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THE ROLE OF INFORMATION IN THE ACQUISITION OF A MOTOR SKILL

BY

© JIM MCAULIFFE

A THESIS

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THE UNDERSIGNED CERTIFY THAT THEY HAVE READ, AND RECOMMEND TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH FOR ACCEPTANCE, A THESIS ENTITLED THE ROLE OF INFORMATION IN THE ACQUISITION OF A MOTOR SKILL SUBMITTED BY JIM MCAULIFFE IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT

Two experiments, using transfer paradigms, were designed to investigate the role of spatial and temporal information in the acquisition of a motor skill. In the first experiment subjects were transferred from an information impoverished condition (spatial or temporal information available) to an information rich condition (both types of information available). The form of the transfer was A to AB or B to AB. In the second experiment, subjects who received spatial information in the training phase had temporal information available during the transfer phase. In contrast, subjects who had temporal information available during the training phase received spatial information during the transfer phase. The transfer was in the form of A to B or B to A. The results from the first experiment indicated that subjects were able to use spatial and temporal information independently and together without interference. The data from the subjects performance in the second experiment indicated that the transfer was asymmetrical. The subjects appeared to only learn the temporal component of the task. The results were discussed in terms of the importance of informational content in motor learning and the use of transfer paradigms in the study of motor learning.

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INTRODUCTION

Researchers studying learning have concerned themselves with three main questions: (1) what is learned, (2) what is the nature of the stimulus, and (3) under what conditions does learning take place?

The question of under what conditions does learning take place has received a great deal of experimental attention with the study of knowledge of results (KR) (see Salmoni, Schmidt, & Walter, 1984 for a review). Franks and Wilberg (1984) provided data from a tracking experiment which related to the question of what is learned. Subjects learned the major component of a movement track prior to learning the finer details. The question of what is the nature of the stimulus has taken on a somewhat different form since the advent of the information processing paradigm. Underwood (1963) was concerned with the nominal and functional stimuli in a learning situation. The nominal stimulus being that which was actually presented to the subject. The functional stimulus was that which the subject used. Underwood proposed that subjects were more involved in the learning situation by actually processing the stimulus information. The questions concerned with learning are not necessarily dealt with exclusively in one experiment or another. Most learning studies deal directly or indirectly with one, two or all three questions.

The three questions which surround learning stem from a behaviourist view of learning. Behaviourists (e.g. Thorndike, 1927) thought of learning in terms of the strengthening of a bond between a stimulus and a response as a result of reinforcement. The concept of bond strength was adequate in explaining the results of a number of animal learning experiments. However, the complex problem of human motor learning might best be investigated within the confines of the information processing paradigm.

Schmidt (1988) outlined the possible information a person may be exposed to in a learning situation. The most global classification of information available to a learner would contain all sensory information. All sensory information would include information which is both related and unrelated to the learning situation. Information related to the task may be present to the learner before, during, or after the movement. The initial position of one's limbs, the flight of a projectile, and the nature of the environment the learner is in, are all types of information present before the movement commences. Each type will likely have a bearing on the movement outcome.

Feedback information present during or after the movement may be categorized as either intrinsic or extrinsic. Intrinsic feedback is available to the performer through his/her own sensory system (e.g. proprioception, vision, audition, and touch). Adams (1971) termed intrinsic information as subjective reinforcement. Subjective reinforcement was thought to aid learning by providing a mechanism whereby the learner could compare his/her performance with a reference of correctness thus allowing for error correction and learning. Extrinsic feedback "is information about the task which is supplemental to, or augments, intrinsic feedback" (Schmidt, 1988: p. 425). KR is considered to be extrinsic feedback.

Fitts and Posner (1969) define feedback as "information arising as a consequence of the organism's response" (p. 27). They outline three functions of feedback. Feedback is thought to provide knowledge, motivation, and reinforcement. Feedback can be informative in that it provides an organism with knowledge about its response. It may also serve in a motivational capacity, helping keep a person interested in a task. The reinforcing function of feedback stems from Thorndike's (1927) Law of Effect. The Law of Effect states that "an organism tends to repeat rewarded responses and extinguish (or avoid) responses followed by no reward or punishment" (Schmidt, 1988: p. 451). Of interest in the present set of experiments is the informative function of feedback in the learning of a motor skill.

<u>Two Theories of Motor Learning</u>

Researchers such as Adams (1971) and Schmidt (1975) have developed motor learning theories consistent with the information processing view of learning. These two theories propose that subjects learn a task as the result of processing error correction information which is used on subsequent practice trials to adjust the subjects performance. The subjects attempt to alter their performance until they respond in a way consistent with the task requirements.

Adams (1971) proposed a closed loop theory of motor learning in which the acquisition of a motor skill was viewed as a "problem to be solved" (p. 122). The problem was to be solved by the subject with the use of information in the form of KR. It was proposed that the KR be used by the subject to correct errors on subsequent trials. The error correction role of KR was proposed as a cognitive activity in contrast to the habit building role associated with KR in Thorndike's (1927) terms.

Adams' theory of motor learning required the development of two forms of memory which he termed the perceptual trace and the memory trace. The perceptual trace is the image, reference mechanism, or the memory of the past movement. The memory trace is a "modest motor program that only chooses and initiates a response rather than controlling a longer sequence, as advocates of motor programs usually imply" (Adams, 1971:p. 126).

The perceptual trace is developed as a result of the subjects use of KR. Early in learning the subjects cannot rely on the existing perceptual trace to determine if the movements performed are correct. The perceptual traces are weak at this point and if the subjects continued to respond based on these traces, they would continue to make errors in relation to the movement goal of the learning situation. The subjects must use the perceptual traces, in relation to the KR provided by the experimenter, to adjust the movements on the next trial. As a function of trials with KR, the subjects develop a perceptual trace consistent with the movement goal. This early stage of learning is called the verbal-motor stage as "corrections are based on KR and verbal transforms of it" (Adams, 1971:p. 124).

The second stage of learning is termed the motor stage. During this stage errors in terms of KR are minimal and have been so for some time. Movement is characterized by eloquence and automaticity. The role of KR is not essential, and learning can occur in this stage without it. The subject matches the response produced feedback to the perceptual trace to determine if the movement was performed as intended. The subject can then make the appropriate corrections for the next trial. Adams referred to the feedback used in this type of learning as subjective reinforcement.

Although the memory trace selects and initiates a response, it is the perceptual trace that controls the movement extent. While both are hypothesized to have independent roles in the performance of a movement, Adams proposed that KR functions to develop both traces in the same way.

A rival to the closed loop theory of Adams (1971) is Schmidt's (1975) schema theory. Schmidt criticized Adams' theory for a number of reasons. First, the closed loop theory was limiting in scope as it applied only to slow positioning movements and did not include rapid movements. Second, learning without KR through the use of subjective reinforcement does not follow logically from the theory. Schmidt (1975) claims that subjective reinforcement in Adams' theory can only serve to guide the movement. That is, the perceptual trace represents the movement extent. Subjective reinforcement results from the comparison of the response produced feedback with the perceptual trace. When the difference between the perceptual trace and the subjective reinforcement reaches zero, the subjects know they have reached the endpoint of the movement. As a result, no error correction information could be derived upon the completion of the movement. Without error correction information to use on subsequent trials, further learning is frustrated. Finally, Schmidt (1975) states that a storage problem would exist if every movement was represented by way of its own motor program as implied by Adams' theory.

