, 1978; Summers, 1977), typing (Terzuolo & Viviani, 1979), and locomotion

(Shapiro, Zernicke, Gregor, & Diestal, 1981) generalized the idea of an essentially constant relative timing to a variety of tasks. This work generated a great deal of interest, as it seemed to provide one kind of solution to the storage and novelty problems of the earlier motor program ideas. Further, it suggested that this abstract structure might be one of the products of motor learning, and that each motor program might have a particular relative timing "signature," allowing us to recognize when one program (versus some other one) was being produced (e.g., Schmidt, 1982, 1985b). In terms of our present interests in motor transfer, these "signatures" could provide evidence of what was transferred by seeing that a particular timing structure learned in the transfer task is also evidenced in the criterion task after transfer. We return to this idea in a later section examining specific transfer phenomena.

Other movement parameters. This work has also revealed other ways that movements can be varied, while retaining their original timing structure. One common example is the parameter of movement size, revealed particularly well in handwriting. Consider one's signature, written on a check versus on a blackboard some 10 times larger. The two patterns, reduced photographically to the same size, show nearly identical features (Merton, 1972), suggesting that the same pattern was produced in both instances, but with a variable amplitude parameter. This example is interesting from another perspective when one realizes that the muscles and joints involved in the two actions are different. Check-sized writing involves mainly the fingers, with the "heel" of the hand fixed on the writing surface; blackboard writing involves essentially fixing the fingers, and moving the elbow and shoulder joints. The fact that the patterns are the "same" implies that the movement representation was certainly more abstract than the level of specific muscles and joints. In addition, various other parameters, such as movement direction (Shapiro & Schmidt, 1983),

movement loading (Denier van der Gon & Thuring, 1965; Sherwood, Schmidt, & Walter, 1986), and the slant in writing (Hollerbach, 1981), have been suggested. This work is relevant for transfer because it suggests that movements learned in one condition can be easily transferred to certain other conditions (only) if the underlying temporal structure is the same.

Current status of the generalized motor program concept. Looking back on this body of research conducted over the past decade, some general conclusions seem to emerge quite clearly. First, there is clear evidence that the patterns of activity in such actions "expand" and "contract" with changes in movement time, with the various segments in the action being nearly proportional to movement time. But a more careful analysis of this problem by Gentner (1985) recently reveals that a proportional expansion model is too simple to account for the data. And various nonlinear expansions have been shown in both limb movement studies (Schmidt, Sherwood, Zelaznik, & Leikind, 1985; Zelaznik, Schmidt, & Gielen, 1986) and in speech motor control (Kelso et al., 1984; Ostry & Cooke, in press). While this realization detracts considerably from the idea of a simple, abstract temporally organized movement program, it does not deny the possibility that some abstract structure is involved. And, it does not detract very much from the idea that these abstract structures--however they be defined exactly--will be the major basis for the learning and transfer of movement control.

Movement Specificity

We turn now to a completely different set of findings--using entirely separate methodology, tasks, and analyses emerging from the work on individual differences in skills--which appear to have considerable relevance to motor transfer. Many different investigations, produced mainly in the 1950s and 1960s, show consistently that movement skills are quite specific. That is, even skills that appear to be quite similar to

each other show very little correlation with each other. Not generally recognized by scientists dealing with learning and transfer, this phenomenon is evidenced by two different but related lines of research.

Intercorrelations. The formation of the specificity concept for motor behavior appeared against a backdrop of thinking about the generallity of motor (and cognitive) abilities that had emerged from the factor analytic work of the 1930s, in which a "general motor ability" was thought to underlie much of human motor responding. Although it was never precisely spelled out, the overall idea was that motor behavior was based on a relatively small number of movement capabilities, such as "balance," "eye-hand coordination," "agility," and the like. It was not until the 1960s that the underlying structure of movement skills began to be studied in earnest, with Fleishman's (e.g., 1965) work leading the way.,

But in the 1950s and 1960s, Henry (e.g., 1958/1968), in his studies of a wide number of laboratory movement skills, noticed that the correlations among skills was never very large. Indeed, even skills which seemed to be substantially the same, and thus would seem to be based on essentially the same ability structures, were found to correlate very poorly. One example from this series is Bachman's (1960) study of two balancing tasks--the stabilometer balance platform, and the Bachman ladder-climb task; here, the correlation between the two tasks, for subjects of different ages and sexes, ranged from +.25 to -.15, with the average correlation being essentially zero. This was surprising to many who expected an important "balancing ability" to account for much more of the variance between these two tasks. Lotter (1960) studied striking tasks, where a forward stroke of the right or left hand or the right or left foot was required. The hand-foot correlations were quite low (ranging from .18 to .36), which was unsettling to the ideas about some general "speed" or "quickness" factor. However, the correlations between the two hands (.58) and the two feet (.64) were

somewhat higher, suggesting that the "same" skills done bilaterally are somewhat more strongly related, which is relevant to work on bilateral transfer as we will see later on.

In general, an impressive volume of carefully done work on various motor skills tends to show that the correlations among tasks are generally very low. It is informative to peruse some of the intercorrelation matrices from the large abilities-oriented programs of movement skills done in this period. For example, Parker and Fleishman (1960) studied 50 widely varied tasks, and evaluated the intercorrelations among them as a basis for later factor analysis. Of the 1,225 separate correlations, most correlated .40 or lower, and only rarely was there a correlation of greater than .50. The highest correlation was .85. A fair generalization is that motor skills tend to be very poorly correlated unless they are very minor variants of each other, making them essentially identical.

The usual interpretation of these findings is that the underlying abilities for movement skills tend to be very <u>specific</u> to the task. Henry's (1958/1968) and Fleishman's (e.g., 1957) views are that the number of abilities underlying all motor behavior are very large, perhaps 100 or so. Each skill has underlying it a large number of these abilities, but "selected" differently depending on the exact nature of the skill to be produced. Even a slight modification in the task requirements, such as slight shifts in the control-display relationships, the overall force requirements, or the role of sensory information, would be expected to call in a substantial number of different abilities for the two "tasks." Since these various abilities are presumably independent in these models, subtle shifts in task requirements tend to make the correlations drop sharply. Even though we would agree subjectively that the two tasks were really the same, and would happily assign them the same name (e.g., a test of "anticipation"), they might not correlate to any appreciable degree.

Shifting ability structure with practice. Another important principle from the motor skills work, also with important implications for understanding transfer, is that the pattern of abilities underlying a skill appears to shift with practice, a clear demonstration of which is provided by Fleishman and Rich (1963). Subjects learned a two-hand coordination task, in which movements of two handwheels had to be coordinated to cause a pointer to follow a target. Separately, subjects were tested on two other tasks--a kinesthetic-sensitivity task involving judging the differences among lifted weights, and a spatial-relations test. Subjects were then divided into two groups according to the performances on these latter tests, and the group performances on the two-hand coordination test were plotted separately, although the groups were treated identically.

Figure 3 about here

In the top graph in Figure 3, the two-hand coordination test scores are shown for subjects grouped as high and low on the kinesthmetic sensitivity measure. Subjects classified as high performed no differently from subjects classified as low in early practice, but a difference between groups emerges as practice continued. We can say that the kinesthetic sensitivity test (and whatever ability or abilities it measures) became increasingly important in this task with practice. The bottom graph shows the two-hand coordination performances for the groups classified as high and low on the spatial-relations test. Here, subjects classed as high performed more effectively than subjects classified as low in early practice, but this difference disappeared with continued practice. Generally, the interpretation of this work has been that the pattern of abilities underlying a given skill shifts with practice, with some abilities (e.g., kinesthetic sensitivity) becomming more important with practice, and others becomming less important (spatial relations). One is tempted to say that various cognitive abililties seem to drop out, while other more motor

abilities come into play; but this generalization is probably too simple to be useful for more than the most global analysis of skilled behavior.

