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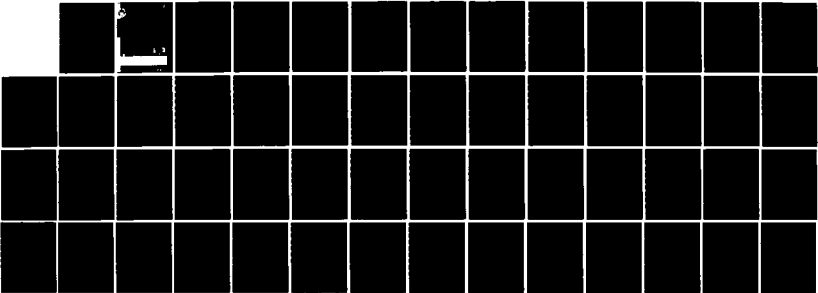
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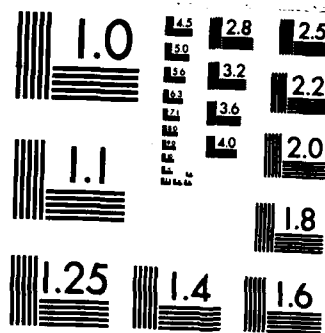
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A. PERCEPTUAL LEARNING
APPROACH TO SKILL TRANSFER
FOR MANUAL CONTROL

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<p>The impetus for a new approach to skill transfer for manual control grew out of dissatisfaction with some of the more popular explanations of transfer. Explanations of enhanced transfer in terms of similarity or manipulation of difficulty are inadequate. In particular, departures from similarity have been shown to enhance transfer, and manipulations of difficulty have sometimes shown that transfer is better following training on a more difficult task and at other times following training on a easier task. Other theories and hypotheses from basic motor skill research were also considered. None of the models or concepts that seemed relevant to transfer-of-training issues in manual control could account for all of the available data. Nor have they effectively guided research into transfer for manual control.</p>			
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A perceptual differentiation approach was proposed to account for opposing trends in a wide range of experimental paradigms. This view implies that detection, discrimination and differentiation of critical features, patterns and dimensions of difference in task-related stimuli are important in acquisition of manual control skills. Some of the data that were considered did not fit easily with explanations that ignore the role of perceptual learning. Manipulations that impact the perceptual dimension of manual control skills have been far more successful in producing transfer effects than have manipulations that impact only the response dimension. Thus, perceptual modification appears to dominate the learning challenge associated with acquisition of manual control skills. Emphasis on this dimension in future transfer-of-training research, and in theoretical developments, is likely to be particularly useful in advancing our understanding of processes that contribute to skill transfer.

The perceptual differentiation approach has clear implications for flight training. Techniques that enhance perceptual learning should improve instructional efficiency. The benefits could be substantial and may lead to better asymptotic performance as well as faster learning. Recent discussions of the role of simulators in flight training have noted the potential value of special instructional techniques, many of which are not feasible when aircraft are used for flight instruction. Thus, flight simulators offer potential benefits in addition to their cost advantage for training. The challenge for psychology is to determine how these simulators can be used to maximize training effectiveness.

TABLE OF CONTENTS

Section	Page
I INTRODUCTION.....	1
II BASIC CONCEPTS OF TRANSFER.....	3
Similarity.....	3
Task Difficulty: Easy-to-Difficult Transfer....	4
Task Difficulty: Difficult-to-Easy Transfer....	4
Summary.....	8
III ELEMENTS OF MANUAL CONTROL.....	9
IV DIFFERENTIATION THEORY OF PERCEPTUAL LEARNING...	13
V PERCEPTUAL LEARNING AND MANUAL CONTROL.....	17
Trials-Delay of Performance Feedback.....	17
Variations in Training.....	18
Task-Related Feedback.....	20
Higher-Order Structure.....	24
System Adaptations.....	27
Summary.....	28
VI ISSUES.....	31
Structural Changes.....	31
Principles of Learning.....	33
Summary.....	35
VII CONCLUSIONS.....	37
REFERENCES.....	39

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LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Transfer Between Pursuit and Compensatory Displays.....	5
2	Effects of Blocked, Random, and Serial Trial Sequences on Acquisition of a Barrier Collision Task.....	7
3	Schematic of a Typical Tracking Task.....	10
4	Effects of Immediate and Summary Feedback on Acquisition of Motor Tasks.....	19
5	Effects of Augmented Feedback on Acquisition of a Continuous Tracking Task.....	22
6	Effects of Training Scene Type on Acquisition of Bombing Skills.....	23
7	Effects of Part-task Training on Acquisition of Carrier Landing Skills.....	26

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Effects of Training Scene Type on Acquisition of Bombing Skills.....	24

SECTION I

INTRODUCTION

Following a period of relative disinterest, theories and concepts relating to acquisition and transfer of motor skill have received considerable attention over the last 15 years. An interest in the use of simulators for teaching manual control skills has also developed over that time, and it seems that the two areas should have much to offer each other. Unfortunately, the theoretical work on skill acquisition has offered little to guide designers and users of training simulators. Furthermore, research into the use of training simulators has not noticeably advanced our theoretical understanding of how motor skills are learned.

For those working in simulator training research there are two problems. The first is that research is conducted in an atheoretical framework that prevents generalization of principles beyond the immediate bounds of the study that produced them. Isolated results contribute little to our understanding of the process of skill acquisition and do not advance theory development. A second and contrasting problem is that lack of supporting theory or integrated body of knowledge leaves results standing in isolation. Their believability suffers from lack of consensual support, and the widespread acceptance of instructional techniques they suggest is slowed.

In this paper I review theoretical concepts that might guide the usage of simulators for teaching manual control skills, and examine how well these concepts account for data obtained from a variety of transfer-of-training studies. Similarity and task simplification have been the most popular concepts used to explain transfer, but they fail to account for a considerable amount of data. Perceptual learning is proposed as a dominant process underlying the acquisition of manual control skill. The differentiation theory of perceptual learning presented by Gibson (1969) is shown to provide a consistent explanation for much transfer-of-training data that have hitherto been difficult to rationalize. Implications for the use of simulators for teaching manual control are considered.

Transfer refers to effects on performance with an operational system of prior practice on a training device. Although transfer is generally positive, but less than 100% (meaning that the prior training is effective, but not as effective as equal training on the criterion or operational

*Additional topics: motor skill theory; motor learning;
Flight Training*

system), a number of studies have shown transfer of more than 100%. Such studies have strong implications for a theoretical understanding of skill acquisition and for development of applied training principles. This paper concentrates on studies showing transfer of more than 100% specifically because they offer insights into crucial and largely ignored issues of transfer.

Several studies to be discussed were presented by their authors as retention studies. However there are important similarities between tests of transfer and those of retention studies. Both have subjects learning a new skill in an early phase, and both test proficiency in a later stage. A retention experiment that uses multiple training strategies with independent groups, and that tests subsequent performance on a common set of conditions, can be viewed as a transfer study if the retention interval approximates the training-transfer interval used in transfer studies. For consistency within this paper, the acquisition and retention phases of the retention experiments that are discussed are referred to as training and transfer phases.

SECTION II

BASIC CONCEPTS OF TRANSFER.

SIMILARITY

Similarity has had a strong conceptual influence on simulator training research. Likeness to the operational task is often invoked to justify simulator design features, and this concept has dominated discussion of motion and visual systems for flight simulators. The theoretical rationale is heavily embedded in the response surface proposed by Osgood (1949). Although that surface was modelled entirely on the basis of verbal learning research, Holding (1976) reviewed it for its applicability to motor behavior. Holding's model indicates that maximum stimulus and response similarity should yield maximum positive transfer, but that some variation in stimuli should also yield high positive transfer. This latter point, that less than perfect fidelity on the stimulus side permits high transfer if response fidelity is maintained, seems to have escaped the notice of those involved with simulator training and, if recognized, may have blunted the ardent push for high fidelity motion and visual systems.

However, similarity fails as a general explanatory concept in a more fundamental way. For example, some research data show better transfer if the training task differs on specific dimensions from the criterion or transfer task. Lintern (1980) has shown, for example, that the addition of visual augmented feedback can speed acquisition of landing skill in an aircraft simulator. Wightman (1983), in an investigation of part-task training for teaching carrier landings, has shown that a backward-chaining procedure can enhance transfer to the whole task. In both of these experiments, deliberate departures from similarity actually speeded acquisition of the criterion skill and produced better performance on the criterion task. Thus, similarity is not a sufficient and may not even be a necessary or useful element of an explanation for skill transfer.

A related principle is that of inclusion. Holding (1965, p. 114) proposed that transfer will be high if the second task includes all essential elements of the first task. As an example, he argued that an archer who practiced shooting an apple would need no further practice to hit a barn door. Evidence of transfer that is higher than 100%, as in Lintern (1980), Wightman (1983), and several other studies to be discussed, suggests that transfer cannot be explained fully in terms of inclusion.

TASK DIFFICULTY: EASY-TO-DIFFICULT TRANSFER

The notion of an optimum level of difficulty for training has been raised occasionally in motor skill research. It has been the basis for adaptive training; a procedure in which the criterion task is simplified, and then difficulty is increased as the trainee becomes more skilled (Kelley, 1969). Underlying this procedure is the intuitively appealing assumption that skills can be learned more quickly if the difficulty of the training task is matched to each student's current ability. The simplification method of part-task training, in which students are pretrained on an easy version of the criterion task, also appears to be based on a similar assumption. It too involves manipulations of difficulty that are intended to speed skill acquisition (Briggs and Waters, 1958; Briggs, 1961; Briggs and Naylor, 1962).