Also, related to the storage problem is the problem of the novel response. That is, a subject will not reproduce a given movement the same way twice. The question then becomes how do subjects generate novel movements in a given task situation (e.g. all the different possible skating movements performed during a hockey game).

Schmidt (1975) used the concept of the schema to answer his concerns with Adams' theory. Schmidt (1988) defines a schema as "a rule, concept, or relationship formed on the basis of experience" (p. 491). Schmidt (1975) was mainly concerned with rapid movements (less than 200 msec), but also felt that schema theory could apply to slow positioning movements.

The mechanism for learning a movement in schema theory may best be described by the relationship of the four types of information subjects are purported to store in memory when a movement is executed. These are: (1) the initial conditions, (2) response specifications, (3) sensory consequences, and (4) response outcome (Schmidt, 1975). It is through the relationship of these four types of information that a schema for movement is learned.

The initial conditions represent the sensory information available to the subject prior to the execution of the movement. An example is the proprioceptive information about the position of the limbs and body during a movement. The response specification information determines the specific movement parameters in the motor program. The stored response specifications refer to the specific movement produced. The sensory consequences of the movement arise from the different types of response produced feedback present throughout the subject's sensory system. Finally, response outcome information represents how well the subject performed in relation to the movement goal. The outcome information is seen as that information which the subject actually received. It may either be in the form of KR or of subjective reinforcement.

The relationship between the four types of information stored in memory results in the formation of two types of schema: the recall and the recognition schema. The primary function of the recall schema is movement production. The recall schema is formed through the relationship between the actual outcome of the movement, the initial conditions and the response specifications. The recognition schema is established to evaluate the correctness of the response. The relationship of the initial conditions, the actual outcome, and the sensory consequences results in the formation of the recognition schema.

The use of feedback and KR result in the formation of a motor response schema which includes both the recall and recognition schema. Schema theory proposes that an error correction mechanism must be developed to compare the actual feedback with the expected feedback. It is through this mechanism that subsequent responses are altered to meet the environmental goal. Also, the information is used to develop an error labelling system which is used to update the schema.

Both Adams (1971) and Schmidt (1975) propose theories of motor learning which are highly dependent on feedback and KR for the acquisition of a motor skill. Of prime importance is the informational property contained in the feedback or KR which functions to correct errors on subsequent trials.

KR and Motor Skill Acquisition

Much of the research on the role of feedback in motor learning has confined itself to the study of KR. Although some differences exist, the basic components in the definition of learning are held in common. Research on KR has consistently followed from the definition of learning (Adams, 1976; Magill, 1989; Salmoni et al., 1984; Schmidt 1988). Schmidt (1988) defines motor learning as "a set of processes associated with practice or experience leading to a relatively permanent change in the capability of responding" (p. 346).

Schmidt (1988) defines KR as "verbal (or verbalizeable), terminal (i.e., post response) feedback about the outcome of the movement in terms of the environmental goal" (p. 426). Magill's (1989) definition claims that KR is "information provided to an individual after the completion of a response that is related to either the outcome of the response or the performance characteristics that produced that outcome" (p. 318). The difference between the two views of KR is that Magill's definition includes both response outcome information as well as information about the actual performance of the response (the later often being referred to as knowledge of performance). On the other hand Schmidt only refers to KR in terms of response outcome information. Schmidt (1988) claims that the restrictive definition of KR allows researchers to control feedback in a learning environment which makes it possible to determine the function of error correction information in the learning of a motor skill. Both definitions incorporate the concept of information as being important in the learning of a motor skill.

The most widely used experimental paradigm for the study of the effects of feedback on motor learning is the KR paradigm (Schmidt, 1988). The task most commonly used in this paradigm usually requires some type of linear positioning response. This task requires that the subjects learn to move a slide or lever to a target position. The procedure involves the experimenter manipulating the KR (e.g. the absolute frequency of the KR) available to the subjects during the acquisition trials. The acquisition phase typically involves the subjects receiving a number of training trials with a specified KR treatment.

Following a rest interval, the subjects are required to perform a number of trials <u>without</u> KR. This phase is commonly referred to as the retention and/or transfer phase. Authors (Salmoni et al., 1984) refer to the acquisition trials as performance trials. They claim that in order to infer learning, a test of the relatively permanent effects of the KR treatments during the acquisition phase must be conducted. The retention phase is used to determine if the effects of the KR persist over time.

When KR is presented to a subject in a learning situation, two properties are associated with the KR. First, there is the specific nature of the KR as an independent variable. For example, the KR could be presented verbally or visually which would require the subject to process the information via the appropriate modality. Second, there is the content of the information presented as KR (e.g. type of information such as spatial or temporal information). The informational content is contained within the specific nature of the independent variable.

Different types of information may have different effects on learning. The benefits that each type of information brings to the learning environment may effect learning independently, interactively, or repetitively (i.e. they may be redundant with each other). Also, when subjects are given different types of information, these types of information may add together to effect learning. Further, if they do add together to effect learning, the nature of their additivity is unclear.

Researchers have completed experiments which indicate that KR as an independent variable effects learning. One of the early studies in motor learning by Bilodeau, Bilodeau, and Schumsky (1959) demonstrated the importance of error correction information in the learning of a linear positioning response. In their experiment subjects were required to position a linear slide while blindfolded. Error correction information containing both direction and extent was given to the subjects. The subjects were assigned to one of four KR treatments. One group received KR on every trial. Two other groups had KR withdrawn either after two trials or six trials. The last group did not receive KR.

The results indicated that the subjects could improve on the task when KR was present but performance deteriorated when KR was withdrawn. There was no improvement in performance by those subjects who did not receive KR. Following the acquisition phase the subjects in the no-KR group were given KR for an additional five trials. The results were similar to that of the first five trials of the group of subjects who received KR on every trial. These results indicate that the subjects could learn when given KR but improvements in performance could not be obtained in the absence of KR. This study supported the importance of KR as a learning variable.

Newell (1974) conducted an experiment similar to that of Bilodeau et al. (1959) with respect to withdrawing KR after a number of practice trials. Subjects were required to move a handle on a slide within a specific time. The results showed that subjects could maintain their performance if given enough practice trials with KR prior to withdrawal of KR. Newell concluded that subjects need KR early in learning. The studies showed that subjects could learn tasks with spatial error correction information (Bilodeau et al., 1959) and temporal error correction information (Newell, 1974). These studies manipulated KR as an independent variable. That is, either the subjects received KR or they did not. The results indicate that spatial and temporal error correction information can be used to learn a motor task.

Studies have been completed which were concerned with the temporal locus of KR (Lee and Magill, 1987; Schmidt and Shea, 1976; Shea and Upton 1976; Swinnen, Schmidt, Nicholson and Shapiro 1990). The temporal locus issue refers to the time frame in which KR is presented to the subject during a learning sequence (Schmidt, 1988).

There are three intervals associated with the temporal locus of KR (Salmoni et al., 1984). The KR delay interval refers to the amount of time between the completion of a trial and the presentation of the KR. The post-KR delay interval is the amount of time between the KR delivery and the start of the next trial. It is during this time period that the subjects can process the information contained in the KR for subsequent use on the next trial. The intertrial interval refers to the amount of time between trials. Varying one or all of these intervals can possibly affect both the amount and performance of the acquired skill.

Ramella (1983a, 1983b, 1982) asked his subjects to position a linear slide to a specific point within a specific time frame. Error information was provided to the subjects in the form of KR as to their spatial and temporal deviations from the desired goal. Ramella (1982) found that the subjects learned only the spatial component of the task when the post-KR delay interval was limited to three seconds. When the post-KR delay interval was expanded to six seconds, subjects learned both the spatial and temporal components of the task (Ramella, 1983b).