Finally, in addition to movement skills being very specific (i.e., uncorrelated with each other), evidence suggests that they become increasingly so with continued practice. This is usually seen in various factor analytic studies of skills, such as the well known analysis by Fleishman and Hempel (1955). Here, various stages of practice of a given task (discrimination RT) are examined in the same factor analysis with a number of reference tests. In addition to the expected reference factors, the authors identified a "specific" factor, which is thought of as containing abilities specific to the task and not related to the other reference abilities. This specific factor grows in importance with practice, so that at the end of the practice session it accounts for more variance than any of the other factors. One interpretation of this work is that the task becomes increasingly specific with practice, so that it correlates systematically lower with other tasks. Another view, which appears less certain, is that practice generates a "learned ability," specific only to <u>that</u> task, and with nearly nothing in common with other tasks. As we will see, this idea has a number of interesting implications for understanding transfer of learning.

Some Principles of Motor Transfer

In this section we consider some of the more common "kinds" of transfer, or at least situations or experimental designs in which transfer is seen. After describing some of the generalizations from the emprical work in these situations, updated with the relatively few new findings in this area from the past decade, we attempt an analysis in terms of the principles of movement control discussed in the previous sections.

Measurement of Motor Transfer

Figure 4 about here

An important starting point will be the description of the "amount of

transfer" found in motor-task situations, where a rough estimate of this "amount" can be had through percentage transfer. Consider a simple two-group design, in which all groups transfer to the criterion Task B, but where Group I practices some Task A beforehand and Group B does not. Some hypothetical results are shown in Figure 4 (left), where the fact that Group II performs more effectively than Group I on the first Task B trial(s) is evidence for positive transfer from Task A to B. Considering the improvement on Task B by Group II (i.e., X-C in the figure) as a kind of total, the gain in initial performance of Group I over Group II (i.e., X-Y) can be expressed as a percentage of this total [i.e., (X-Y)/(X-C) x 100]. While these and similar measures (Murdock, 1957) are generally useful, they raise many problems for subsequent interpretation. Ceiling and floor effects in task scoring, and phenomena that alter the scores temporarily (e.g., fatugue), make interpretations in terms of some transferred capability for performance difficult to draw (Schmidt, 1982). But even with these limitations, some insights into the magnitude of motor transfer can be provided by such measures.

Transfer Among Different Motor Tasks

When such measures are applied to experiments on motor transfer, the outcomes are relatively consistent: Motor transfer is generally very small. Consider a case in which the various "tasks" were formed by varying the speeds of pursuit rotor rotation (e.g., Lordahl & Archer, 1958; Namikas & Archer, 1960), with groups practicing at either 40 or 80 RPM before being transferred to the 60-RPM criterion task. From our computations of percentage transfer to the 60-RPM task, transfer never exceeded 64%, and the average percentage transfer computed across these various experiments was only 37%. See also Ammons, Ammons, and Morgan (1956), Baker, Wylie, and Gagne (1950), Jensen (1976), Lincoln and Smith (1951), and Siegel and Davis (1980) for other examples showing essentially the

same thing. This low transfer is quite remarkable, in view of the fact that the tasks were essentially the same, and varied only in speed.

When the pursuit rotor is varied by changing the radius of rotation on the rotor), transfer in the Lordahl-Archer (1958) study was somewhat higher (54% by our computations) than for changes in speed, which lends some support to the idea that changing the temporal structure is more detrimental to transfer than changes in size. Fumoto (1981) found that changing the shape of the track produced no transfer in some situations, and low transfer in others. Overall the transfer among these task variations appears to be very small.

These findings of low transfer can be explained by, or at least are in general agreement with, some of the principles from the motor control literature discussed earlier. First, when the task requirements are shifted slightly (e.g., among different speeds for the pursuit rotor) to produce two "different" tasks, the literature on specificity suggests that the two variations would not correlate well with each other, implying considerable differences in the underlying ability structures of the tasks. If so, then it is understandable how even slight shifts in the response requirements, which subjectively only alter the task in a minor way, may actually provide massive changes in the individual differences and in the underlying motor control requirements of the task. Thus an important point from this literature, as viewed from a motor-control perspective, is how "fragile" the structure of tasks is to variations in response requirements.

These results on low transfer among skills seem surprising in view of the work on generalized motor programs. One of the ideas was that a given program could be used at different speeds, maintaining the relative timing structure, simply by using a different speed parameter. Thus, one can ask why the variations in the pursuit rotor speed did not show large positive transfer, as each variant would presumably be controlled by the same

structure, but with a different overall rate parameter. We have no particularly satisfying answers. But one possibility is that the "span" of variations over which a given generalized motor program can operate is much narrower than the motor-control literature has led us to believe. Thus, the variations in rotor speed might not have resulted in simply parametric changes, but could have produced a shift from one program to a completely different one. If so, because there is good reason to suspect that these programs are distinct and generally nonoverlapping, there should be little reason to expect much positive transfer among speeds. Determining the "span" of movement programs is a difficult empirical question because of problems in distinguishing (a) two different variations of a given program from (b) two different programs (Schmidt, 1985b), and good answers are not available at present.

But another possibility is that shifting the speed requirements of these tasks disrupts not only the motor control requirements, but also the information processing and/or strategic patterns of the learner. For example, a shift in speed could change the perceived subgoals of the task (e.g., being quick versus being accurate), it could change the attentional focus of the subject (attending to what has happened versus what will happen), or it could change the strategies (Fumoto, 1981) that the learner brings to bear on the situation. This is possibile in tasks like the pursuit rotor, where ample time is involved in a 30-s trial to process sensory information, modify strategies, and the like, as not all the performance is determined by the effectiveness of some motor program as it would be in a more rapid movement. If so, then these changes in the fundamental information processsing activities when the movement requirements are changed even slightly may explain the relatively small transfer found.

In one way, these observations could be helpful in training and/or simulation settings by encouraging a more careful consideration of what

motor-control and information-processing activities might be changed by rather arbitrary alterations in the training or simulation conditions. But in another way, these views are disappointing because they only tell us what kinds of situations lead to a lack of transfer, and are inadequate in telling us about what is transferred. Part of the problem is that systematic work on the fundamental bases of motor transfer, in which hypotheses about the similarities and differences among tasks which do and do not transfer to each other are evaluated, have simply not been done.

Bilateral Transfer

Bilateral transfer is one of the oldest subdivisions of the transfer problem (e.g., Davis, 1898), and was studied extensively early in this century using tasks like handwriting, drawing and figure production, maze learning, and the like (Cook, 1934; Weig, 1932; see Ammons, 1958, for a review). While all of this work involved manual responding, from the perspective of movement control the "motorness" of these tasks was not particularly high. In most of the cases, the understanding of the transfer that was produced could be attributed largely to the subject's symbolic learning of the structure of the maze, the figure, etc., and applying this largely verbal/cognitive representation to the production of the same response with the other hand. Of course, many of the submovements (draw a line, turn left, etc.) were learned pre-experimentally, and the basis of transfer seems to be knowing when, under what conditions, or in what order to produce these already learned actions. This older literature, and similar recent additions to it (e.g., Dunham, 1977; Puretz, 1983; Tsuji & Ide, 1974), represent additional support and some limitations (e.g., Hicks, Frank, & Kinsbourne, 1982) for bilateral effects, but unfortunately do not seem to provide much insight into the nature of motor transfer.