Improved transfer performances following training on an easy task are evident in reviews of augmented-feedback research (Lintern and Roscoe, 1980) and part-task training research (Wightman and Lintern, 1984). An experiment by Gordon (1959) can serve to illustrate a common trend. In that experiment subjects trained on either pursuit or compensatory tracking. As is generally found (cf. Poulton, 1974), pursuit tracking proved to be easier than compensatory tracking (Figure 1). However, the data most pertinent to this discussion are from a subsequent transfer test in which some subjects transferred to the alternate display while others remained with their training display. Subjects who had pretrained with the pursuit display (the easy task) performed better on the compensatory display than did subjects who had pretrained with the compensatory display (difficult task). Thus, simplification did enhance transfer to the more difficult task.

Nevertheless, the evidence in support of reducing task difficulty is variable. Reviews by Day (1956) and Holding (1962) have failed to clarify whether transfer is enhanced generally by simplifying the training task. In addition, reviews of adaptive training (Lintern and Gopher, 1978) and part-task training (Wightman and Lintern, 1984) indicate that reduction of task difficulty is not a reliable method of increasing training effectiveness. While some simplification methods do speed acquisition, many others do not.

TASK DIFFICULTY: DIFFICULT-TO-EASY TRANSFER

Possibly the most convincing argument against widespread application of task simplification derives from the observation that enhanced transfer can sometimes result from increases in training task difficulty. Battig (1966) observed such a trend in verbal learning research and suggested that a similar pattern might be found for motor learning. Shea and Morgan (1979) subsequently found this pattern with a motor-learning task and

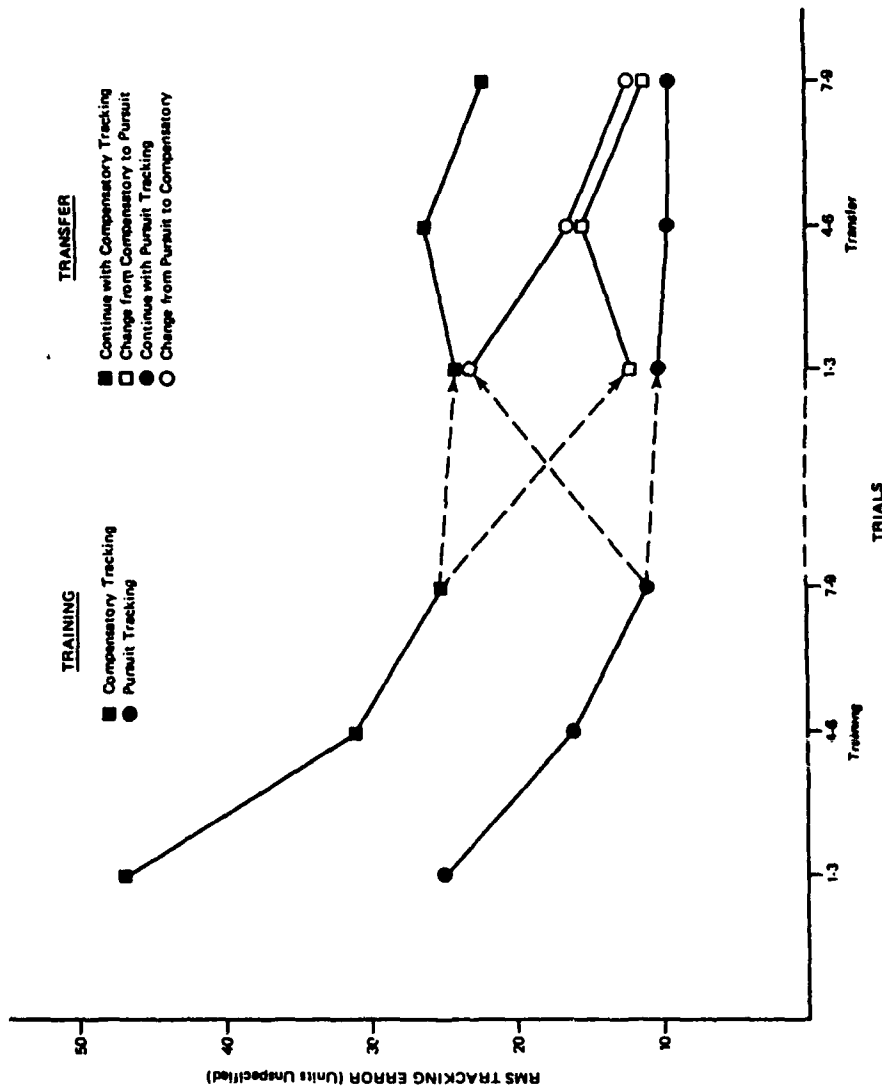


Figure 1. Transfer between pursuit and compensatory displays. Half of each group of subjects transferred to the alternate display (adapted from Gordon, 1959).

have referred to it as contextual interference. Note that the interference occurs in training and that the effect in transfer is one of facilitation.

Task variety is one manipulation that has sometimes led to enhanced performance in transfer. Although training performance is generally poorer, transfer to a different version of the same task has been shown to be better after varied training with substitution tasks (Dashiell, 1924), perceptual-motor paired associate tasks (Duncan, 1958), paired-associate learning tasks (Morrisett and Hovland, 1959), and category search tasks (Schneider and Fisk, 1984). A task variation effect of this type is one of the foundations of schema theory as proposed by Schmidt (1975). Variation in training was considered as a means of strengthening the schemata that guide behavior so that transfer to new task variations would be better.

Shea and Morgan (1979) and Lee and Magill (1983) offered slightly different views that explained the effects of variety in training in terms of deeper processing or greater cognitive effort. Shea and Morgan (1979) demonstrated that scheduling sequence rather than variety in itself reversed the performance trends from training to transfer. They had taught three variations of a barrier collision task in which subjects learned to knock down small barriers in a prespecified sequence with one hand. Training trials were either blocked (subjects would practice several trials with one task variation before switching to practice with another) or randomized (subjects would switch task variations from trial-to-trial). Although training performance was poorer with randomized training, later performance on transfer to a randomized series of trials was better. Lee and Magill subsequently demonstrated that the training series did not have to be random, and that an orderly series of switches between training-task variations could also result in poorer training performance followed by better transfer to a randomized series of trials (Figure 2).

Shea and Morgan (1979) argued that the randomized sequence forced multiple processing strategies that resulted in deeper cognitive processing during acquisition. Lee and Magill (1983) similarly argued that alternation of task variations created a need for subjects to actively regenerate new movement plans and that this greater cognitive effort produced better transfer. On the other hand, a blocked series of events generally permitted subjects to rely on the action plan generated for the previous trial. The regeneration of action plans is a type of cognitive effort, or active participation, that could depress performance during acquisition but enhance it during transfer.

The schema concept as elaborated by Schmidt (1975), and the notion of deeper cognitive processing as discussed by Shea and Morgan (1979) and Lee and Magill (1983), represent more detailed efforts to explain underlying processes than is generally found

training and in later transfer to nonaugmented conditions. However, the off-target group performed best in transfer and there was a noticeable performance decrement at transfer to the nonaugmented condition for the on-target group (Figure 5). The results suggest that augmented feedback might encourage subjects to focus on perceptual dimensions that could be used to discriminate correct and incorrect tracking performance. In contrast, on-target augmented feedback may encourage a dependency on the supplementary cues that causes some difficulty at transfer.

On-target augmented feedback does not generally result in enhanced transfer even when there is a noticeable enhancement in training. This is particularly evident when the intrinsic feedback is obscure (Lintern, 1980), or otherwise difficult to interpret (Kinkade, 1963). It can be hypothesized that the combination of obscure intrinsic feedback and on-target augmented feedback can create strong dependencies that may entirely negate any potential transfer benefit. On the other hand, off-target augmented feedback might not permit development of dependencies because it is not available during accurate tracking. Data reviewed by Lintern and Roscoe (1980) are consistent with this interpretation and provide further support for a perceptual-learning interpretation.

Quality of intrinsic visual feedback during training apparently can also enhance both training and transfer performances. This factor was manipulated in an experiment in which pilots were taught a complex task in a flight simulator; that being a 30-degree bombing approach from an 8000-foot altitude circular pattern (Lintern et al., 1984). Training was accomplished either with a well-detailed landscape of flat terrain with fields, towns, and roads or with a schematic scene of a white grid on a green background. Transfer was to a series of trials that included both of these scenes, and another highly detailed scene that contained a river, bridges, buildings, and mountains.

It was evident that pilots trained with the high-detailed landscape performed better in training and in transfer (Figure 6). Particularly intriguing was the observation that those trained with that scene performed better in transfer to the grid pattern than did those trained on the grid pattern (Table 1). These data suggest that not only does better visual information speed learning, but also enhances progress towards some independence of that visual information. Thus, there is evidence here that perceptual learning enhances progression towards a more open-loop mode of behavior.

perceptual rules that could be applied to the novel transfer situation.

One area of uncertainty for a perceptual model of skill acquisition lies in data obtained from children. Shapiro and Schmidt (1982) have noted that the advantages of variability in training have been easier to demonstrate with young subjects. In some studies, children aged from five to twelve years were taught tossing skills. Varied training was more efficient than constant training with both randomized schedules (Carson and Weigand, 1974) and with blocked schedules (Kerr and Booth, 1978; Moxley, 1979). As the two experiments with blocked schedules used relatively long blocks of trials their data cannot be explained easily in terms of perceptual learning.

Nevertheless, an advantage of blocked variability over constant training does not invalidate the thesis developed here, although an advantage of blocked variability over random or serial variability would create a problem. A specific requirement for perceptual learning is that there be many opportunities for close comparison and contrast of different stimulus events. Thus, varied training in which trials are scheduled in random or serial order, or even in short blocks, should be more efficient than either constant training or varied training in which trials are scheduled in long blocks. Pigott (1979, cited in Shapiro and Schmidt, 1982), demonstrated that seven-year old children learned a training skill more effectively under varied training with three-trial blocks than under varied training with six-trial blocks, or under varied training with randomized trials. The varied training under three-trial blocks was also more effective than was constant training. While these data do not clearly support the perceptual learning view of skill acquisition, they do indicate that the trials-scheduling variable is important. Further exploration of this variable's effects could provide a critical test of some of the ideas outlined in this paper.