All of the Ramella experiments manipulated the informational content (spatial and temporal) and the delay interval following the presentation of the information. Ramella was interested in the time the subject would have to process the relevant information. Ramella concluded that the post-KR delay interval determined whether or not subjects could learn both the spatial and temporal components of the task.

Although these experiments were only concerned with the informational content as presented within the specific nature of the information, they provide support for the notion that subjects could learn both spatial and temporal components of a task if provided with this information as KR.

KR has been manipulated as an independent variable in many motor learning studies. Some examples of the manipulations are: the presence or absence of KR

(Bilodeau et al., 1959), the temporal position of KR in a learning sequence (Schmidt and Shea, 1976), the precision of the KR information (Magill and Wood, 1986), schedule of KR delivery (Bilodeau and Bilodeau, 1958; Ho and Shea, 1978; Winstein and Schmidt, 1990), and the presentation of KR as summary information about a number of trials (Schmidt, Young, Swinnen, and Shapiro, 1989). In each instance KR was investigated in terms of the manipulations of the specific property of the information. No effort was made to manipulate the informational content of the KR to determine its role in the learning of a motor skill. That is, independent of the manipulations of the delivery of information in the form of KR, the effect of the information itself on learning remains unclear.

The Guidance Hypothesis,KR and Motor Learning

Salmoni et al. (1984) have outlined the guidance hypothesis to explain how KR effects learning. Central to the guidance hypothesis is that information in the form of KR guides performance during acquisition. If subjects become reliant on KR to perform the task, then their performance when KR is withdrawn will be poorer than if they had some practice in acquisition without KR.

Schmidt et al. (1989) provide data which supports the guidance hypothesis. In their study subjects were required to perform a ballistic timing task. Subjects were given summary KR after 1, 5, 10 or 15 trials. Summary KR provides the subjects with information about the completed trials. For example, summary KR after five trials would include KR about all five trials and would be available to the subject following the fifth trial. The results of their study indicate that relative to immediate KR, longer KR summaries enhance learning as evidenced through a no- KR retention test. Schmidt et al. hypothesized that if subjects received KR on every trial learning would be depressed due to the guidance properties of the KR. The KR guidance properties are thought to block processing activities necessary for performance when KR is withdrawn. The guidance function of KR was not as consistent in Schmidt's et al. longer KR summaries. Consequently, the subjects were required to engage in alternative processing activities which presumably lead to better retention and therefore more learning.

The guidance hypothesis was developed to account for the apparent detriments in learning due to a reliance on KR to perform a task. The ultimate guidance function of KR would be obtained in a situation where subjects received KR on every trial. KR does not have to be administered on every trial. According to the guidance hypothesis, subjects who receive KR on less than 100% of the trials should show better effects of the KR on learning than those subjects who received KR on all the acquisition trials. The proportion of trials in which KR is available to the subjects is referred to as the KR's relative frequency. Relative frequency may be calculated by dividing the number of KR trials by the total number of trials.

An example of a study which manipulated the relative frequency of KR is that of Wulf and Schmidt (1989). They used the guidance hypothesis to explain data they obtained from subjects who performed a sequential timing task. They manipulated the relative frequency of the KR. They found that subjects who had a 67% relative frequency performed better than subjects who were given KR on 100% relative frequency schedule.

In order to more fully understand motor learning within an information processing context, it is necessary to assess the influence and frequency of the available information present in a learning situation. As mentioned earlier, information which could have an effect on learning can be present before, during, and after the trial (Schmidt 1988). In the following experiments, the informational content available during and after the trial is manipulated to determine its effect upon learning. The following experiment was developed to investigate the relationship between spatial and temporal information on the acquisition and retention of a motor skill.

EXPERIMENT ONE

When people make movements they do so in a space-time coordinative structure (Bernstein, 1967). Every movement, according to Bernstein, has a spatial and temporal parameter associated with it. In this experiment the relationship between the informational content of the spatial and temporal feedback is examined.

The study of the relationship between spatial and temporal information, as independent variables, requires the use of a different experimental paradigm than the KR paradigm popularized by Schmidt (1982). The following experiment utilizes a variant of the double transfer paradigm. The transfer paradigm is characterized by three phases. A pre-training phase used to familiarize the subjects with the task and apparatus, a training phase, and a transfer phase.

During the training phase subjects receive either spatial, temporal or both types of information. The purpose of this phase of the experiment is to determine the extent to which the subjects can use each type of information independently and without interference.

The transfer phase is characterized by one-half of the subjects in the spatial and temporal groups receiving both types of information. Subjects go from an information impoverished condition (i.e. only one type of information, spatial or temporal) during the training phase to an information rich condition (i.e. both types of information) in the transfer phase. The subjects in the 'both' group receive both types of information in the training and transfer phases. They serve as a control against which the other groups can be compared. The purpose of the transfer phase is to determine how subjects use spatial information when it is added to temporal information and conversely how subjects use temporal information when it is presented in addition to spatial information.

One way to illustrate the nature of the transfer paradigm utilized in this experiment is to let 'A' represent temporal information and 'B' represent spatial information. The transfer is in the form of A to AB or B to BA. The relationship between the two types of information are determined given this form of transfer paradigm.

The subjects are asked to work at their own pace during a trial sequence. No time constraints are placed on the post-KR delay interval. Consequently, the subjects have ample time to process the spatial and temporal information. This procedure was designed to overcome the effects of the short post-KR delay interval found by Ramella (1983b, 1982).

The subjects are asked to complete three no-KR retention tests. The purpose of the no-KR retention tests was to determine the relative permanence of the learning due to the treatments. Separate retention tests follow the pre-training phase, the training phase, and the transfer phase.

METHOD

Subjects

Twenty-five students and staff from the Department of Physical Education and Sport Studies volunteered to serve as subjects in the experiment. The ages ranged from 19 to 35. Subjects were assigned to 1 of 3 groups, (spatial, temporal, or both), with each group having 10 subjects except the both group which had 5.

Apparatus and Task

The subjects were required to perform a linear tapping movement using a pen shaped stylus on a Summagraphics Supergrid digitizing tablet. The movement required the subjects to tap a home position, move to the target, then tap on the target position. The transparent nature of the Supergrid allowed for the illumination of a home LED and a target LED from beneath the digitizing tablet. A moveable opaque shield positioned above the Supergrid could occlude spatial information when required. The opaque shield was positioned at a sufficient height so that it could not obstruct the movement in any way. Temporal information was provided to the subjects in the form of verbal feedback from the experimenter. The verbal feedback was error information which included direction (fast or slow) and magnitude (to the nearest msec). Movement time and spatial accuracy data were recorded using a PDP 10/11 digital laboratory computer interfaced with the Supergrid.

Procedure

The experiment was conducted in 3 phases: (1) pre-training, (2) training, and (3) transfer. In addition, the subjects were required to perform 3 no-information retention tests following each of the phases of the experiment.

Pre-training phase. All 25 subjects completed 5 blocks of 10 trials for a total of 50 pre-training trials. These trials were used to familiarize the subjects with the task and apparatus. The trials were performed with the opaque shield in place thus occluding spatial information from the subjects. Also, subjects did not receive temporal feedback. As a result the pre-training trials were performed without the use of spatial or temporal information to guide performance.