But some recent findings, using more "motor" tasks, do provide considerable insight into this problem. One example comes from Shapiro

(1977), who had subjects learn a complex wrist rotation task similar to that used by Armstrong (1970; see Figure 1). The learner had to move to each of seven target positions in the proper order and in the proper time, the entire response occupying 1600 ms. The subjects practiced this task for five days with the right hand, receiving feedback of their space-time patterns after each trial from a computer screen, and the average patterning of the movements on the fifth day are shown in Figure 5 (open circles). These are expressed in terms of relative timing as discussed earlier, where the proportion of the total movement time occupied by each of the segments is plotted for each of the segments, the entire plot providing one kind of description of the temporal structure. As one might expect, this patterning changed considerably over the five days, and the pattern shown here is the result of considerable experience.

Figure 5 about here.

On the fifth day, Shapiro unexpectedly asked her subjects to do the task again, but this time to do it with the left hand. The filled circles in Figure 5 represent the proportions for these trials, and it is immediately obvious that the patterning was nearly identical to that done with the right hand, implying very high transfer from the right to left sides. This was true even though the left- and right-hand movements were not anatomically opposite to each other; the same directions of the handle were required for each limb, thus requiring opposite movement directions and muscle groupings (defined anatomically). Thus, something abstract was being transferred, which was not related to the specific muscles and joints involved.

These results, at first glance, might not be seen as involving motor transfer, as the abstract basis for transfer here could be some cognitive representation of "what to do." But evidence from the motor literature converges to suggest a more "motor" interpretation. Other aspects of Shapiro's work (right-handed performances only) show that when the

subjects are asked to speed up this pattern, they do so with only minor shifts in the temporal paterning; and, when the subjects are asked to speed up these patterns, and to ignore the timing they learned in previous practice, they again maintain the relative timing. This evidence, plus other work cited earlier here, suggests strongly that the representation for action was a kind of generalized motor program that was run off at various speeds depending on the task instructions. Our interpretation of the bilateral transfer effects, consistent with this programming view, suggests a relatively abstract program structure that can employ various limb systems in producing the response.

Other previous findings enrichen this picture considerably. Bray (1928) showed transfer of mirror-tracing performance from the hand to the foot. Using somewhat less rigorous methods, Raibert (1977) recorded his own *writing with the dominant hand, with the dominant arm (hand fixed), with* the nondominant hand, with the pen gripped in his teeth, and with the pen taped to his foot, all of which produced similarities in the movement patterning. The example cited earlier by Merton (1972), in which a check-sized and blackboard-sized signature were structured similarly, makes an additional point; the muscles and joints used in the two movements are entirely different, involving primarily the fingers in small writing and the elbow and shoulder in larger writing. In another example (Schmidt, 1982), try writing your signature backward with your nondominant hand; most people say it is nearly imposible. But now try it at the same time you are producing your normal signature with the dominant hand; most people say that the nondominant-hand movements just "flow out," simultaneously with the dominant-hand movements, although the signature is not perfect. This is similar to the recent two-handed aiming experiments, where the timing of the two hands is remarkably similar (Kelso, Southard, & Goodman, 1979), but can be slightly different depending

on various task constraints (e.g., Marteniuk, MacKenzie, & Baba, 1984).

All of this work is consistent with the idea that movement control is based on a centrally structured movement program, with rather rigid temporal structure, perhaps defined in something like relative time. When the same structure is used to produce the movement in another way, perhaps at another speed, with another size, with another limb, or with two limbs simultaneously, the motor system has relatively little difficulty in doing so. This is not to say that all of the learning that occurs is muscle independent, because that view would expect perfect bilateral transfer, which is certainly not usually the case. But it does force the view that a sizable part of what is learned, and what is then transferred in shifts to similar situations, is some motor progam representation such as described here. And, the work showing the similar kinematic patterning of the left- and right-hand movements adds considerable credence to this viewpoint. It provides strong direction for future work, in which similar bases for motor transfer from one task to another might be sought.

Part-Whole Transfer

The literature on the effects of practicing a part of a task on its subsequent whole-task performance--so-called "part-whole transfer"--is not particularly large, but a number of results agree well with an interpretation in terms of motor programming. Such effects are relevant for skill training situations, where instructors are tempted to "break down" a skill into its parts for individual practice before transfer to the whole task again. As we shall see, the effectiveness of these procedures depends strongly on the nature of the task examined.

If we define the "task" as a series of serially organized subactions, with a relatively long task duration (e.g., >10 s), then there is clear evidence that practicing the subtasks in isolation can transfer substantially to the total task (e.g., Seymour, 1954). This is not

particularly surprising, because with the long movement times, the subtasks are treated as essentially independent activities, and there is little difference in performing them alone versus in the "context" of tne other subtasks. If the task is continuous, with segments that are less well defined sequentially, then the effectiveness of part practice appears to decrease markedly. Or, if the "parts" are defined as two simultaneous dimensions (e.g., X and Y in tracking), the practice on these parts can transfer to the whole task, with transfer increasing as the "complexity" of the task increases (e.g., Naylor & Briggs, 1963; Stammers, 1980).

But if the task is discrete, with short movement times, tne effectiveness of part practice changes markedly. Lersten (1968) examined a rapid (<1 s) sequentially organized discrete movement. Grasping a knob attacned to a lever, the subject made a circular movement to contact a stop, then released the knob and made a linear movement to a target, attempting to minimize movement time for the whole (circular plus linear) response. Different groups practiced various parts of this task (circular, linear, etc.) in isolation before being transferred to the whole task. Unlike the situation with the slower sequential tasks, transfer was generally very low (less than 7%) or zero from the parts to the whole task. Surprisingly, for the group which practiced the linear component alone, the transfer to the whole task was negative, measured as -8%, but it is questionalbe as to wnether this effect is reliably different from zero. In any case, essentially no transfer from part practice to the whole task was shown

One interpretation of this interaction between part-whole transfer and task type is based on the notions discussed earlier about movement programming. In the long-duration sequential tasks, the parts can be controlled by movement programs organized sequentially, where the learner's task is to initiate each of the programs when its predecessor has run its course. In the rapid movements, however, there is not sufficient

time during the whole task to initiate each of the subparts sequentially, and here it is more reasonable to believe that the whole task was orgainized as a separate unit. Even though, at one level, the part in isolation and the part in the whole-task context are formally identical, on closer examination there may be considerable differences between them. In Lersten's case, for example, the linear part in isolation required the subject to accelerate from a stop located at the end of the circular phase; in contrast, this part in the context of the whole task already had the limb at a high velocity when it began. Thus, there should be marked differences between these two linear phases, especially when viewed in terms of the movement kinematics or in the structure of the EMGs.

If the kinematic or neuromuscular (i.e., EMG) structure of the "same" part is fundamentally different depending on whether it is performed alone versus in the context of the *whole movement* sequence, then it is reasonable to think of these otherwise identical parts as being <u>different</u> movements, with different temporal structures, and different motor programs. Thus, practicing a part in this situation involves practicing a motor program which is not involved in the whole task, resulting in essentially no transfer between them, which is essentially the result found. This interpretation holds that the programs for the part and for the whole are distinct, and that the part-program is not capable of being "merged" or transferred into the whole-program

When can practice of parts be beneficial for whole-task performance? From the motor programming perspective, the answer could be based on an analysis of the structure of the whole task. If the task is actually made up of two separate motor programs run sequentially, then practice on the first part in isolation should transfer to that part in context. An example might be a tennis serve, where (apparently) the movement is made up of a ball-toss and backswing as the first program, followed by a second

program which produces the hit at the proper time and place. Between programs, the performer analyzes the result of the first program (where the toss sent the ball), and decides where and when to produce the hitting motion. Presumably, effective decisions about whether or not to divide a task into its some component parts for practice in isolation could be based on estimations of the structure of the actions involved. According to this view, parts should be formed only on natural boundaries, and tasks that are programmed as a single unit should porobably not be divided at all.