TASK-RELATED FEEDBACK

Concepts of deeper processing or greater cognitive effort do provide a consistent explanation of the trials-delay and task-variation data, they do not appear to offer an explanation for patterns of data that show enhanced transfer following training on an easy version of the criterion task. One major body of data to show this pattern is from augmented-feedback research.

A tracking experiment by Williams and Briggs (1962) can serve to illustrate important data trends. In that research auditory augmented feedback was provided in training. One group of subjects received the supplementary auditory cues when they were off target, while another group received them when they were on target. Both groups outperformed a control group in

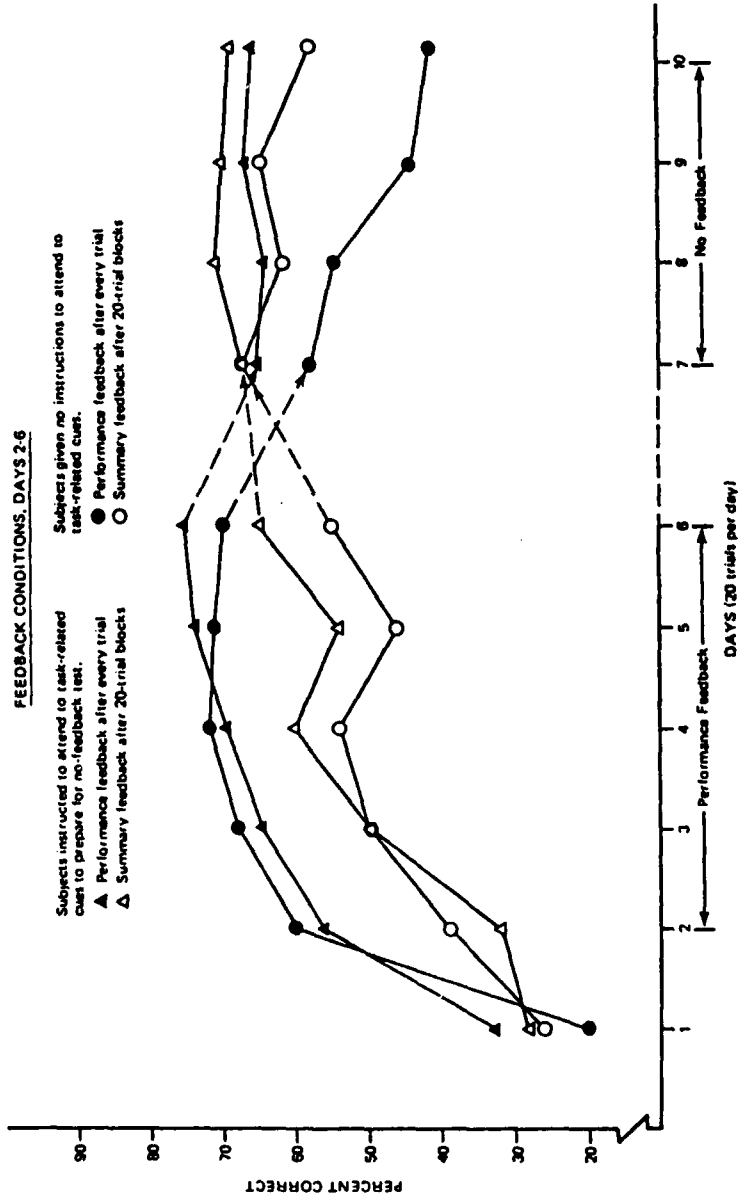


Figure 4. Effects of immediate and summary feedback on acquisition of discrete, ballistic motor tasks. Performance feedback was given after every trial or after every 20 trials for days two to six inclusive (from Lavery, 1962).

Lavery (1962) speculated that the delay of feedback over a series of trials forced subjects to attend to task-relevant cues that could help them with the no-feedback test, and that subjects who were given feedback after every trial paid less attention to those important cues. He repeated an experiment that had shown a strong trials-delay effect, but added a condition in which subjects were advised of the nature of the transfer session and were instructed to attend to the task related cues. The results from that experiment are shown in Figure 4 and indicate that the instructions prevented the decrement at transfer so that there was no transfer disadvantage from training with performance feedback after every trial. This result supports the idea that transfer of ballistic motor tasks will be disrupted if subjects neglect the task-relevant cues during training. Thus, my proposal that perceptual learning is a significant component of motor skill acquisition, is supported by these experiments.

VARIATIONS IN TRAINING

Several motor-learning studies have shown a transfer advantage after training with multiple versions of a task (McCracken and Stelmach, 1977; Wrisberg and Ragsdale, 1979; Zelaznick, Shapiro, and Newell, 1978). These studies compared the effects of different numbers of task variations in the training phase on transfer to one new task variation. Variety in training led to poorer training performance but better transfer to the test condition. However, other data failed to reveal any consistent transfer advantage following varied training (Husak and Reeve, 1979; Newell and Shapiro, 1976; Zelaznik, 1977).

As noted previously, concepts of deeper processing and greater cognitive effort have been proposed to explain the reversal in performance trends from training to transfer that sometimes results from varied training. However, better perceptual learning is also a plausible explanation. Lee and Magill (1983) observed that the performance reversal from training to transfer has been found reliably in experiments that changed the task from trial to trial, but not in those that changed the task between blocks of trials. The alternation of trials placed the different stimulus response events in close temporal proximity. The process of isolating relevant sensory dimensions and of differentiating critical stimulus values on those dimensions might be assisted by the close comparison and contrast that would be possible under these circumstances. The three experiments that have shown a reliable advantage for varied training (McCracken and Stelmach, 1977; Wrisberg and Ragsdale, 1979; Zelaznik et al., 1978) required a timed response from the subjects. The close comparison of different task variations may have permitted subjects to more effectively identify and calibrate sensations that could be used to discriminate different response variations, and thus to generate

SECTION V

PERCEPTUAL LEARNING AND MANUAL CONTROL

Only data from transfer-of-training experiments are considered here as appropriate support for a perceptual learning view of skill acquisition. Salmoni, Schmidt, and Walter (1984) have outlined the case for transfer-of-training research. In summary, they argue that trends in training data gathered under various instructional methods do not necessarily reflect differences in learning. Some of those training effects are short-term, and they do not remain evident in later transfer to a standard test condition.

Thus, a distinction is made between stable learning effects and temporary performance effects that do not indicate learning differences. Changes in some variables will enhance or disrupt performance, but when those variables are returned to their former levels the effects will disappear. In contrast, learning effects are relatively permanent and persist even when the instructional variables are returned to their former levels. Salmoni et al. argue that learning and nonlearning effects cannot be discriminated in the training phase of an experiment. Some of the data presented below will attest to the validity of their view.

TRIALS-DELAY OF PERFORMANCE FEEDBACK

Lavery and his associates (Lavery, 1962; Lavery and Suddon, 1962; Suddon and Lavery, 1962; Smith, 1963) contrasted performance feedback given after every trial with summaries of performance feedback given after blocks of trials for differential effects on the acquisition of simple motor skills. A variety of tasks were used, but all were ballistic. Visual feedback was occluded or absent. Learning progressed smoothly with either type of feedback, but feedback after every trial led to better training performances. However, transition from feedback after every trial to no feedback produced a substantial decrement in performance, while transition from summary feedback after blocks of trials to no feedback produced only a minor decrement, and in some experiments, no decrement at all. The performance decrement for groups trained with feedback after each trial was large enough to reverse the trend found in the training session. Thus, trials-delay of performance feedback produced better transfer to the no-feedback test condition. Hagman's (1983) observation that transfer is enhanced by withholding knowledge of results on some training trials is also consistent with these data.

cognitively oriented theories assume a sparse stimulus world in which the observer constructs perceptions either through inference or from cognitive schema that enrich and give meaning to stimulus patterns.

Response oriented theories postulate that motor activity is the basis for perceptual learning, either through construction of a motor-sensory representation, or through improvement in discrimination by way of responses that produce added stimulation which becomes associated with the perception. By implication at least, it would seem that the long standing emphasis on control system manipulations in manual control research is based in a response oriented view of skill learning. Nevertheless I will argue that the emphasis on control system variables has done little to enhance our understanding of skill transfer in manual control, and that an emphasis on concepts central to perceptual differentiation theory will be more productive.

As noted previously, differentiation theory contains a cognitive element, but emphasizes noncognitive processes such as detection of distinctive features and filtering of irrelevant information. From the following discussion it will become apparent that this emphasis parallels the trend of research in manual control, although it may also become evident that a stronger concentration on the cognitive elements of the theory could benefit future research.

development of differentiation rules that, once learned, permit generalization beyond the specific stimulus examples used in pretraining. If the assumption of a crucial relationship between perceptual learning and manual control is correct, these techniques should aid acquisition of manual control skills. Furthermore, if the assumption about independent error detection and response evaluation mechanisms is correct, perceptual differentiation would have significant roles to play in the development of both mechanisms.

Although Gibson questions the usefulness of perceptual theories that are predominantly cognitive, her own theory has a strong cognitive element, specifically in relation to the role played by higher-order structures. Such structures are built from abstraction of invariant relations, as well as from progressive differentiation of stimulus features. They can be considered as a type of invariant that may be extracted to enable more effective perception. A typical higher-order structure may be constituted from a set of distinctive features, and may gain some of its usefulness from the fact that it draws attention to the relationship between distinctive features, as well as to their specific characteristics.