Subjects were asked to perform movements of 6, 8, 10, 12, and 14 inches in random order restricted by equal incidence of each movement length within a block of 10 trials. Each movement was initiated from a consistent home position. The subjects were instructed to move as quickly and accurately as possible. Trial initiation was self-paced. Following each block of trials subjects were allowed to turn away from the apparatus and relax for approximately 60 seconds before continuing. Mean movement time and standard deviation were calculated for the 50 trials for each individual subject. These calculations were used later as the required movement times in the training and transfer phases.

Training phase. The 25 subjects were randomly assigned to one of the 3 conditions, spatial (Sp), temporal (Te), or both (Bo), referring to the type of information available to the subject during the training phase. The Sp and Te groups had 10 subjects each and the Bo group had 5.

The subjects in the Sp group performed a 10 inch movement as quickly and accurately as possible. The required movement distance was indicated by the illumination of a home LED to the left centre of the Supergrid and a target LED illuminated 10 inches to the right. The same Y axis coordinates were used for both the home and target LEDs. The subjects had spatial information available by being able to see their responses and compare them to the location of the target LED. No temporal KR was given, therefore, subjects did not receive external information concerning the temporal accuracy of their responses.

The subjects were required to respond within a specified time window to deter them from varying their response strategy (i.e. adopting a variable speed accuracy strategy). The time window was determined by the pre-training trials mean movement time plus or minus

2 standard deviations for the 10 inch movement. If the subjects performed a trial that was 2 standard deviations slower than their mean, they were reminded of the task requirements. It was important for the subjects to use the spatial information to learn the spatial component of the task without the confounding effects of a speed accuracy trade off (SATO) strategy.

The subjects in the Te group were required to perform the 10 inch movement with the opaque shield occluding the visuo-spatial information. Temporal KR information was provided to the subjects verbally by the experimenter. Subjects were informed whether they were too fast or too slow and by how much (in milliseconds). The required movement time was determined by the subject's mean movement time for a 10 inch movement obtained from the results of the pre-training phase.

The Bo group subjects received temporal information in the form of KR and spatial information from performing the task without the shield to occlude visuo-spatial information. The Bo group had available both the temporal and spatial information provided to the subjects in the Te and Sp groups.

<u>Transfer</u>. Following the training phase subjects from the Te and Sp groups were split into 2 groups. Five subjects from each group continued to receive the same information they received during the training phase (Te

to Te and Sp to Sp). The remaining 5 subjects from each of the Sp and Te groups were transferred to the Bo condition (Te to Bo and Sp to Bo). Therefore, 5 subjects from the Sp group also received temporal information during the transfer phase and 5 Te group subjects received spatial information in addition to temporal information during the transfer phase. The Bo group from the training phase continued to receive both spatial and temporal information during the transfer phase. Table 1 outlines the information available to the subjects in the training and transfer phases for all groups in the first experiment.

Retention tests. Following each of the pre-training, training, and transfer phases subjects were required to perform a retention test. Subjects performed the task in the absence of relevant spatial and temporal information. The purpose of the retention tests was to determine if the subjects' performance could be maintained in the absence of information. If so, it would satisfy the 'relatively permanent change in the capability of responding' requirement of the learning definitions.

The training phase and transfer phase trials were given on each of 5 days. The pre-training phase took a single day. The 3 retention tests were run on separate days, making a total experimental length of 14 days. On each day subjects completed 5 blocks of 10 trials for a total of 50 trials. The training and transfer phases required a total of 500 trials. All trials were self-paced and subjects were provided a rest interval following each block.

Table 1

Experiment 1. The types of information available to the subjects in the training and transfer phases.

Group		Training Phase	Transfer Phase
1.	TeTe	Temporal	Temporal
2.	TeBo	Temporal	Temporal and Spatial
3.	SpSp	Spatial	Spatial
4.	SpBo	Spatial	Temporal and Spatial
5.	BoBo	Temporal and Spatial	Temporal and Spatial

TeTe = temporal to temporal, TeBo = temporal to both, SpSp = spatial to spatial, SpBo = spatial to both, BoBo = both to both

Error scores. The dependent variables measured included absolute (AE), constant (CE), and variable (VE) error scores for temporal and spatial deviations. The temporal error scores were measured in milliseconds. The spatial error scores were measured to the nearest one thousandth of an inch, a measure which represented the precision of the data obtained from the Supergrid apparatus. The error scores were calculated for both the spatial deviations on the X and Y axis.

RESULTS

Preliminary Analysis. A two way (Groups by Day) multiple analysis of variance (MANOVA) was performed on the AE and CE scores obtained from the training and transfer phases. There was a significant main effect for Day $F(54,1080)=2.502$, $p<.001$ and Group $F(24,72)=2.80$, $p<.001$. There was also a significant Day by Group interaction $F(216,1080)=2.038$, $p<.001$. An additional two way (Groups by Day) MANOVA on the VE scores was completed, yielding significant main effects for Day $F(27,600)=2.92$, $p<.001$ and Group $F(12,600)=13.994$, $p<.001$. The interaction was also significant $F(108,600)=1.258$, $p<.052$.

As a result of the significant effects found in the MANOVAs a number of univariate analysis of variance (UANOVA) were performed on the AE, CE, and VE scores for X axis, Y axis, and time data. The results of the univariate tests are presented in Table 2. Only the Day by Group interactions are shown in Table 2.

The post-hoc analyses using the Student Neuman-Keuls (SNK), with alpha set at $p<.05$, were run to determine the significant differences. Of interest in the preliminary analysis was the possibility of differences existing between days in the training phase (Days 3 to 7), or in the transfer phase (Days 9 to 13) within a group. SNK results indicated that for the Group 2

Table 2

Experiment 1. UANOVA on dependent variables AE, CE, and VE for the Day by Group interaction.

Dependent Variable	F Ratio	M.S. Error	Probability	
AE X	F(36,180)=6.72	185898.44	p<0.001	*
AE Y	F(36,180)=1.90	14101.41	p<0.01	*
AE Time	F(36,180)=3.93	82.24	p<0.001	*
CE X	F(36,180)=2.16	391089.94	p<0.001	*
CE Y	F(36,180)=0.84	27298.06	p>0.05	
CE Time	F(36,180)=4.75	127.05	p<0.001	*
VE X	F(36,200)=2.20	28246.17	p<0.001	*
VE Y	F(36,180)=2.98	1974.72	p<0.001	*
VE Time	F(36,180)=0.25	91.96	p>.05	

M.S. Error = Mean Square Error, * = significant

(TeBo) training phase, Day 7 was significantly different from Days 3,4, and 5 when AE data from the X axis was considered. For AE on the time dimension SNK results indicated that for Group 3 (SpSp) in the training phase Day 3 was different from Days 5,6, and 7. In the transfer phase Day 9 was different from Days 10 and 12. For VE, Group 2 (TeBo) Day 4 was found to be different from Days 3,5,6, and 7 on the X axis.

The significant post-hoc SNK mean differences within the days of the training or transfer phases of a particular group were only found on the dependent measure for which the particular group did not receive that type of information. For example, there were significant mean differences found during the training phase of Group 2 (TeBo) on AE scores for the X axis. AE scores on the X axis are considered to be a measure of spatial accuracy. The subjects in the TeBo group did not have spatial information available to them during the training phase, therefore the mean differences may be due to inconsistent responding as a result of the lack of information to aid in performance. Also, there were no consistent mean differences, indicating an increment in learning as a function of days of practice with spatial and temporal information. Therefore, for ease of explanation and further analysis the 5 days of training and 5 days of transfer were grouped together to form one mean. The MANOVA and appropriate UANOVAs were run on the collapsed data to determine the effects of the different types of information presented as independent variables.