Although such analyses of motor skills have not, to our knowledge, actually been conducted, adequate bases for separating the action into parts already exist. For example, the temporal structure within each of the programmed parts should show very little variability (across trials), whereas the temporal structure between two different programmed parts should show more variability. Thus, points at which variability increases could be taken as boundaries between two movement programs. Such analyses, of course, would require continuous records of the subject's behaviors during the action, and would not be simple to conduct. But such procedures are technically possible with the newer recording methods being used today, and could provide a strong link between movement control thinking and concepts of part-whole transfer.

Negative Transfer

In spite of its importance for understanding learning and transfer in motor behavior, negative transfer has not been examined very much since the systematic examination of these problems by Lewis and colleagues (Lewis, McAllister, & Adams, 1951; Lewis, Smith, & McAllister, 1952; McAllister, 1952, McAllister & Lewis, 1951). Lewis et al. (1951) used the so-called "complex coordination task," in which the subjects had to move a two-dimensional joystick and a foot control to match each of three stimulus positions, where a "standard" version of the task had the display

respond in the same direction as the controls. They studied the effect of practicing this task with a reversed control-display relationship on transfer to the standard task, varying the number of original (standard task) trials and the number of reversed task trials. They showed considerable negative transfer, which increased as the number of reversed task trials increased, as seen in Figure 6. This evidence suggested that negative transfer might be a serious problem in many practical settings.

Figure 6 about here.

Although little new evidence on negative transfer has been provided since the early 1950s, current speculation is that negative transfer will not be such a large problem after all. First, most of the transfer experiments examined in a previous section here showed essentially zero or low-positive transfer, and never showed negative transfer, leaving the Lewis et al. experiments as the only ones that provide clear evidence of negative transfer in motor situations. Second, in order to achieve the negative transfer they did, Lewis et al. completely reversed the control-display relationships--a drastic change that probably exceeded the task-to-task interference found in most everyday learning situations. And third, it is likely that the negative transfer was mediated in large part by cognitive processes (confusions about "what to do"), rather than to any negative transfer of motor control.

These ideas are supported by one of the few recent studies directed at negative transfer. Ross (1974) examined a common idea that two tasks having many early features of the motor pattern in common, but with some critical difference later on (e.g., a tennis vs. badminton stroke), provides a sufficient condition for negative transfer to occur. In a laboratory analog of this situation, where the force requirements of the final segment of an otherwise identical three-segment limb-movement task was manipulated, only minimal negative transfer between the versions was demonstrated;

and what negative transfer did occur was eliminated with just 10 trials of criterion task practice. Again, negative transfer did not seem to be a serious problem in these movement situations. Rather, we seem to find that, when the tasks are changed from being opposite to being merely different, transfer quickly switches from negative to zero, or perhaps to low-positive if similarities might outweigh the differences.

But various divergent findings make us uneasy about our conclusions concerning the general lack of negative transfer. Shapiro (1978) had subjects learn a nine-segment movement with a particular spatial and temporal pattern. When subjects were asked to speed up the movement, and to ignore the temporal pattern learned earlier,. subjects had great difficulty in doing so. Rather, they sped up the same pattern that they had been practicing previously, thus failing to produce a different pattern that might have been faster. This effect can be regarded as negative transfer, where doing the task at maximal speed was interferred with by prior learning of the particular temporal structure experienced earlier. Such effects appear to have important implications for practice situations in which the learner attempts to modify only a part of an action, and suggests that such patterns could be particularly resistant to modification.

Another example involves second-language learners. Speech production (not grammar or vocabulary) can be thought of as another example of a complex motor skill involving many muscles and articulators. We all know that difficulties in producing particular speech sounds in, say, English is critically related to the speaker's first language; for example, the "same" acoustic goal is produced systematically differently in speakers whose first language is French versus German. If negative transfer were not occurring, we would not expect to have these pronunciation difficulties be common for a particular group of first-language speakers, and we would not expect to be able to recognize one with a French accent. As such,

"foreign accents" might be our best evidence for negative transfer.

Specificity. Even with the two examples just given from limb patterning and speech tasks, the evidence still points to a general lack of negative transfer for skills. This conclusion fits well, however, with the evidence discussed earlier about movement specificity. Changing a task slightly presumably alters the processes and abilities involved in its execution, with only minor alterations being needed before the correlations among tasks approach zero. If so, then perhaps the reason we find so little negative transfer is that the task variations used in the literature are related so poorly to each other that there is no common basis for negative transfer to occur. In terms of the motor programming literature, we argued earlier that changing a movement task slightly can be argued to involve the same generalized motor program, but parameterized differently. However, changing it more than slightly, perhaps beyond the narrow limits of the program's capabilities, demands that a completely different movement program be used, having essentially nothing in common with the previous one. If the practice of one program does not alter the "strength" of other ones, then neither negative nor positive transfer would be expected between apparently similar tasks that use different movement programs.

Forgetting. The evidence on lack of negative transfer also agrees well with the common findings of nearly perfect long-term retention of at least some movement skills. Bicycling is the common example, and continuous tasks like pursuit tracking and stabilometer balancing provide the empirical justification (Fleishman & Parker, 1962, Ryan, 1962). If, as the interference theory suggests, forgetting is mainly caused by negative transfer from other tasks learned either prior to or after the original learning of some motor task, and negative transfer does not appear unless the tasks are essentially opposite to each other, then long-term retention might be so complete because at least some motor tasks do not have any

other motor tasks to interfere with them. This, of course, seems quite different than in the verbal domain, and indicates at least one place where forgetting of motor versus verbal skills might be explained differently.

Transfer Among Various Conditions of Practice

At this point, we change directions slightly to deal with a somewhat different, but strongly related, area of transfer research--that dealing with the transfer among different conditions under which a task is to be performed. At first glance, this area does not seem to fall clearly within the bounds of transfer research, which is concerned with transfer from one variation of a task to another. However, remember that changing the conditions under which a task is to be performed, such as eliminating illumination, changing the mass of the control lever, or even performing under massed vs. distributed conditions, can be thought of as altering the task somewhat. And, it is nearly impossible to define how much we can change task conditions before we are no longer willing to say that the task is the "same" task as before. Such task variations may be continuous, and decisions about where to "draw the line" are often arbitrary.

In the traditional learning experiment, the variations in the conditions of practice are studied in an acquisition phase, and then the effects of these variations on learning are evaluated in a "transfer test" (or a "retention test"), where all groups are switched to identical levels of the independent variable[2]. Such transfer designs allow the separation of temporary effects of the independent variable (e.g., fatigue) from the relatively permanent effects that we usually wish to ascribe to learning (see Schmidt, 1982). For the present purposes, it is interesting to note that the effects of practice (i.e., learning) under various conditions is evaluated in terms of transfer to another condition. Thus if a change in conditions really amounts to a change in task, as we argue here, then learning is evaluated by transfer to a different "task." Viewed in this way,

transfer experiments and learning experiments share many similarities, and perhaps cannot be distinguished at all.

Using this approach, a number of lines of research have been conducted which provide interesting insights into what might be learned (and, hence, transferred) in practice situations. One of these involves variability in practice, discussed next.