Properties such as pattern, contour, and symmetry may serve as higher-order structures. In a discussion of acquisition of Morse code, Gibson cites data that show the emergence of sensitivity to temporal patterns in the codes that serve to aid discrimination. Sensitivity to these temporal patterns was not evident in early learning. It also seemed that the types of temporal patterns that aided discrimination changed with learning so that there was some evidence for progressive differentiation of structure.

Detection of higher-order structure can aid the differentiation process and permit earlier discriminations. In addition, Gibson suggests that higher-order structures have a recursive function in that they also speed the perceptual learning of the dimensions that are featured in discriminations based on higher-order structures. Presumably, this means that new discriminations would be facilitated if those dimensions were important, even if the higher-order structure was no longer relevant. Thus, continued interplay between cognitive and noncognitive processes may appreciably enhance skill acquisition.

It would be remiss at this point to ignore cognitive and response-oriented theories that make contrasting assumptions and predictions. In particular, those theories differ in regard to the learning processes they postulate. Differentiation theory assumes a rich and varied stimulus world that is capable of giving rise to diverse and complex perceptions. It is a stimulus oriented theory in that the perceiver's role is to select from and make sense of available stimuli. In contrast,

SECTION IV

DIFFERENTIATION THEORY OF PERCEPTUAL LEARNING

Perceptual learning refers to an improvement in the ability to extract information from sensory stimulation. The differentiation theory of perceptual learning is a data-based theory that was developed by Gibson (1969). In its essence this theory states that perceptual learning is accompanied by an increase in the specificity of correspondence between stimulus information and the observer's perception of that stimulus information. Although Gibson's formulation of her theory rests heavily on data from visually oriented experiments, she considers sufficient other data to suggest her theory's generalizability to other sensory dimensions. The remainder of this section summarizes Gibson's differentiation theory and her views on theories of perceptual learning in order to abstract the points of major interest for the subsequent discussion of learning in manual control.

Within the context of differentiation theory, changes in behavior may be described in several ways. There may be reduced generalization and increasing precision of response to fine differences along a stimulus dimension. Invariant stimulus relations or stimulus structure that could not be detected previously may become perceptible. Detection of distinctive features of stimulus objects or events may improve. In general, the theory explains improved perceptions in terms of accentuated sensitivity to consistencies, relationships, patterns, and distinctive features that permits discrimination of different stimuli.

Abstraction and filtering are significant concepts underlying principles of perceptual learning. Critical features are abstracted and irrelevant features are filtered to permit accurate differentiation of stimulus patterns. Sensitivity to dimensions on which objects or events differ aids the discriminative process. Repeated exposure to stimulus objects aids perceptual learning by facilitating the abstraction of distinctive features. This leads to progressive differentiation of stimulus objects, a process that may be speeded by isolating or enhancing distinguishing properties. Close comparison and contrast of stimuli that differ on critical dimensions can also help.

Gibson (1969) cites transfer studies to show that perceptual learning is enhanced by pretraining with these differentiating techniques. Much of the data suggest the

with appropriate timing and magnitude, and in ascertaining the effects of control behavior. This further suggests a dominant role for perception in the development of manual control behavior.

learning is accompanied not only by improving accuracy, but also by substantive changes in the processes that are used to support performance. For example, displacement and rate errors are the dominant influences on control behavior in early learning, but as skill improves, operators rely less on displacement errors and more on acceleration errors (Fuchs, 1962). In addition, as is consistent with slide-positioning data from basic motor skill research (Adams, Gopher, and Lintern, 1977), improving manual-control skill is accompanied by relatively less reliance on visual abilities and more on proprioceptive abilities (Adams, 1968; Fleishman, 1967, 1972).

Possibly one of the most important observations from the manual control data is that the use of visual feedback about system error states diminishes during learning. Pew (1966) has shown that operators advance from a strictly closed-loop, visually-dependent mode of behavior in which error feedback is checked constantly, to a predominantly open-loop mode that demands less attention to perceptual feedback. In support of this observation, Lintern, Thomley, Nelson, and Roscoe (1984), have found that higher levels of skill in a simulated flight task are associated with less need for high-quality visual feedback.

The research relating to process changes during acquisition of manual control is sparse. Nevertheless, the observations of Adams (1968), Fleishman (1967, 1972), Fuchs (1962), Newell (1976), and Pew (1966) could form the basis of a description of skill development. Skilled operators appear to perform differently than unskilled operators, not only in terms of accuracy, but also in the manner they execute the task. They seem to rely less on any sort of error feedback (Pew, 1966), but even when they do attend to error feedback, it is of a higher order (Fuchs, 1962). Proprioceptive feedback may emerge as a significant influence, with an accompanying decrease in the importance of visual feedback (Adams, 1968; Fleishman, 1967, 1972). Under the assumption that there are independent error-detection and response-evaluation mechanisms (Newell, 1976), a progression from closed- to open-loop behavior (Pew, 1966) could be viewed as corresponding to a shift from reliance on system-error feedback to a heavier reliance on response-induced feedback. This analysis suggests that many important perceptual changes occur during skill development.

In reviewing the underlying nature of manual control behavior, it is worth noting that many of the elements commonly associated with some perceptual-motor behaviors pose minimum difficulties in manual control. Strength, speed, and agility may be taxed to their limits in sport or in the performing arts, but by design are not critical in manual control. Coordination may provide a challenge, as in hover control of a rotary-wing aircraft, but the most general problems lie in identifying correct system states and error states, in selecting responses

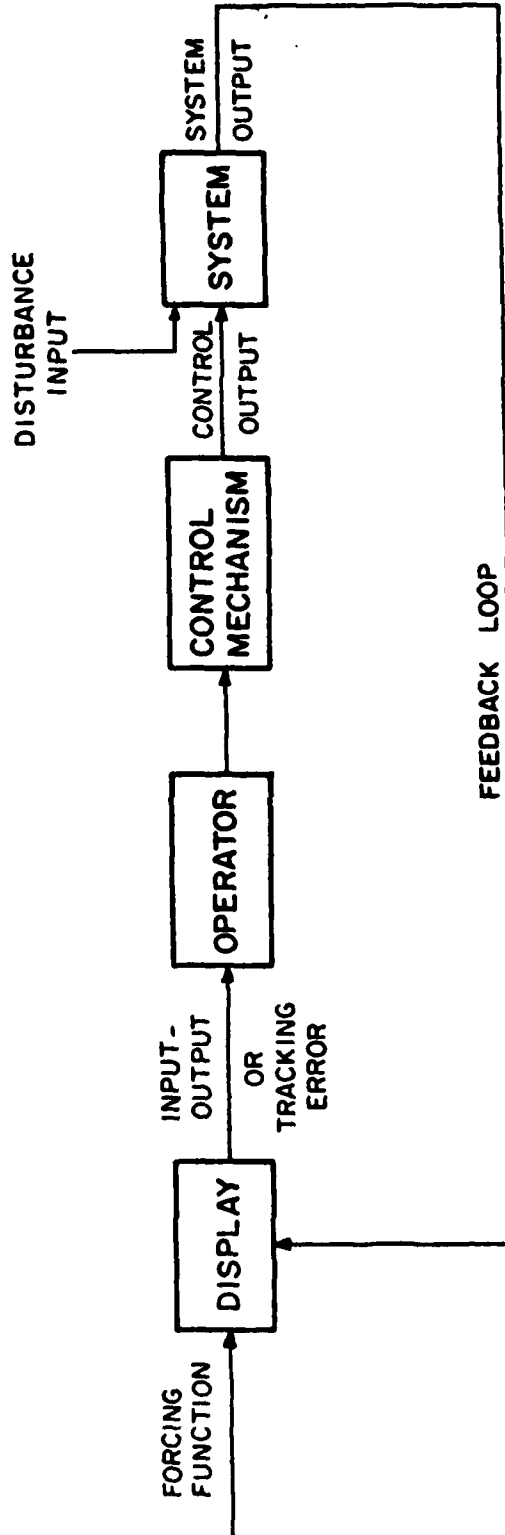


Figure 3. Schematic of a Typical Tracking Task.

SECTION III

ELEMENTS OF MANUAL CONTROL

Manual control is a continuous perceptual-motor activity that is error correcting and goal directed. The term refers to the behavior of a human operator in manipulating a dynamic control system. Accurate performance requires assessment of current system state, selection and execution of response patterns, and evaluation of the effects of control activities. Thus, an operator must be able to anticipate goals, recognize error states, visualize correct system states, and control the system in a manner that will minimize error and ensure progress towards the goal. It is characteristic of manual control that the path or strategy taken to achieve a goal can be as important as achievement of that goal. Thus, operators endeavor to minimize error or to employ efficient strategies throughout the ongoing activity.

Discussions of manual control generally emphasize the closed-loop nature of behavior in which the guidance and correcting roles of vision dominate (cf. Poulton, 1974). In that model, system errors are detected (most often visually) and corrected by adjustment of controls (Figure 3). The same perceptual cues are used to evaluate the effects of corrective actions, and if errors remain, further control activity is generated.

Newell (1976) has, however, offered evidence for a response evaluation mechanism that does not depend on system errors, but rather depends on a memory state that can be compared with perceptions generated by the response itself. Thus, skilled operators may be able to judge the accuracy of their response even without knowledge about the outcome of their behavior. In Newell's experiment these perceptions were based on aural cues. Some basic motor skill research to be discussed in a later section (Lavery, 1962; Lee and Magill, 1983) support the existence of a response evaluation mechanism that would seem to be based on proprioceptive cues. The specific characteristics of the response-evaluation mechanism are not well defined, but it could be supported by any sensations (e.g., visual, aural, proprioceptive) that are generated by the response. Some of the same sensory modalities might also support the detection of system errors, but the specific cues would be generated by the system response rather than directly resulting from the operator's movements.