<u>Training and Transfer Data</u>. A two-way (Groups by Phase, i.e. training or transfer) MANOVA was calculated on the AE and CE scores for X, Y, and time. There was a significant main effect for Phase $F(6,15)=11.456$, $p<0.001$ and Group $F(24,72)=2.8$, $p<0.001$. The interaction was also significant $F(24,72)=2.184$, $p<0.01$. The two-way

MANOVA on the VE scores for X, Y, and time yielded significant Phase $F(3,38)=14.953$, $p<0.001$ and Group $F(12,120)=7.802$, $p<0.001$ effects, as well as a significant interaction $F(12,120)=3.081$, $p<0.01$.

The UANOVA results for the Group by Phase interaction are presented in Table 3. The post-hoc analyses were calculated on the means using the SNK with the alpha set at $p<0.05$.

AE on the X axis scores for the training and transfer phases are plotted in Figure 1. SNK comparisons revealed that for Group TeTe, the training and transfer phases were different from that of all other groups. In addition the training phase of Group TeBo was significantly different from the training phases of all other groups as well as the transfer phase of all other groups including its own. Results of the SNK tests on AE for the Y axis were similar to that of the X axis except that the training phase of the TeBo group was not different from the training or transfer phases of the TeTe group. Mean data for AE on the Y axis is plotted in Figure 2. The AE scores for time showed that the training and transfer phases for the SpSp group were different from all other groups'

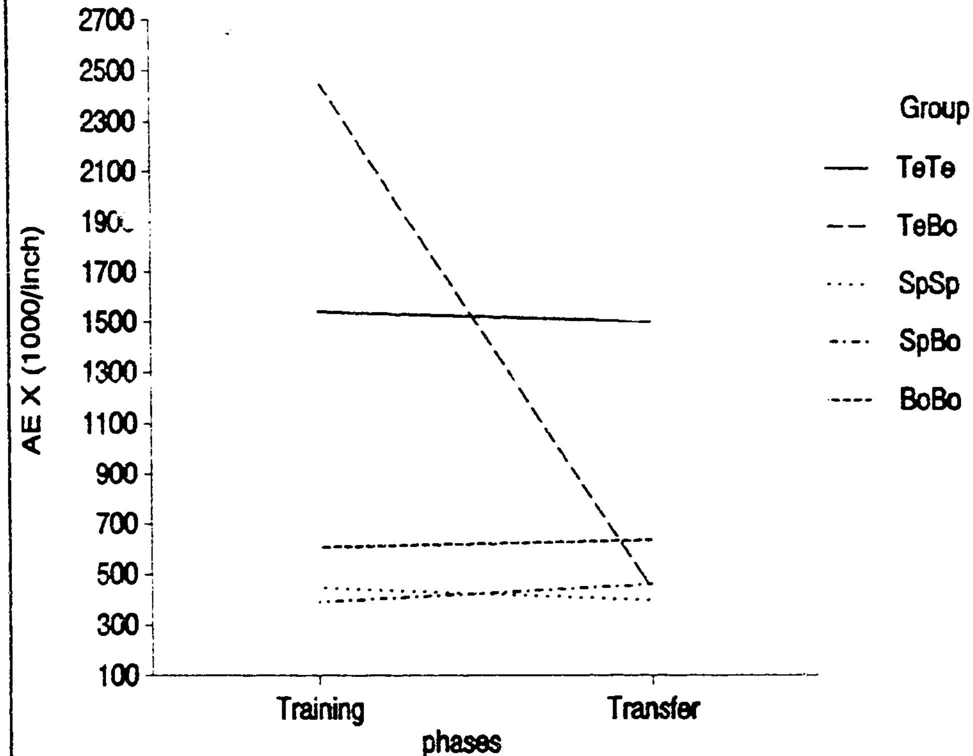

Figure 1. EXP 1. Absolute Error on the X axis for the training and transfer phases.

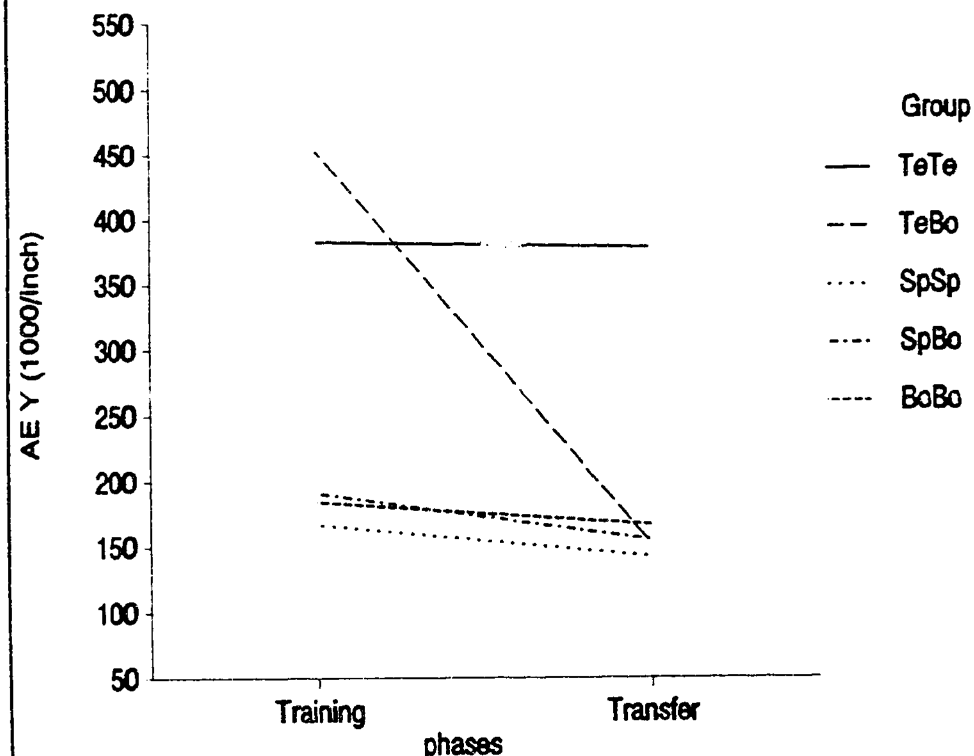

Figure 2. EXP 1. Absolute Error on the Y axis for the training and transfer phases.

Table 3

Experiment 1. UANOVA results on AE, CE, and VE for the Phase by Group interaction (collapsed data).

Dependent Variable	F Ratio	M.S. Error	Probability	
AE X	$F(4,20)=17.85$	116060.81	$p<0.001$	*
AE Y	$F(4,20)=3.70$	10661.04	$p<0.05$	*
AE Time	$F(4,20)=10.92$	38.33	$p<0.001$	*
CE X	$F(4,20)=3.09$	384705.25	$p<0.05$	*
CE Y	$F(4,20)=0.84$	26446.68	$p>0.05$	
CE Time	$F(4,20)=12.78$	69.06	$p<0.001$	*
VE X	$F(4,40)=10.39$	31354.73	$p<0.001$	*
VE Y	$F(4,40)=7.08$	2076.06	$p<0.001$	*
VE Time	$F(4,40)=0.19$	26.96	$p>0.05$	

M.S. Error = Mean Square Error, * = significant

training and transfer phases, with one exception. The training phase of the SpBo group was not different from that of either phases of the SpSp group and was significantly different from both phases of all other groups as well as its own transfer phase. The AE scores for time are presented in Figure 3.