Variability in Practice

The motivation for much of this work was Schmidt's (1975) schema theory, which holds that practice generates abstract rules that govern classes of responses, with each class being represented by a generalized motor program. For example, throwing motions are presumably produced by a generalized throwing program, and individual instances (e.g., throwing a particular object a particular distance at a particular speed) are generated by specifying parameters for the generalized motor program. Parameter selection is based on rules (or schemas), formed on the basis of past experience with the program, which define the relationship between the environmental outcomes of the movements and the values of the parameters that were chosen. Thus, when the performer wants to throw a particular distance, the schema defines the parameter for the generalized throwing program, and the program is run off with this parameter value. In this way, each separate throwing movement does not have to be represented, and the person can generate novel movements which he/she has not produced previously (see Schmidt, 1975, 1982, for more details)

One major prediction of this theory is that increased variability in practice along the task dimensions relevant to the generalized motor program should result in greater performance on a novel variant of that task. Numerous recent experiments have examined this prediction in a variety of tasks (e.g., Johnson & McCabe, 1982, Husak & Reeve, 1979, Kerr & Booth, 1977, 1978, McCracken & Stelmach, 1977, Pease & Rupnow, 1983,

Pigott & Shapiro, 1984; Siegel & Davis, 1980; Wrisberg & Mead, 1981, see Shapiro & Schmidt, 1982, for a review of the earlier work). One study which shows these effects particularly strongly was reported by Catalano and Kleiner (1984). Two groups performed a coincience anticipation task, in which a series of lights "moved" toward the subject who responded with a button press when they "arrived." A Constant group received practice at the same speed of light travel on each trial, which was either 5, 6, 7, or 8 MPH for each of four subgroups. The Variable group received practice at each of these speeds in a variable order, the number of total trials being constant across groups. Then, after a rest, each subject was tranferred to four novel light speeds, two which were slower than the previous experience (1 and 2 MPH), and two which were faster (11 and 12 MPH).

Figure 7 about here.

Absolute errors on the transfer tests for these two groups are shown in Figure 7. Errors increased as the speed of light travel deviated more from the speeds practiced previously, and there was a clear advantage for the variable practice groups on the novel transfer tests. Such findings are reminiscent of generalization gradients, in which the errors are smaller as the test situation is made more similar to those involved in earlier learning. If so, then one can say that variable practice made the generalization gradient flatter, providing improved capability to generalize the earlier skill learning to novel situations. Such results are reasonably well established (but are occasionally absent) for adults (see Shapiro & Schmidt, 1982, for a review), and are very strong for children (but see Wrisberg & Mead, 1981).

These variable-practice effects have been important for theory in various ways. Their major impact has been seen in terms of support for schema theory, especially because the prediction of variable practice leading to improved performance on some novel variant of the task could

not be made by earlier viewpoints (e.g., Adams, 1971). Consequently, such results have been interpreted to mean that variable practice produces "stronger" rules for parameter selection, a view strengthened by the converging evidence from motor control on generalized motor programs. Although there have been other lines of support, the fact that variable practice produces more effective transfer to novel variants of the task has been seen as the single strongest line of evidence for the concept that motor learning is based on schemata. And, of course, this support increased our confidence that an important basis for motor learning and transfer was the generalized motor program, with the particular invariances in relative timing discussed in an earlier section here. This increased confidence tempted us to believe that we were close to understanding what was learned in motor skill acquisition, and what might be the basis for the transfer of motor control.

Contextual Interference Effects

But some recent findings concerned with so-called "context effects" have detracted considerably from this viewpoint. Shea and Morgan (1979) examined the acquisition of three similar motor tasks which involved knocking over a series of barriers in a prescribed order, with minimum movement time as the goal. Each of the tasks was defined by a separate pattern of barrier contacts, indicated by a diagram available to the subject before each trial. Subjects practiced these tasks in two different ways, for a total of 54 trials. Blocked practice involved doing 18 trials of Task A, then 18 trials of Task B, and then 18 trials of Task C, whereas Random practice involved a random ordering of Tasks A, B, and C across the 54 trials. Then, subjects in were transferred to either Blocked practice or Random practice in a transfer test, forming a 2x2 design, these transfer tests were conducted either 10 min or 10 days after acquisition.

Figure 6 about here

Figure 8 shows the results during the acquisition and transfer phases. Consider first the Blocked retention test (squares). Subjects who practiced under the Random conditions in the acquisition phase (filled squares) performed more effectively than those who practiced under the Blocked condition in acquisition (open squares), suggesting that the Random practice was more effective for learning. For the Random retention test (circles), subjects practicing under Random conditions in acquisition (unfilled circles) were again more effective than those who practiced under Blocked conditions in acquisition (filled circles), but the differences here were very much larger than in the Blocked retention test. Thus, even though the Random practice produced less effective performances during the acquisition phase, they produced more learning as measured on a retention test; this was true regardless of the nature of the retention test (Random vs. Blocked) or the length of the retention interval. Other studies have shown much the same thing (e.g., Lee, in press; Lee & Magill, 1983; Lee, Magill, & Weeks, 1985; Shea & Zimny, 1983), although the effects do not appear to be present in children (Wrisberg & Mead, 1983) or in "inexperienced" subjects (Del Rey, Wughalter, & Whitehurst, 1982).

The leading explanations of these effects come in essentially two forms. First, Shea and Morgan (1979; Shea & Zimny, 1983) have argued convincingly using verbal protocols that the interference produced by Random practice results in "deeper" processing of task-related information, with more extra-experimental relationships being formed and increased distinctiveness among the various tasks to be learned. This "deeper" processing then results in more effective performance at transfer. Lee and Magill (1983; Lee, in press), on the other hand, argue that Random practice causes forgetting of the <u>solution</u> to the movement problem, so that when the subject faces that problem again, a solution must be generated again, with this generation being an important process in

learning. Subjects with Blocked practice can presumably use the solution generated on the previous trial (perhaps with slight modification), leading to fewer generations, and to less learning as seen on the transfer tests.

But whatever the explanation, these findings produce considerable difficulty for the schema theory. First, if random practice is viewed as a kind of variable practice, then across the whole acquisition phase both the random and blocked conditions receive exactly the same degree of variability; the difference is merely in the ordering of trials. Thus, the schema theory would expect that, with the amount of variability being equal between groups, transfer would be equivalent as well, which is of course contrary to the findings seen in Figure 8. Second, the versions of the tasks studied in the context-effect experiments can not easily be thought of as "parametric variations" of each other; there is no simple way that one movement task can be transformed into another, and hence no way that a single generalized motor program (at least as conceptualized by schema theory) could control all of them with only a parameter change.

But most importantly, the variability in practice experiments supporting schema theory can be considered as studies of blocked and random practice. Along with more variability in responses, variable practice conditions also make the subject do something different on successive trials, whereas the constant conditions allow the subject to produce the same response on successive trials. Thus, there is a strong liklihood that the basis of the variabile practice effects is mainly related to the fact that subjects were prevented from doing the same response sequentially, rather than to the fact that they had more varied practice per se across the range of movements. If so, then there remains little compelling reason to continue to believe that variability in practice effects--the most solid evidence for schema theory as we have just indicated--indicate the learning of schemata and the use of generalized

motor programs. Also, variabile practice effects tend to be quite small and difficult to demonstrate in adults, whereas blocked-random effects tend to be very large, and easily demonstrated. Perhaps the variability in practice experiments have not made the task versions sufficiently different to generate the random effects seen in the context effect literature.

In terms of the major goal of this paper, a discussion of the evidence about the nature of motor-control transfer, these contextual interference effects detract considerably from the credibility of our earlier arguments. Earlier, we argued that motor learning involved acquiring generalized motor programs and schemata to parameterize them. And, we argued that these motor program representations were primary "ingredients" in transfer, perhaps even to the point that what is or is not transferred could be recognized by the kinematic structures produced. Such optimism was based on the belief that the concepts of the generalized motor program and schemata were secure and well protected by the compelling evidence about variability in practice. But now, with the plausible suggestion that variability in practice effects may actually be nothing more than random practice effects, much of the strength of the argument for schema learning and generalized motor programs has been withdrawn.