Many manual control tasks require a considerable learning effort to achieve efficient performance. The progress of

in manual control research. These concepts from basic motor skill research offer some promise that disparate findings from experiments that employ a variety of tasks and procedures could be cohered to form the basis for a robust theory of acquisition in manual control. Unfortunately, they cannot explain the part-task and augmented-feedback research that shows enhanced transfer following better training performance. Thus, an alternate conceptual approach appears necessary to account for the diverse data.

It might be argued that the data and theoretical notions discussed in this section on difficult-to-easy transfer are based in motor skill research that has depended on artificial and simple laboratory tasks, and are therefore of questionable relevance to issues of manual control. However, many of the tasks used in this research contain skill components that are related to those of manual control. The requirement for subjects to time an elaborate movement to accuracies within 100 msec (Lee and Magill, 1983) is a good example. Given the current limitations of data from research into manual control, it would seem neglectful to ignore this substantial body of data in developing a theoretical explanation of transfer for manual control.

SUMMARY

Neither task similarity nor task difficulty account for all of the major empirical trends found in transfer-of-training studies. In fact, the emphasis on these global concepts appears to have done little to further understanding of the processes underlying transfer. Only the discussions of task variety and contextual interference demonstrate an attempt to provide a substantive theoretical explanation of processes that could contribute to transfer. These attempts fail, however, to provide an explanation that is consistent with a considerable amount of data.

In the following discussion I will argue that learning trends evident in manual control and other motor skill research can be explained in terms of perceptual learning. The differentiation theory of perceptual learning proposed by Gibson (1969) is offered as a major theoretical perspective. Although perceptual learning is not offered as a complete explanation of acquisition in manual control, I will propose that it should be considered as a dominant, if not the dominant process underlying the early stages of skill acquisition, and that Gibson's theory should be accorded a major explanatory role. This orientation represents a considerable departure from other explanations of skill acquisition and, I believe, will offer a better understanding of skill acquisition and skill transfer.

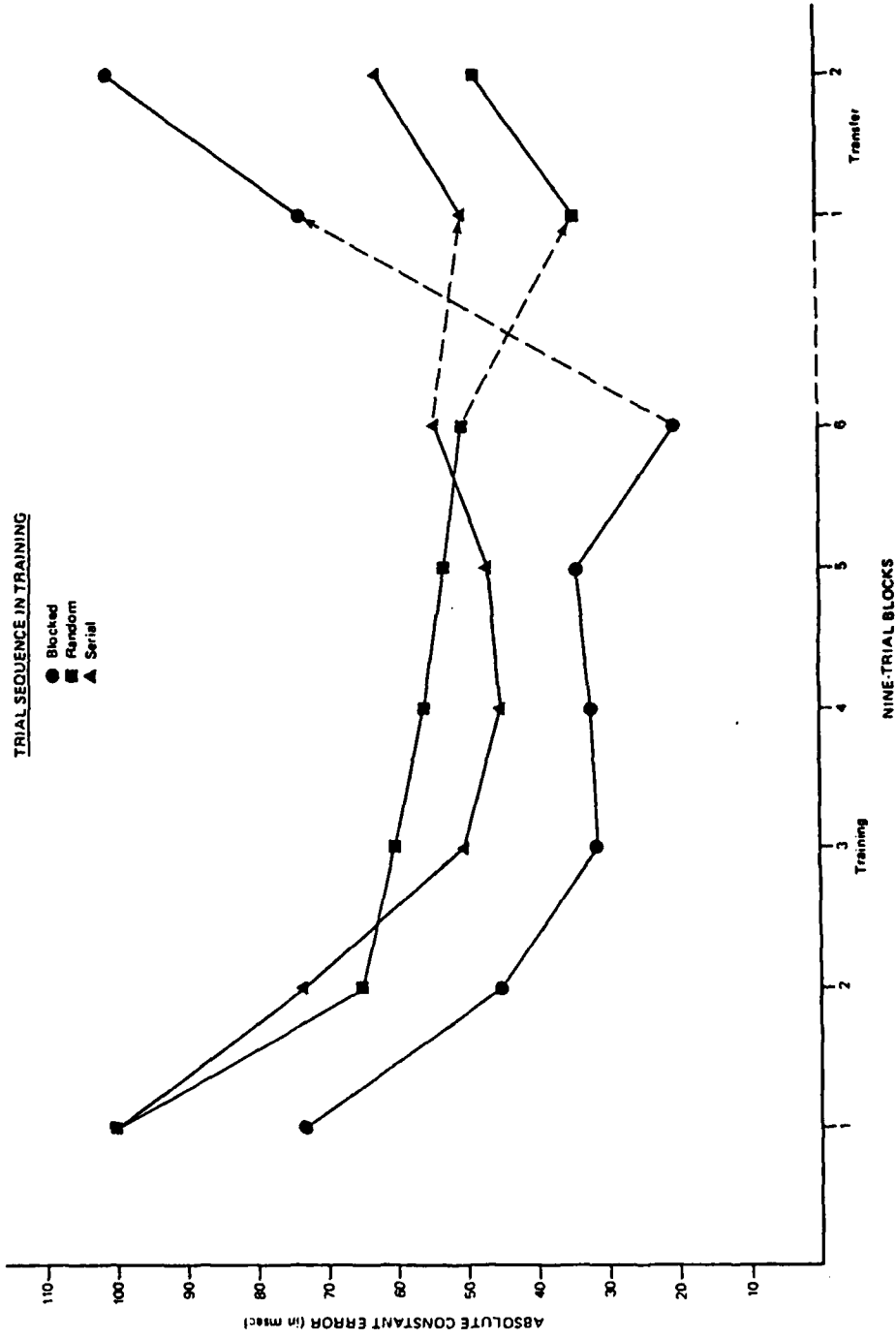


Figure 2. Effects of blocked, random, and serial trial sequences on acquisition of a barrier collision task.

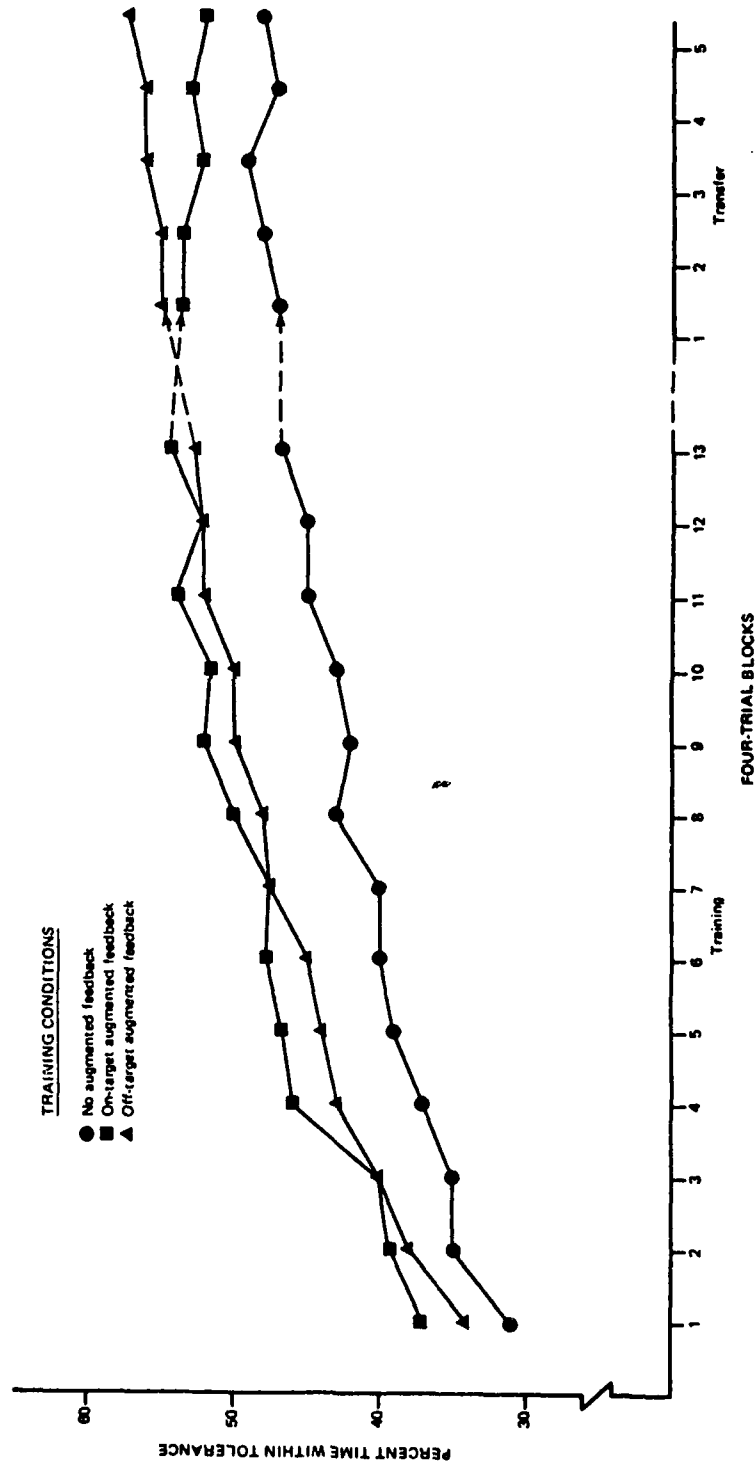


Figure 5. Effects of augmented feedback on acquisition of a continuous tracking task. All subjects transferred to a non-augmented condition (Williams and Briggs, 1962).