Only four of the comparisons for CE proved to be significant. On the X axis dimension the training

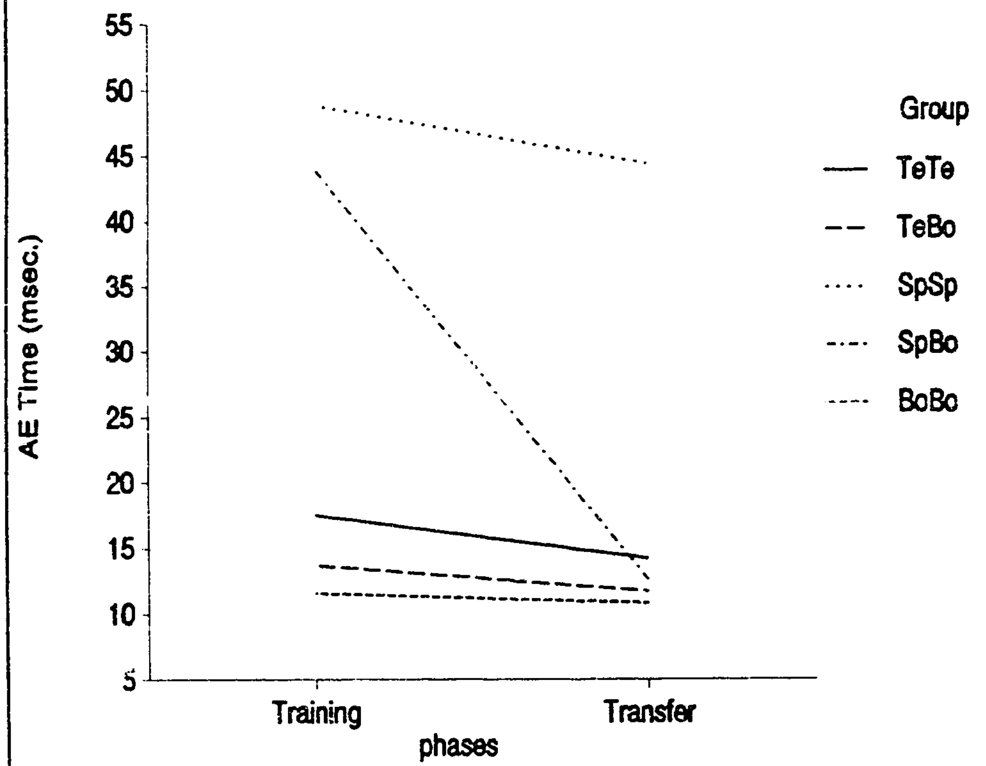

Figure 3. EXP 1. Temporal Absolute Error for the training and transfer phases.

phase of Group TeBo was different from transfer phases of Group TeBo and SpBo, as well as the training phase of Group SpSp. The SNK results on the time scores revealed that the training phase of the SpSp group was significantly different from its transfer phase. The interaction for CE on the Y axis was not significant.

The post-hoc SNK comparisons for VE on the X axis revealed the same significant pair-wise differences as that of AE on the X axis. The mean data is plotted in Figure 4. The TeTe training phase for VE Y axis was significantly different from all other groups' training and transfer phases except its own transfer phase. Also, the TeBo group training phase was different from all other groups' training and transfer phases.

There was no significant interaction for VE on the temporal dimension. However, there was a significant Phase main effect $F(1,40)=4.96$, M.S. Error=26.96, $p<0.05$,as well as a Group main effect $F(4,40)=12.83$, M.S. Error, $p<0.001$. Subsequent post-hoc SNK analysis on the Group main effect revealed that the SpSp group was slower than the four other groups.

<u>Retention Data</u>. A two-way (Groups by Days) MANOVA was performed on AE and CE scores from the retention tests. There was a significant main effect for Day $F(12,56)=2.562$, $p<0.01$. The MANOVA for the VE scores approached significance when considering the

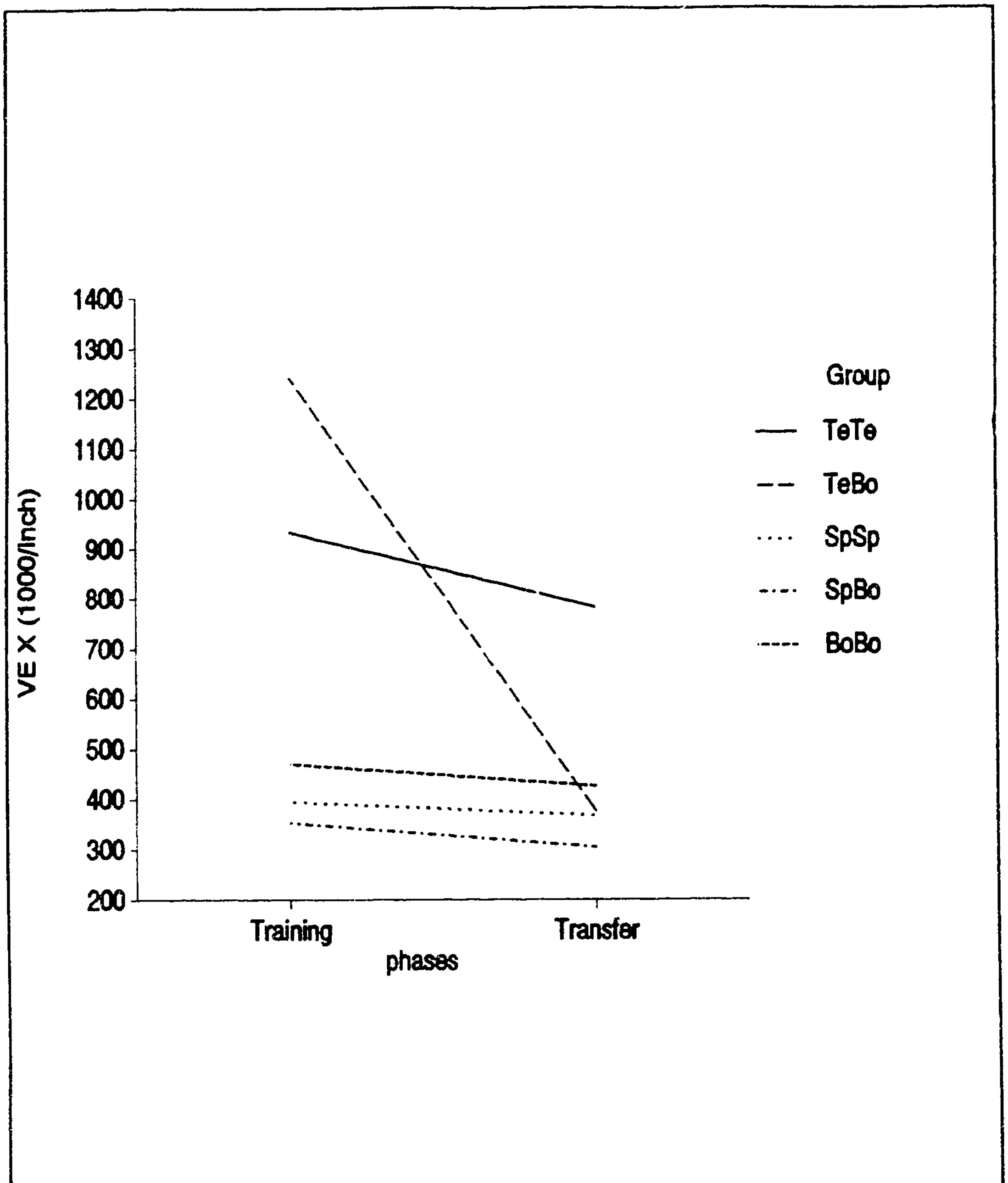

Figure 4. EXP 1. Variable Error on the X axis for the training and transfer phases.

main effect of Day $F(6,94)=2.180$, $p<0.052$. All other MANOVAs failed to reach significance.