But two kinds of findings make us wonder whether all of the effects of variable practice are capable of being explained in terms of blocked/random practice effects. First, for children, variable practice is more effective than constant practice (Shapiro & Schmidt, 1982), and yet random practice is not more effective than blocked practice (e.g., Wrisberg & Mead, 1983). Second, variable practice conditions in which practice on a given variant of the task is presented in small blocks seems to be more effective for learning than completely randomized practice in children (Pigott & Shapiro, 1984, Wrisberg & Mead, 1983), not less effective as might be expected if random practice dominated. Also, there is the

question of how novel behaviors are produced, which does not seem predictable from the notions of how blocked and random practice operates. But the issues are complex, and it is probably premature to reject the concept of generalized motor programs and schemata, as a number of lines of evidence do support them relatively well. But it gives us strong motivation to consider other ways to explain data on learning and transfer.

Generalizations and Future Directions

In the previous pages we have described a number of important ideas from the literature on movement control, and have attempted to show how such concepts might be merged with various phenomena involved in transfer of motor learning. The outcome provides mixed messages, with some interesting suggestions about the basis of motor control transfer, but at the same time with some serious shortcomings.

On the positive side, we appear to be close to identifying some important invariant features that are a part of the representations of at least programmed acts, the most important of which was the idea that relative timing is reasonably well preserved across changes in a number of "surface" features such as movement time and movement amplitude. If so, then an exciting possibility is that this relative timing structure can be used as a kind of "fingerprint" to identify whether, or under what conditions, a particular movement program has become a part of, or has been transferred to, some other movement task. As we indicated, these ideas have a number of weaknesses, and they do not account for the precise details in the data very well (e.g., Gentner, 1985). Perhaps future models along similar lines will be able to account for the phenomena more effectively. If this can be done, then a number of important hypotheses can be evaluated with respect to what is learned, and what is transferred.

Even if these ideas about the nature of generalized motor programs do not provide the kinds of explanations we need, the fundamental data about

the specificity of skills, the sensitivity of these correlations to apparently small changes in task situations, and the underlying motor-program structure of at least quick actions seem to help considerably in understanding the important findings in transfer of motor learning. The overall amount of transfer found is apparently low because of the lack of commonality among even similar-appearing movement tasks. The lack of negative transfer, and the nearly perfect long-term retention of many skills, may arise because there are almost no tasks which are similar enough to interfere with a particular learned action. And, understanding some of the fundamental ideas of motor programming may provide a way to explain why part practice is effective for slow, sequential actions, and is essentially ineffective for quick movements. The answers are incomplete about movement programming, and there are as a result many gaps in our capability to apply these findings to transfer phenomena. But with the additional emphasis on kinematic and kinetic analyses of movement skills, progress in this area is occurring quickly, and these newer insights should have relevance to problems of transfer of movement control in the ways we have suggested here.

But a final problem is that problems of movement transfer have not been studied very extensively in the past few decades. In reviewing the recent literature on transfer in preparation for writing this chapter, we were shocked to find so little interest in problems of transfer of movement control capabilities represented in the literature. We find this curious, as transfer is certainly important in its own right, related as it is to simulator design and many training methods. We also see transfer as being more fundamentally related to, and perhaps inseparable from, larger problems of motor learning, which has also been relatively neglected lately. We do detect a renewed interest in motor learning, fueled by the interesting new findings in contextual interference discussed briefly here,

as well as new insights into the ways that feedback processes operate to maximize learning (Salmoni, Schmidt, & Walter, 1984). This rekindled interest in learning, together with the presently strong emphasis on kinematic and kinetic analyses that inform us about motor programming processes, should contribute strongly to the related area of motor transfer, hopefully generating a more systematic approach to problems in transfer that have been awaiting a solution for so long.

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Footnotes

1 Other models, also using sensory information from the responding musculature as a critical feature, are possible also. See Fel'dman (1974) for one such example, and Schmidt (in press) for a critique of it.

2. The use of the term "transfer test" is in some ways unfortunate, as it implies a shift to a different task. What is meant here, however, is a transfer to common conditions of a given task. But this again highlights the difficulties in deciding when a change in conditions is to be considered severe enough for it to be regarded as a change in "task."

Figure Captions

1. Rectified EMG patterns from a rapid arm movement (Normal), and for trials (Blocked) on which the movement was unexpectedly blocked mechanically; many features of the EMG patterns occured even though the limb was prevented from moving (after Wadman et al., 1979).

2. Position-time trace of a goal movement pattern (solid) and of a trial which was performed too rapidly (dotted); the dotted trace appears to be roughly "compressed" in time (after Armstrong, 1970).

3. Performance on the two-hand coordination test over trials. (Upper graph, groups classified as high and low on kinesthetic sensitivity; lower graph, groups classified as high and low on spatial relations, after Fleishman & Rich, 1963).

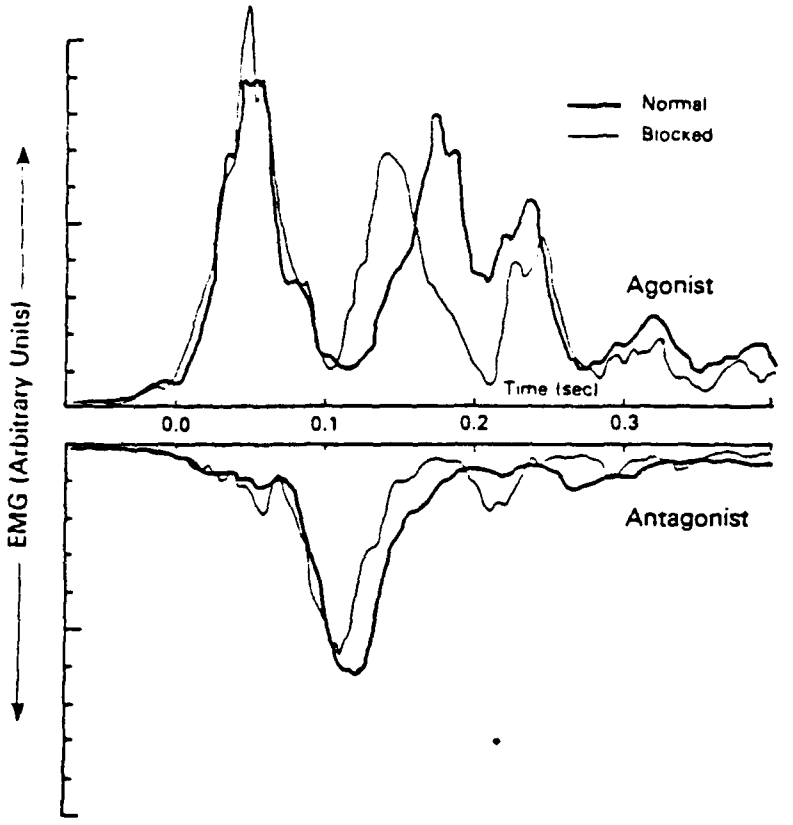
4. Hypothetical performance curves on Task B for Group I (prior practice on Task A) and Group II (without prior practice on Task A), whether transfer is positive (left) or negative (right), percentage transfer is [(X-Y)/(X-C) x 100] (from Schmidt, 1982).