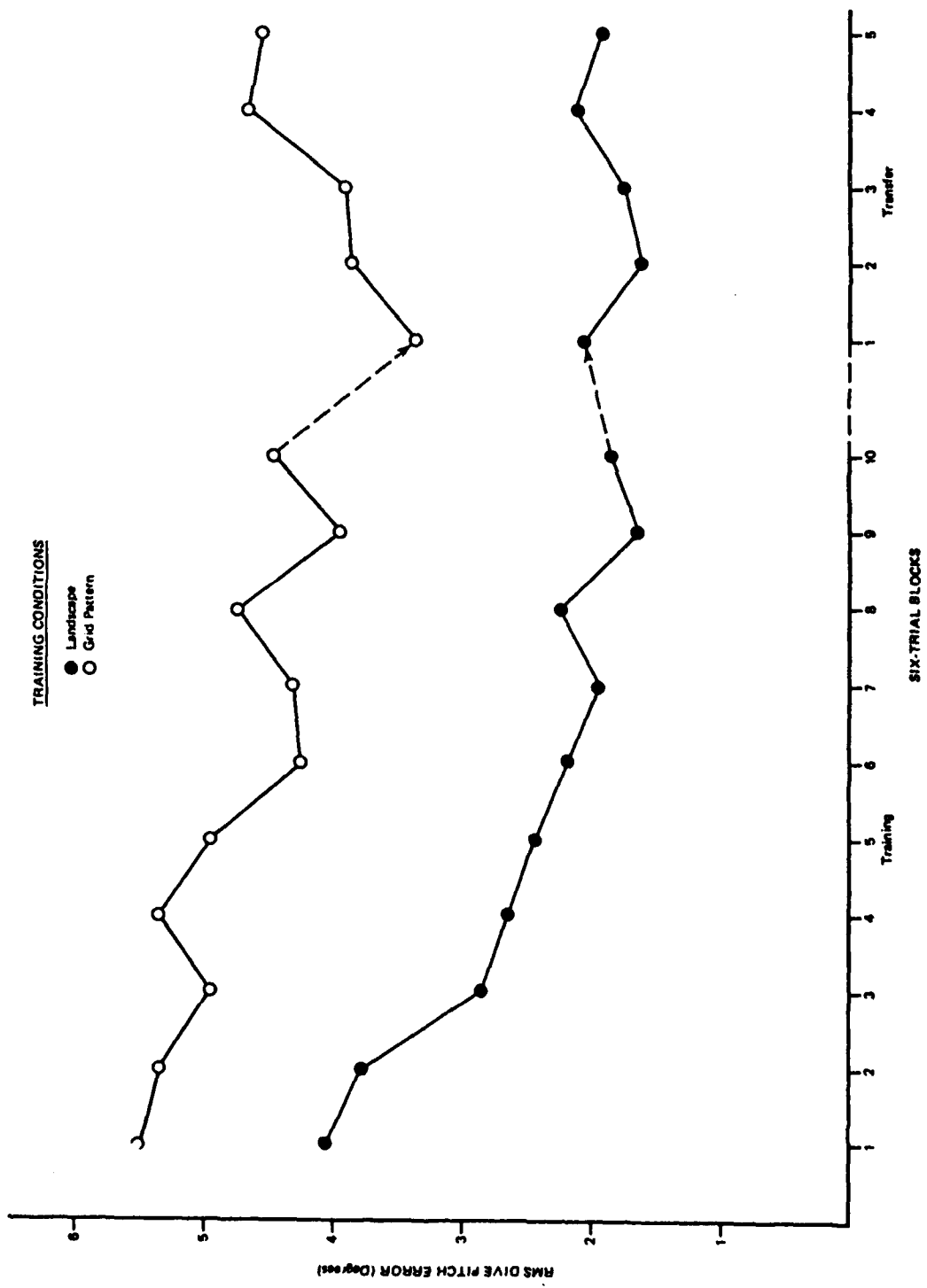


Figure 6. Effects of training scene type on the acquisition of bombing skills. (Lintern, Thomley, Nelson, and Roscoe, 1984).

TABLE 1. EFFECTS OF TRAINING SCENE TYPE
ON ACQUISITION OF BOMBING SKILLS
(RMS Dive Pitch Error in Degrees)

	<u>Training Scene Type</u>		
	<u>High Detail Landscape</u>	<u>Grid Pattern</u>	
<u>Transferring to:</u>			
All Scenes	1.88	4.02	p < .05
Grid Pattern	1.98	4.72	p < .05

HIGHER-ORDER STRUCTURE

One possible means of isolating dimensions that enable perceptual differentiation would be to establish a cognitive abstraction of relationships in the stimulus pattern. Gibson (1969) proposed that a higher-order structure could be developed both through perceptual learning and by abstraction of invariant relations, and that it could support further perceptual learning. To illustrate, she argued that language provides one means of establishing a higher-order structure that could support perceptual learning, either by drawing attention to previously unnoticed features or by characterizing critical dimensions in an economical manner.

Consistency is one higher-order structure that appears to be of value in teaching manual control skills. Reflection on the results of Gordon (1959), which are depicted in Figure 1 of this paper, may serve to illustrate. In that experiment subjects learned to follow a clover-leaf pattern with a two-dimensional tracking system. Some subjects learned with a pursuit display while others learned with a compensatory display. In a pursuit display, error reductions induced by control movements are clearly distinguished from perturbations of the path to be followed. However, those two sources of information are confounded in the display of a compensatory system, and can be distinguished only through visual and proprioceptive cues derived directly from movement of the controls (Licklider, 1960). In a visual tracking task, such as the one used by Gordon, subjects would have little time to look at the controls, so that proprioceptive information would be the primary means of distinguishing control effects from forcing

function perturbations. This, presumably, is the source of added difficulty generally associated with compensatory tracking.

One primary requirement in the acquisition of control skills is to learn the relationship between control inputs and system response. That relationship is lawful, and can be perceived more clearly in a pursuit system because the effects of control inputs are not confounded in the display with other effects. In Gordon's experiment, transfer to the compensatory task was better after pretraining on the pursuit task than after equivalent pretraining on the compensatory task; a result that might be attributed to the enhanced perception of consistency in the input-output relationships of the pursuit tracking system.

The data from backward-chaining experiments of Bailey, Hughes, and Jones (1980); Westra (1982); and Wightman (1983) can be interpreted similarly. In the study by Wightman, subjects were taught simulated carrier landings first from 2000 feet behind the landing point, then from 4000 feet, and finally from 6000 feet. A control group learned the task only from the 6000-foot mark. In subsequent testing from the 6000-foot mark, subjects who had learned with the backward-chaining manipulation performed much better than the control group (Figure 7). One significant aspect of the backward-chaining technique is that it allows practice on the final segment of a task without the confounding effects of errors accumulated earlier in the task. In this experiment, and those of Bailey et al. and Westra, the final segments of the task were crucial to overall success. The opportunity to practice this segment in isolation enhanced acquisition of the total task. Thus, these experiments also suggest the value of clarifying the consistencies inherent in the input-output relationships independently of other effects.

In some manual control tasks the effects of control inputs vary depending on current system state. An obvious example of this is the effect of rudder-pedal movements on aircraft response. While taxiing on the ground, rudder pedals are used to turn an aircraft, but in the air they are used to maintain coordinated flight. A less obvious example, again from aviation, is that airspeed influences the effect of pitch-control inputs. Thus, pilots must not only learn the input-output relationships, but also how these relationships vary over different flight regimes.

Eberts (1983) examined this type of problem in a laboratory tracking task. He sought to formalize the relationship between effects of control inputs and changing system states. Of particular interest to the perceptual differentiation hypothesis is that a continuous predictor display was programmed to accentuate or enhance the consistency of the input-output relationship as it varied over system states. A point predictor display that did not enhance the input-output consistencies and