Subsequent UANOVAs revealed main effects of Day for AE on the X axis $F(2,32)=6.41$, M.S. Error=720188.19, $p<0.01$; AE for time $F(2,32)=5.16$, M.S. Error=264.92, $p<0.05$; CE for time $F(2,32)=10.39$, M.S. Error=561.54, $p<0.001$; and VE on the Y axis $F(2,48)=3.41$, M.S. Error=7266.59, $p<0.05$. All other main effects for Day failed to reach significance.

Post-hoc SNK (alpha set at 0.05) analyses revealed that for AE on the X axis the first retention test was significantly different from the second and third retention tests. The second and third retention tests were not different from each other. For AE on the time dimension, the only significant difference occurred between the first retention test and the last (third) retention test. All CE scores for time were different from each other. Finally the first retention test was different from the second and third retention test for VE on the Y axis. The second and third tests were not different from each other. The means for each of the dependent variables are listed in Table 4.

Table 4

Experiment 1. Mean Retention Scores.

	Retention		
Dependent Variable	Test 1	Test 2	Test 3
AE X	2099.580	1467.311	1157.117
AE Time	39.965	29.808	23.592
CE Time	-31.393	-13.524	2.746
VE Y	324.694	269.325	259.370

DISCUSSION

Training. When spatial and temporal information were available in the training phase subjects were able to use that information to improve their performance in respect to the spatial and temporal goals of the task. The training phase performance of the subjects from SpSp and the SpBo groups differed significantly from the training phase performance of the TeTe and TeBo groups. The differences were evident for AE, VE, on the X and Y axis as well as AE for time. The SpSp and SpBo groups received only spatial information during the training phase. The TeTe and TeBo groups received only temporal information during the training phase. Subjects which received spatial information performed better on the spatial component of the task than the subjects which had temporal information available to them (see Figure 1 and 4). In addition, subjects who had temporal information available to them performed better on the temporal component of the task than the subjects who received spatial information (see Figure 3). In summary, subjects were able to perform better on the dimension (spatial or temporal) for which they received feedback information.

The results of Experiment One are in agreement with those of Bilodeau et al. (1959) for spatial information and Newell (1975) for temporal information. However, the Bilodeau et al. and Newell studies required the subjects to learn a task with either a spatial component or a temporal component to it. That is, KR was given on a single task dimension. In the present experiment subjects had to learn a task in which both spatial and temporal components were important.

In a series of experiments by Ramella (1983a, 1983b, 1982) subjects received both spatial and temporal information about a task. The task was to move a linear slide 18 inches in 1500 msec. The subjects in these experiments always received both types of information. Ramella could determine that spatial and temporal KR are beneficial to the learning of a motor task. However, the procedure employed by Ramella did not allow for a determination of the relationship between spatial and temporal information when that information was available in a learning environment.

In Experiment One, subjects had both types of information available. They could use both types without any detriments in performance on either the spatial or temporal component of the task. For the BoBo group, performance on the spatial component of the task was the same as the subjects in the SpSp and SpBo groups. Also, the BoBo group performed equally as well on the temporal dimension as the TeTe and TeBo groups. Hence, subjects in Experiment One were able to use spatial and temporal information independently and/or together without interference.

Transfer. A number of studies in which various manipulations of KR were investigated, used the results from retention tests to infer that learning had taken place (Buckolz, Renger, Salmoni, Hall, and Paunonen, 1990; Ho and Shea, 1978; Schmidt et al., 1989; Swinnen et al., 1990; Winstein and Schmidt, 1990). A number of other studies required that subjects be transferred to a novel variation of the task (Magill, Chamberlin, and Hall, 1991; Wulf and Schmidt, 1989). Results from the novel transfer tasks were used to infer whether or not learning had taken place. The subjects in these experiments were required to perform a variety of tasks with some manipulation of KR as an independent variable. Consequently, it was not possible to ascertain the effects of the informational content on learning other than to indicate whether information was available or not available to the subjects on a trial.

In the first experiment, subjects were transferred from an impoverished information condition (having only spatial or temporal information available) to an information rich condition (having both types of information available). The transfer phase of Experiment One was designed to examine the relationship between spatial and temporal information.

Subjects were able to maintain their performance on one component of the task when transferred to a condition in which they received both types of information. In addition subjects were able to improve their performance on the component of the task for which they did not receive information during the training phase of the experiment.

The subjects in the SpBo group maintained their performance on the spatial component which they had established during the training phase. The SpBo group subjects also performed at the level of the BoBo group subjects on the temporal dependent measures during transfer. The subjects in the TeBo group maintained their performance on the temporal component of the task during the transfer phase. Also, the TeBo group subjects equalled the performance on the spatial component of the task during transfer that was achieved by the subjects in the BoBo group. In fact all the subjects in the groups which received both types of information in the transfer phase (Groups TeBo, SpBo, and BoBo) performed the same on both the spatial and temporal components of the task during transfer.

The subjects in the groups which continued to receive the same type of information in transfer that they received during training (Groups SpSp and TeTe) maintained their performance on the component for which they received information. The subjects performances appeared to reach asymptotic levels during training trials and additional practice with the type information available to them did not improve their performance. The performance of the SpSp and TeTe groups in transfer was the same as the groups who received both types of information in transfer (Groups SpBo, TeBo, and BoBo) for the spatial and temporal components respectively. This further supports the claim that the subjects can use spatial or temporal information independently and together without interference.

The data obtained from the subjects in the first experiment indicated that subjects did not use spatial and temporal information in a redundant fashion. That is, subjects who were given spatial information did not improve on the temporal component of the task and subjects who received temporal information did not improve on the spatial component of the task. This result was supported by the data obtained from the subjects in the SpSp and TeTe groups. The subjects in the SpSp group did not change in performance on the temporal component from training to transfer and were significantly poorer than those groups which received temporal information in either the training or transfer phases (Groups TeTe, TeBo, SpBo, and BoBo). Also, the subjects in the TeTe group did not improve in performance on the spatial component from training to transfer and differed from all groups which received spatial information during either the training or transfer phases (Groups TeBo, SpSp, SpBo, and BoBo).

Retention. Retention tests were employed before and after the training phase as well as after the transfer phase to determine if the performance levels attained during acquisition remained when the spatial and temporal information were withdrawn. Results from earlier studies indicate that the differential effects of KR treatments can be maintained in immediate or delayed no-KR retention tests (e.g. Schmidt et al., 1989; Swinnen et al., 1990; Winstein and Schmidt, 1990). Corroborating results which would indicate that the effects of temporal and spatial information persist over time were not present in this study.

The lack of a retention test by group interaction indicated that the availability of spatial and temporal information in each of the different groups did not effect the retention scores differentially. The Day main effect indicated that all the groups retention scores were effected in the same way. Only AE scores on the X axis, AE for time, CE for time, and VE scores on the Y axis yielded significant differences. In general the first retention day differed from either both the post training and post transfer retention test, or only the final retention test. The CE scores for time were progressively better from the first retention test to the last retention test. Subjects mean CE scores were significantly better in the post training phase retention test than the first retention test. Also, the post transfer phase retention scores were better than the CE scores from the post training phase retention test (see Table 4). These retention tests results are not compelling because they could be due solely to practice or experience with the task and not to the differential availability of spatial and temporal information to the subjects.