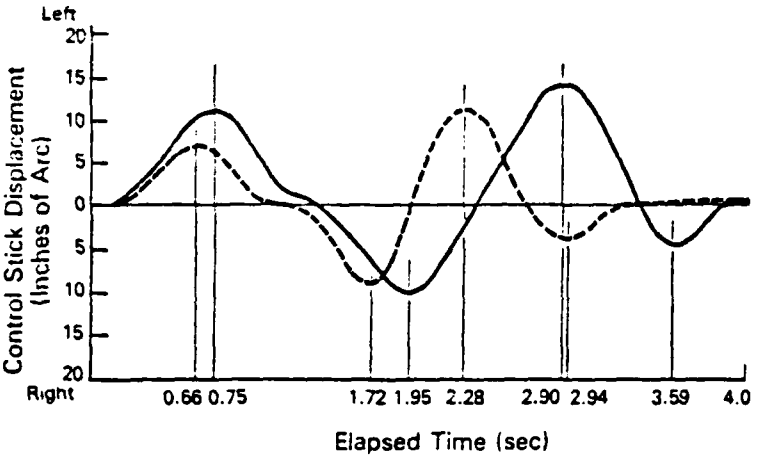
5. Proportions of time for the seven segments in a wrist-twist task for right-hand practice and after transfer to the left hand (after Shapiro, 1977).

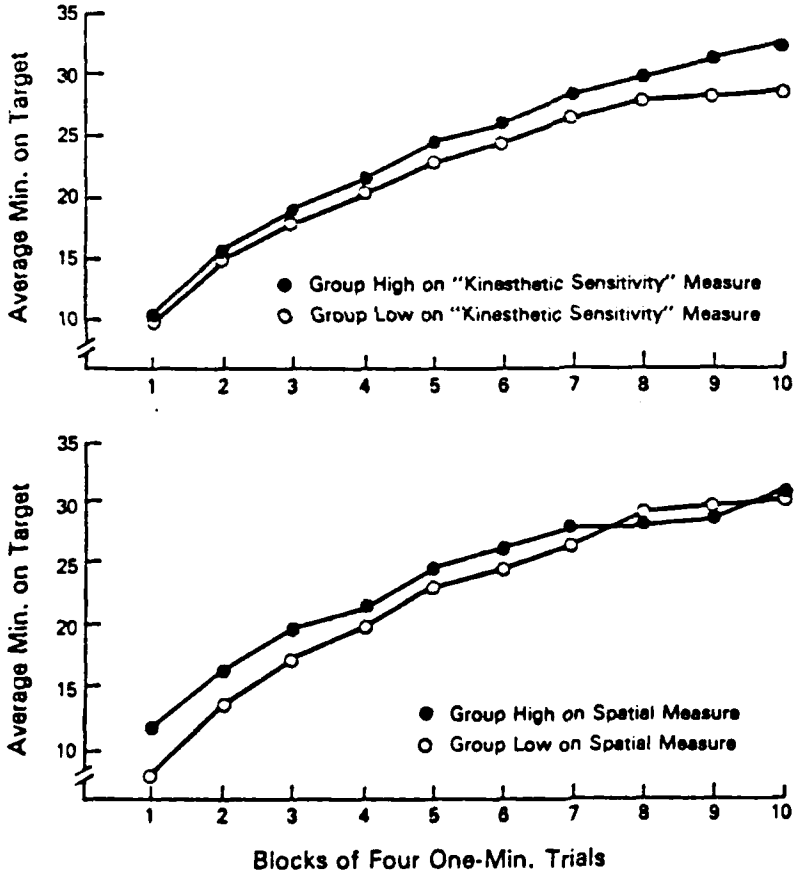
6. Mean decrement in number of correct matches on the Mashburn task as a function of number of original learning trials and the number of reversed-task interpolated trials; clear negative transfer is shown (after Lewis et al., 1951).

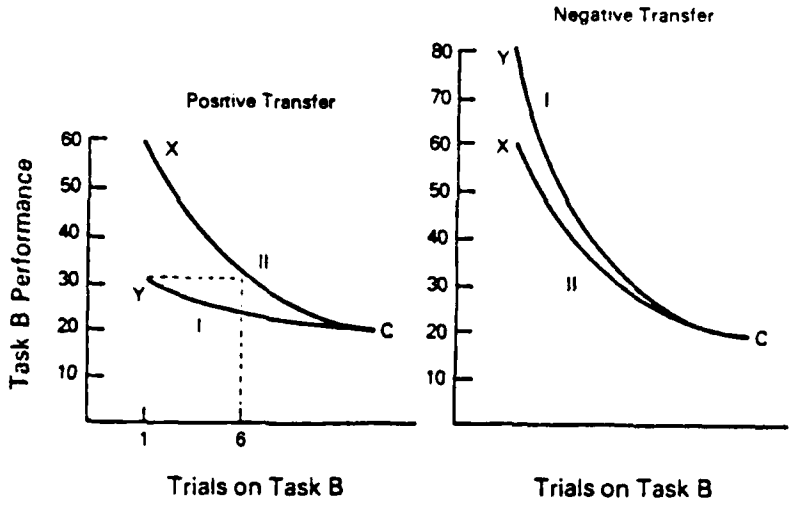
7. Absolute error in coincidence-anticipation after transfer to four stimulus velocities outside the range of previous experience; practice under varied conditions in acquisition produced less error in transfer than practice under constant conditions (from Catalano & Kleiner, 1984).

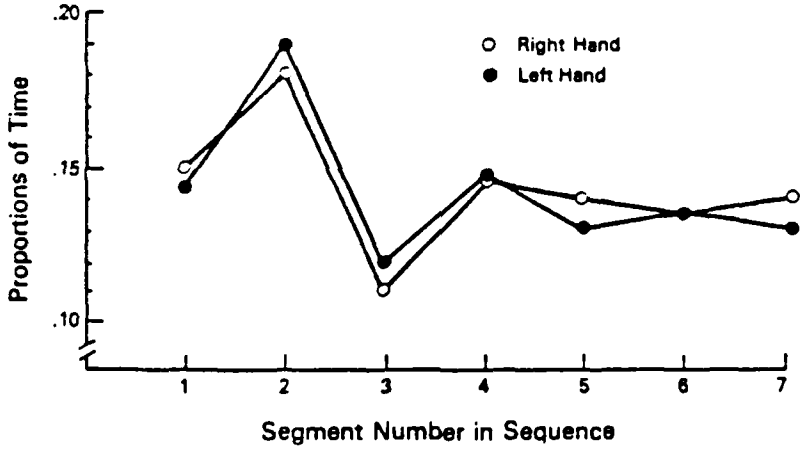
8. Movement time on a discrete arm-movement task as a function of the practice conditions in acquisition, and the practice conditions in transfer; practice under random conditions in acquisition produced faster performance in transfer than practice under blocked conditions (from Shea & Morgan, 1979).