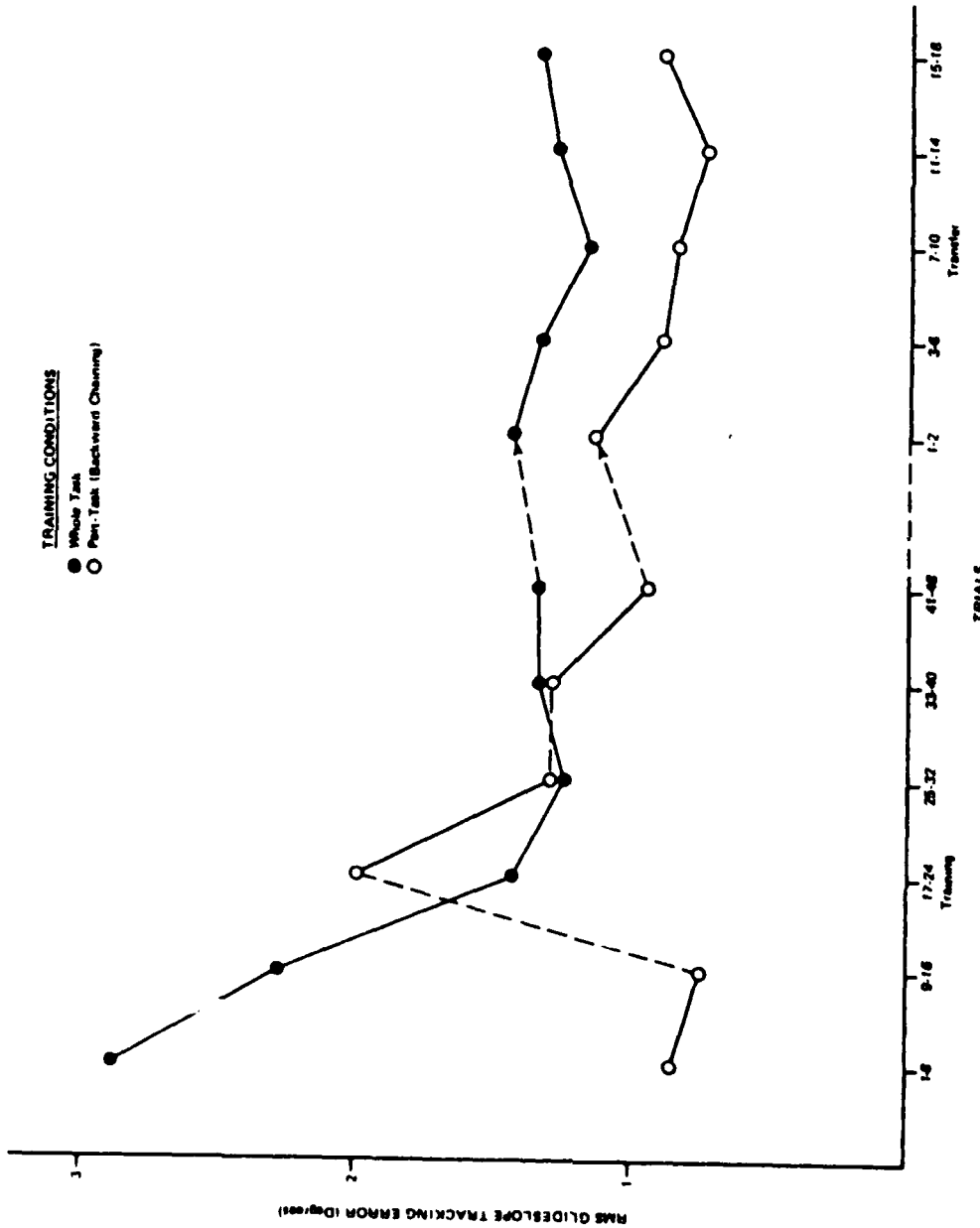


Figure 7. Effects of part-task training on acquisition of carrier landing skills. Dotted lines in the part-task training phase indicate a change to a longer task segment (adapted from Wightman, 1983).

a control (no-predictor) condition were also tested in the experiment. Subjects were taught to operate the system with one of the displays and were then administered a variety of tests.

The most powerful demonstration of the superiority of continuous-predictor training was found in a no-predictor transfer test in which the system had been changed from a moving-track to a moving-cursor display. This change in perspective corresponds to a change from an inside-out to an outside-in display and can be expected to cause severe control problems (Johnson and Roscoe, 1972). Nevertheless, the group trained with the continuous predictor experienced only a minor decrement following transfer to the reversed no-predictor display, while the other groups suffered substantial decrements in performance. In addition, subjects who had trained with the continuous predictor showed, in a series of pencil-and-paper tests, that they understood the nature of the input-output relationship more clearly than did the control or point-predictor subjects.

Eberts argued that subjects trained with the continuous predictor had developed a spatial representation or internal model of system behavior that helped them predict the effects of various kinds of inputs on system output. Mental manipulations of the spatial representation apparently enabled those subjects to transition from one display perspective to the other without disruption. This notion is similar to that proposed by Gibson (1969) of an underlying invariant structure that, if detected, will aid perception. Its particular value in this example is that specific features which may be confusing in isolation can contribute to effective discrimination when they are considered as a part of an overall pattern.

The studies considered in this discussion of higher-order structure suggest that more consistent presentation of stimulus patterns can develop an internal model of how a control system operates. This model appears to incorporate rules or knowledge about stimulus-response relationships in the control task. In particular, the model is one that distinguishes the important variables that affect system response so that the inherent consistencies of the system response are clarified. An operator who develops an accurate internal model of the system should be more resistant to performance decrements that often accompany variations in conditions.

SYSTEM ADAPTATIONS

One major emphasis in tracking research has been on the transfer effects of variations in training system dynamics. Dimensions such as lag, gain, order, and damping ratio have been tested. Inherent in this research, which also encompasses part-task and adaptive training, is the notion that adjustments of tracking system dynamics during training may enhance

acquisition of the criterion skill. As noted earlier, this approach appears to emphasize the need to acquire appropriate response patterns, possibly through development of motor schema or motor programs.

Reference to Levine (1953) will illustrate the underlying rationale. Control-display lag was manipulated over a range of 0.015 to 3.0 seconds during the training phase of a one-dimensional compensatory tracking task. Experimental subjects experienced only one of the training lags and all transferred to the 3.0-second lag. As is generally found, lag had a marked effect during training, with better performance being associated with shorter lags. However, the differences in transfer to a criterion 3.0-second lag were slight and transient. Training with minimum lag produced a brief advantage early in transfer, but there was no difference between the groups in late transfer trials. The general ineffectiveness of system lag as a training variable has been substantiated by Wightman (1983). It seems noteworthy that Wightman's experiment, in which there was such a powerful effect of backward chaining, evidenced no effect one way or the other for the system-lag manipulation.

Transfer studies that manipulate dimensions of system dynamics typically show small or no differential effects of pretraining with different conditions. This pattern has been observed with manipulations of system order (Briggs, 1961; Briggs, Fitts, and Bahrck, 1958; Lincoln, 1953), system gain (Rockway, Eckstrand, and Morgan, 1956), and system damping ratio (Lincoln, 1978). Thus, manipulations that emphasize response learning appear to offer no worthwhile benefit for skill transfer.

SUMMARY

The evidence presented here supports the perceptual differentiation view of skill acquisition in manual control. The data from basic motor learning studies of trials-delay effects and variations-in-training effects strongly suggest a perceptual differentiation interpretation. There is a parallel between those manipulations and techniques of enhancing critical dimensions or of providing repeated stimulus comparisons that Gibson (1969) has argued will enhance perceptual learning. In particular, the fact that a simple instruction to attend to task-related cues can overcome the trials-delay effect (Lavery, 1962) demonstrates that the effect is perceptually based.

The augmented-feedback research is also open to a perceptual learning interpretation in that it could direct attention to important stimulus features or patterns. This interpretation is supported by the observation that off-target augmented feedback, which should be more successful in directing attention to important features or patterns, has been more

effective than has on-target or continuous augmented feedback.

Finally, the work of Eberts (1983), in which there was a deliberate attempt to make perceptual consistencies more salient, can also be explained by perceptual differentiation theory. Results from backward-chaining experiments, and another in which there was enhanced transfer to compensatory tracking following training with a pursuit task, suggest that the enhancement of perceptual consistencies can have a powerful effect on acquisition of manual control skills.

None of the views expressed here deny the contribution of motor programs or schema in skilled behavior and, in fact, they are consistent with those expressed by Summers (1981) in his review of motor program theory. He argues for a significant contribution from perceptual feedback in the acquisition of motor programs. That interpretation is supported by data discussed earlier in this paper (Lintern et al, 1984; Pew, 1966) which suggest progressively decreasing reliance on visual feedback as skill develops.

Nor do the perceptually oriented experiments discussed here speak against the role of response manipulations in skill learning. Nevertheless there is, in the tracking literature at least, a notable lack of data that show enhanced transfer resulting from response manipulation. Thus the significant problem in learning a manual control skill may lie in learning to detect, discriminate, and differentiate critical features, patterns, dimensions of difference, and consistencies, rather than in learning to control muscle action and in programming movement patterns. While it is inappropriate to ignore response manipulations entirely, it does seem that the historical emphasis on them has been misplaced and that more attention to perceptual manipulations would be amply rewarded.

SECTION VI

ISSUES

Transfer of training research in manual control has suffered from lack of direction because there has been no coherent framework to guide the research. The model proposed here may do that. Many hypotheses are implicit in the previous discussion on the role of perceptual learning in acquisition of manual control skills, although the data brought to bear on them were, in many cases, suggestive rather than conclusive. Research that bears more directly on these issues is necessary to establish the perceptual learning view as an explanation of manual control transfer effects. To that end, it seems necessary to be able to describe the structural changes that accompany skill learning and the principles that impact those changes. An integrated attack on these two issues could refine and extend the ideas outlined here.

STRUCTURAL CHANGES

Implicit in perceptual differentiation theory is the notion of structural changes that promote perceptual economy. For example, dimensions of difference and distinguishing properties that are useful for discriminating a range of stimuli are learned. Alternative structural changes such as the establishment of memorial copies of prototypes are considered to be too uneconomical to be useful.

RESPONSE EVALUATION. The type of perceptual changes that take place has some significance in skill acquisition. In the earlier comments on the nature of manual control, the possibility of perceptual learning related both to system error and to response-induced feedback was raised. The perception of system error would presumably rely heavily on exteroceptive feedback, while the perception of response-induced feedback would rely heavily on proprioceptive feedback. There seems little doubt that the perception of system error plays a significant role, at least in early learning of manual control. However, there is growing evidence for the existence of response-induced feedback and for its emerging role.

Some theories of motor learning postulate that an error detection mechanism, such as recognition memory, can be used to evaluate the correctness of a response (Adams, 1971; Pew, 1974; Schmidt, 1975). This mechanism apparently operates independently of any response evaluation based on response outcome or feedback from an observer. Newell (1976), Zelaznick

and Spring (1976), and Zelaznick et al. (1978) have shown that learning of a discrete motor skill can continue in the absence of information about the response outcome. This is strongly suggestive of a response evaluation mechanism. In addition, Schmidt and White (1972) have shown that the accuracy of a learned response can be judged without knowledge of results, and that the accuracy of these judgments improves in their correspondence with accuracy of the response.

The studies by Lavery and his associates (e.g., Lavery, 1962; Lavery and Suddon, 1962) and by Lee and Magill (1983), also provide evidence of a response evaluation mechanism. The tasks used by Lavery were ballistic, and visual feedback was occluded. Thus, the only information available to evaluate the response was the proprioceptive feedback resulting from the action. Lee and Magill, in the third of a series of experiments, adjusted their barrier collision task so that, instead of it having a minimum-time demand, specific movement times (900, 1050, and 1200 msec) were designated for each of the task variations. As shown in Figure 2, subjects were able to perform this task with little error even though there was limited task-related feedback to guide the timing of that response. In the transfer phase, proprioception appears to have been the only available source of feedback for that response.