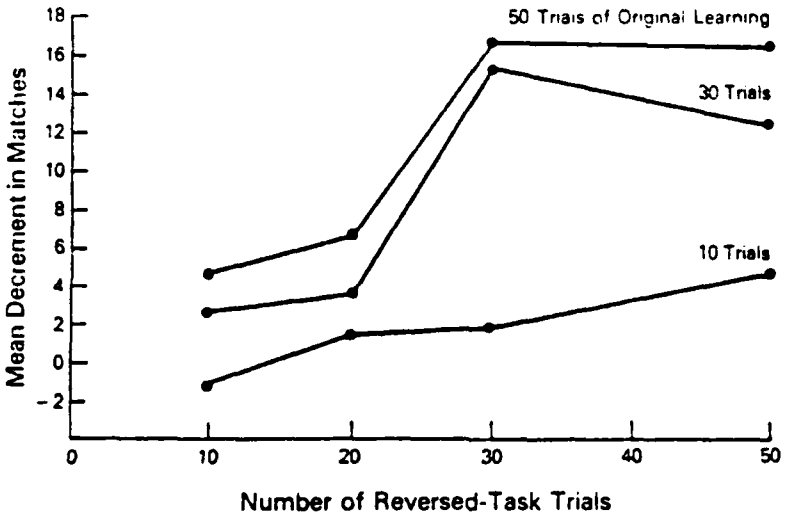

Normal
Blocked
Agonist
Time (sec)
0.0
0.1
0.2
0.3
Antagonist
EMG (Arbitrary Units)

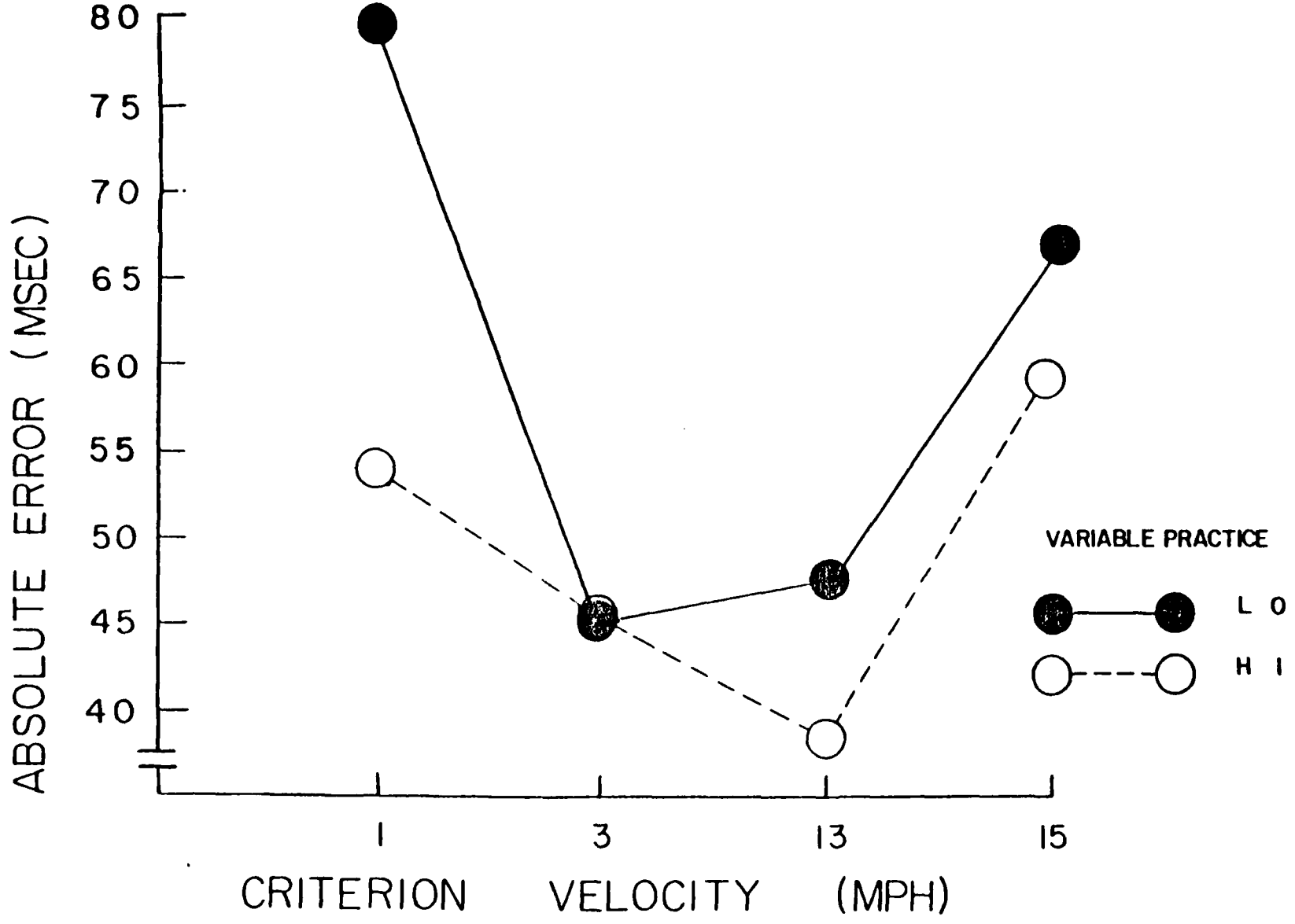

Left
20
15
10
5
0
5
10
15
20
Right
Control Stick Displacement (Inches of Arc)
0.66 0.75
1.72 1.95 2.28
2.90 2.94
3.59
4.0
Elapsed Time (sec)

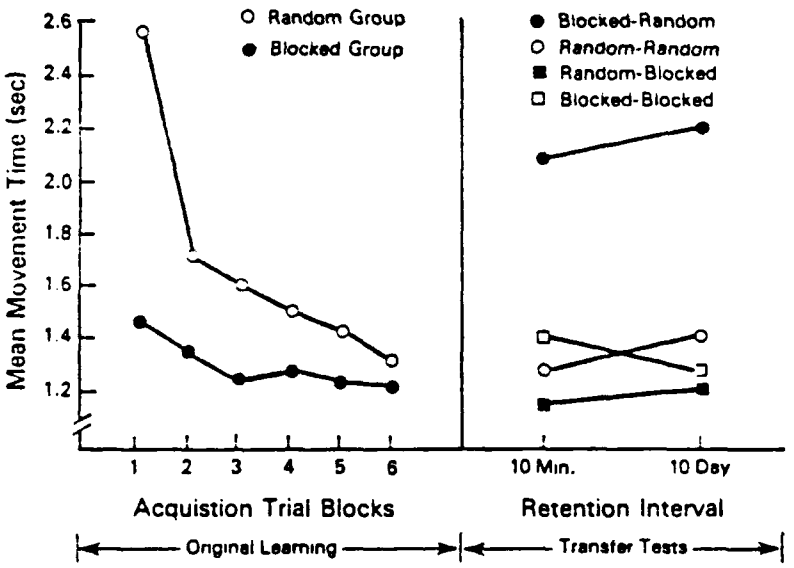

Average Min. on Target
35
30
25
20
15
10
Group High on "Kinesthetic Sensitivity" Measure
Group Low on "Kinesthetic Sensitivity" Measure
1
2
3
4
5
6
7
8
9
10
Average Min. on Target
35
30
25
20
15
10
Group High on Spatial Measure
Group Low on Spatial Measure
1
2
3
4
5
6
7
8
9
10
Blocks of Four One-Min. Trials


Positive Transfer
Negative Transfer
Task B Performance
60
50
40
30
20
10
80
70
X
Y
I
II
C
1
6
Trials on Task B
Trials on Task B


.20
.15
.10
Proportions of Time
Right Hand
Left Hand
1
2
3
4
5
6
7
Segment Number in Sequence


50 Trials of Original Learning
30 Trials
10 Trials
Mean Decrement in Matches
18
16
14
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
Number of Reversed-Task Trials


80
75
70
65
60
55
50
45
40
ABSOLUTE ERROR (MSEC)
1
3
13
15
CRITERION VELOCITY (MPH)
VARIABLE PRACTICE
L O
H I


Random Group
Blocked Group
Blocked-Random
Random-Random
Random-Blocked
Blocked-Blocked
Mean Movement Time (sec)
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1
2
3
4
5
6
10 Min.
10 Day
Acquistion Trial Blocks
Retention Interval
Original Learning
Transfer Tests