Thus, there is a strong suggestion here of the response-evaluation mechanism postulated earlier in this paper. Future research should consider the structural changes that accompany perceptual learning associated with both the task-related feedback and response-induced feedback. Such a consideration may enhance the explanatory power of the perceptual differentiation model of learning in manual control.

HIGHER-ORDER STRUCTURE. Gibson (1969) noted that higher-order structures can impact perceptual learning. Within the manual control literature this type of cognitive intervening variable is often referred to as an internal model. In its early use, the internal model was poorly defined, and often appears to have been a substitute for clear thinking about cognitive processes that support manual control. However Eberts and Brock (1984) have reviewed data that suggest a useful role for the notion of a conceptual representation, formed by an operator, of how a control system works.

In the normal course of events, perceptual learning appears to be a prerequisite for the development of an internal model. Nevertheless Eberts' (1983) data suggest that an internal model can be developed by other means, and that the resulting behavior is more resistant to disruption. This is consistent with Eleanor Gibson's view of the recursive role of higher-order structures in perceptual learning. She suggests that perceptual learning can promote development of higher-order structures, which in turn, then promote perceptual learning.

A possible role for internal models has not been emphasized in this paper primarily because there are limited manual control data that bear on this issue. Nevertheless there could be some advantage for early skill acquisition to bypassing perceptual learning in favor of developing a strong internal model. An attempt to exploit this approach is evident in the applied research of Hennessy, Lintern, and Collyer (1981) in which flight skills were taught with an outside view of a simulated aircraft. This technique was as effective as use of the normal view from inside the cockpit. This is one area that may have worthwhile payoff for both theory and application. In particular, a stronger emphasis on the development of internal models may correct the neglect, noted earlier in this paper, of the role of cognitive processes in manual control.

PRINCIPLES OF LEARNING

A central thesis of this discussion is that manipulations of difficulty, similarity, variety, and trials delay do not, in themselves, improve transfer but will have a positive effect only if they enhance the perceptual learning that is necessary for improved performance. Thus, techniques that aid the discovery of distinctive features or of invariant relationships should be effective. Artificial emphasis of distinctive features, provision of contrasting examples that are differentiated on a critical dimension, or isolation of critical properties are all manipulations that can enhance perceptual learning (Gibson, 1969).

ISOLATION OF CRITICAL PERCEPTUAL CUES. Straightforward instructions to the student to attend to task-related cues can apparently be useful (Lavery, 1962). In complex manual control tasks the student will not always be able to identify the critical cues so that it may be necessary for an instructor to point them out. Unfortunately, neither instructors nor visual scientists clearly understand what perceptual cues and relationships are important in manual control.

The pioneering work of James Gibson (e.g., Gibson, 1955, 1966; Gibson, Olum, and Rosenblatt, 1955) has explored the way in which visual cues might support manual control skills. Some of the ideas developed by James Gibson have been tested experimentally (e.g., Johnston, White, and Cumming, 1973) but uncertainty remains about the specific cues that are useful and how they might be used. Owen and his associates (e.g., Owen and Jensen, 1981; Owen, Wolpert, Hettlinger, and Warren, 1984), in following the lead of James Gibson, are attempting to isolate analytically those optical invariants in the environment that could be associated with vehicular guidance. Once those invariants are identified it should be possible to determine empirically their role in supporting manual control behavior and what degree of learning is required for them to be effective. In the meantime, techniques such as those represented by the use

of augmented feedback may direct attention to critical cues even though they cannot be explicitly pointed out by the instructor.

INSTRUCTIONAL DEPENDENCIES. One danger that has been noted in relation to the use of augmented feedback is the development of unwanted dependencies (Lintern, 1980). Furthermore, Lee and Magill (1983) had sought to strengthen their support for the use of contextually interfering manipulations by arguing that greater cognitive effort during acquisition would avoid dependencies on specific elements of the training task that might disrupt transfer to the criterion task. Schmidt (1982, p.550) used a "crutch" analogy to illustrate the danger. Overdependency on the crutch might disrupt later performance without it. Augmented feedback similarly raises a threat of unwanted dependencies. Where it is continued for too long, or is so strong that it obscures the criterion task, dependencies that completely negate any potential benefit of the manipulation may develop.

However, the fact that some augmented feedback manipulations do enhance transfer suggests that the crutch analogy should be extended. A crutch is first used for early (and often essential) support and becomes a problem only if it is used past the time of need. Similarly, facilitation in acquisition will aid transfer if it is scheduled at the appropriate time and to the correct degree. It will cause problems only if it is used for too long, or if it overwhelms other essential elements of the task, and it is at that stage that the supplementary assistance should be discontinued. Thus, an instructional manipulation that aids performance while it is present may often facilitate learning, particularly if it directs attention to critical cues, but some care should be taken to ensure that it is withdrawn before dependencies develop.

CONSISTENCY VERSUS TASK VARIATION. Eberts (1983) demonstrated the advantage of presenting the perceptual relationships in a consistent manner while other basic motor skill research has shown an advantage for training task variations. At first glance, these effects may appear to be at odds with each other. The experiment by Eberts (1983) had been based on similar work with visual detection and visual search tasks (Shiffrin and Schneider, 1977). Consistent mapping (items presented as targets in some trials were never presented as nontargets in other trials) was shown to lead to efficient and automatic processing of visual information. In contrast, varied mapping (items presented as targets in some trials appeared as nontargets in others) prevented the development of automatic processing (Schneider and Fisk, 1983).

Despite their apparent similarity, task variation as discussed by Schmidt (1975), and varied mapping as discussed by Schneider and Fisk (1983), are conceptually different. The

distinction is clearly made in an experiment by Schneider and Fisk (1984) that employed both types of variation with a category search task. In that experiment subjects searched for a word (e.g., dog) that was an example of a prespecified category (e.g., animal). A few categories were established for each experimental condition and those categories were switched from trial to trial over several hundred trials. The subject was advised of the designated target category prior to each trial. One target from the designated category was presented together with two distractor items, and the subject was required to indicate the position of the target item.

In variably mapped conditions, distractors were often drawn from categories that provided targets in other trials, but in consistently mapped conditions distractors were never drawn from the other potential target categories. Task variation was introduced into the experiment by varying the number of potential targets available in a target category. Conditions with four and eight target items per category were tested. As in previous research, performance improved only in consistently mapped conditions. In addition, transfer to untrained targets drawn from the trained categories was better if more targets had been used in training. Thus, the benefits of consistent mapping and of varied training were demonstrated in this experiment. Unfortunately, there is no similarly compelling demonstration of the relative contributions of training-task variety and of stimulus consistency in the motor skill domain.

SUMMARY

The issues outlined in this section and also in the previous one suggest several lines of research that could establish the perceptual-differentiation model as a viable explanation of transfer in manual control. The trials-delay and variety-in-training effects have been shown only with simple motor tasks, and it could be useful to demonstrate them with manual control tasks. In addition, the uncertainty surrounding the effects of blocking versus randomizing trials should be resolved. While the augmented-feedback, predictor, backward chaining, and pursuit-compensatory manipulations produced data consistent with a perceptual view of skill acquisition, further research is needed to verify that the effects are perceptually based.

Several hypotheses about manipulations that might enhance transfer can be generated from consideration of Gibson's (1969) development of her theory and from the research considered in this report. This work will continue to be limited by a general lack of knowledge about cues that support manual control. Nevertheless, some progress can be made by testing manipulations that do not require prior identification of critical cues, although the possibility of disruptive dependencies or artificial enhancements needs some consideration. A limited

amount of data have shown the value of enhancing cognitive strategies that might be referred to as higher-order structures or internal models, and this line of research could be particularly productive.

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Gibson (1969), in her development of perceptual differentiation theory, has described several techniques that might be applied to flight training. In addition, others were noted in this report. The benefits could be substantial and may lead to better asymptotic performance as well as to faster learning. Recent discussions of the role of simulators in flight training (e.g., Wightman, 1983; Lintern and Roscoe, 1980) have noted the potential value of special instructional techniques, many of which are not feasible when aircraft are used for flight instruction. Thus, flight simulators offer potential benefits in addition to their cost advantage for training. The challenge for psychology is to determine how these simulators can be used to maximize training effectiveness.

SECTION V

CONCLUSIONS

The impetus for a new approach to skill transfer for manual control grew out of dissatisfaction with some of the more popular explanations of transfer. Explanations of enhanced transfer in terms of similarity or manipulation of difficulty are inadequate. In particular, departures from similarity have been shown to enhance transfer, and manipulations of difficulty have sometimes shown that transfer is better following training on a more difficult task and at other times following training on an easier task. Other theories and hypotheses from basic motor skill research were also considered. None of the models or concepts that seemed relevant to transfer-of-training issues in manual control could account for all of the available data. Nor have they effectively guided research into transfer for manual control.

The research considered here, when considered as a whole, does not fit easily with explanations that ignore the role of perceptual learning. Manipulations that appear to impact the perceptual dimension of manual control skills have been far more successful in producing significant transfer effects than have manipulations that impact only the response dimension. A perceptual learning model was proposed and it was able to account for opposing trends in a wide range of experimental paradigms. This model implies that the detection, discrimination and differentiation of critical features, patterns and dimensions of difference in task-related stimuli are important in motor behavior.

One remaining concern is that many of the important results have been found only with laboratory tasks that differ noticeably from manual control tasks. In contrast, other results from the manual control data are limited in that the experimental manipulations have often been too imprecise to force a unique interpretation on the data. Nevertheless, perceptual modification appears to dominate the learning challenge associated with acquisition of manual control skills. Emphasis on this dimension in future transfer-of-training research, and in theoretical developments, is likely to be particularly useful in advancing our understanding of processes that contribute to skill transfer.

The perceptual differentiation approach has clear implications for flight training. Techniques that enhance perceptual learning should improve instructional efficiency.

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