In the next experiment the independent effects of spatial and temporal on learning a motor skill are investigated further. An alternative learning paradigm from that used in the first experiment was used to examine the degree to which learning has taken place.

EXPERIMENT TWO

The relationship of the types of information used in Experiment One were determined in a specific way. The subjects from the first experiment were transferred from an impoverished information condition (training), where they only received one type of information, to an information rich condition (transfer), where they had both types of information available. The results of the first experiment indicate that subjects could use temporal and spatial information independently and together without interference in performing a motor task.

Hicks (1974) used an A to B or B to A transfer paradigm to determine how much training (on inverted and reversed printing) subjects could transfer from right hand (A) to left hand (B) and from left (B) to right (A). Hicks found that the transfer was asymmetrical and that right handed subjects learned more when they began with their left hand.

The use of an A to B or B to A paradigm provides an opportunity for subjects to use spatial and temporal information to determine if one parameter (spatial or temporal) effects the learning of a motor skill at a rate which is different than the other. The amount and type of transfer (symmetrical or asymmetrical) would provide information about the relationship of spatial and temporal information in the learning of a motor skill.

The second experiment used a paradigm similar to that employed by Hicks (1974). Subjects who perform training trials with temporal information were required to perform transfer trials while spatial information was available. Conversely, subjects who performed the training phase with spatial information, experienced temporal information when transferred.

Historically the study of transfer in motor learning dealt mainly with the effect of prior practice of one task on the subsequent learning of another task. Schmidt

(1988) defined transfer "as the gain (or loss) in the capability for responding in one task as a result of practice or experience on some other task" (p. 371). The purpose of this experiment was to determine the gain or loss in the capability of performing on a task when practice or experience with one type of information is followed by practice or experience with another type of information.

METHOD

Subjects

Ten subjects were recruited from the Department of Physical Education and Sport Studies. The subjects were randomly assigned to either the spatial or temporal group with 5 subjects in each group. None of the subjects had participated in the first experiment.

Apparatus and Task

The apparatus and task used in Experiment Two was the same as that used in the first experiment.

Procedure

The pre-training phase, training phase, and retention tests were identical to those used in Experiment One. The transfer phase was similar to that used in the first experiment with the exception that when the Sp and Te subjects were transferred, they only received the information they did not receive during the training trials; and not both types of information as they did in Experiment One. See Table 5 for an outline of the types of information subjects had available to them in the second experiment.

The number of trials per block, blocks per day, and number of days for each the pre-training, training, and transfer phases, as well as the retention tests were exactly the same as those used in Experiment One.

Table 5

Experiment 2. The types of information available to the subjects in the training and transfer phases.

Group	Training Phase	Transfer Phase
1. TeSp	Temporal	Spatial
2. SpTe	Spatial	Temporal

TeSp = temporal to spatial, SpTe = spatial to temporal

RESULTS

Preliminary Analysis. Because the groups from the first experiment could serve as controls against which the results of the second experiment could be compared, the data obtained from this experiment was combined with the data from the first experiment for analysis. The combination of the two experiments allows for the comparison of the TeSp and SpTe groups from the second experiment to the conditions already established in Experiment One.

A two way (Groups by Day) MANOVA was performed on the AE and CE scores obtained from the training and transfer phases. There was significant main effects for Day $F(63,1764)=2.741$, $p<0.001$ and Group $F(42,162)=2.177$, $p<0.001$. The Day by Group interaction $F(378,1764)=1.806$, $p<0.001$ was also significant. An additional MANOVA on VE scores was completed, resulting in main effects for Day $F(27,840)=3.063$, $p<0.001$ and Group $F(18,840)=19.147$, $p<0.001$ as well as a Day by Group interaction $F(162,840)=1.902$, $p<0.001$.

Subsequent UANOVAs were performed on the AE, CE, and VE scores for X axis, Y axis, and time data. The results for the Day by Group interaction from the UANOVAs are shown in Table 6.

Table 6

Experiment 2. UANOVA on dependent variables AE, CE, and VE for the Day by Group interaction.

Dependent Variable	F Ratio	M.S. Error	Probability	
AE X	F(54,252)=9.09	184858.69	p<0.001	*
AE Y	F(54,252)=2.29	16017.34	p<0.001	*
AE Time	F(54,252)=3.91	93.59	p<0.001	*
CE X	F(54,252)=2.85	403030.63	p<0.001	*
CE Y	F(54,252)=1.08	34204.11	p>0.05	
CE Time	F(54,252)=2.69	211.66	p<0.001	*
VE X	F(54,280)=3.69	24654.50	p<0.001	*
VE Y	F(54,280)=3.41	2438.78	p<0.001	*
VE Time	F(54,280)=1.52	52.52	p>0.05	

M.S. Error = Mean Square Error, * = significant

The post-hoc analyses using the SNK, with the alpha set at $p<0.05$, were run to determine the mean differences. As in Experiment One, the preliminary analyses were calculated to determine if there were any mean differences existing between the days in the training phase (Days 3 to 7) or in the transfer phase (Days 9 to 13) within a group. SNK results indicated that for Group 2 (TeBo), Day 7 was different from Days 3 and 5 when AE data on the X axis was considered. Group

3 (SpSp), Day 6 was different from Day 3 and Group 7 (SpTe), Day 6 was different from Day 4 for AE on the time dimension. For VE, Group 2 (TeBo) Day 4 was different from all other days in the training phase on the X axis and different from Days 5, 6, and 7 on the Y axis. Results on VE scores for time indicated that Group 7 (SpTe) Day 6 was different than all other days in the training phase. Also, Day 5 was significantly different from Day 7.

The significant post-hoc SNK mean differences within the training or transfer phase of a particular group were only found on the dependent measures which represented performance on the component of the task for which the subjects in that group did not receive that type of information. For example, significant post-hoc mean differences were found for Group 3 (SpSp) for AE on the time dimension during the training phase. AE scores on time are considered to be a measure of temporal accuracy. The subjects in the SpSp group did not have temporal information available to them during the training phase which would seem to indicate that the mean differences found during this phase were due to inconsistent responding as a result of a lack of information to aid in performance. There were no systematic differences due to the types of information presented during the training or transfer phases. As a result the data was pooled to form one mean for each group. Those means therefore represent the subjects performance over the 5 days of training and the 5 days of transfer.

Training and Transfer Data. A two-way (Groups by Phase, i.e. training or transfer) MANOVA was calculated on the AE and CE for X, Y, time. The results indicated significant main effects for Phase $F(7,22)=10.738$, $p,0.001$; Group $F(42,162)=2.197$, $p<0.001$; and a Phase by Group interaction $F(42,162)=2.258$, $p<0.001$. The two-way MANOVA on the VE scores for X, Y, time revealed the same main effects of Phase $F(3,54)=17.291$, $p<0.001$; Group $F(18,168)=9.225$, $p<0.001$; and Phase by Group interaction $F(18,168)=4.616$, $p<0.001$.

The UANOVA results for the Phase by Group interaction are presented in Table 7. The post-hoc SNK analyses were calculated on the means using the SNK with the alpha set at $p<0.05$. Only the mean differences which involved the training and transfer phases of the TeSp and SpTe groups are dealt with in this experiment. All other group differences which did not include either the TeSp or SpTe group were discussed in Experiment One. Therefore, they will not be repeated in the results of this experiment.

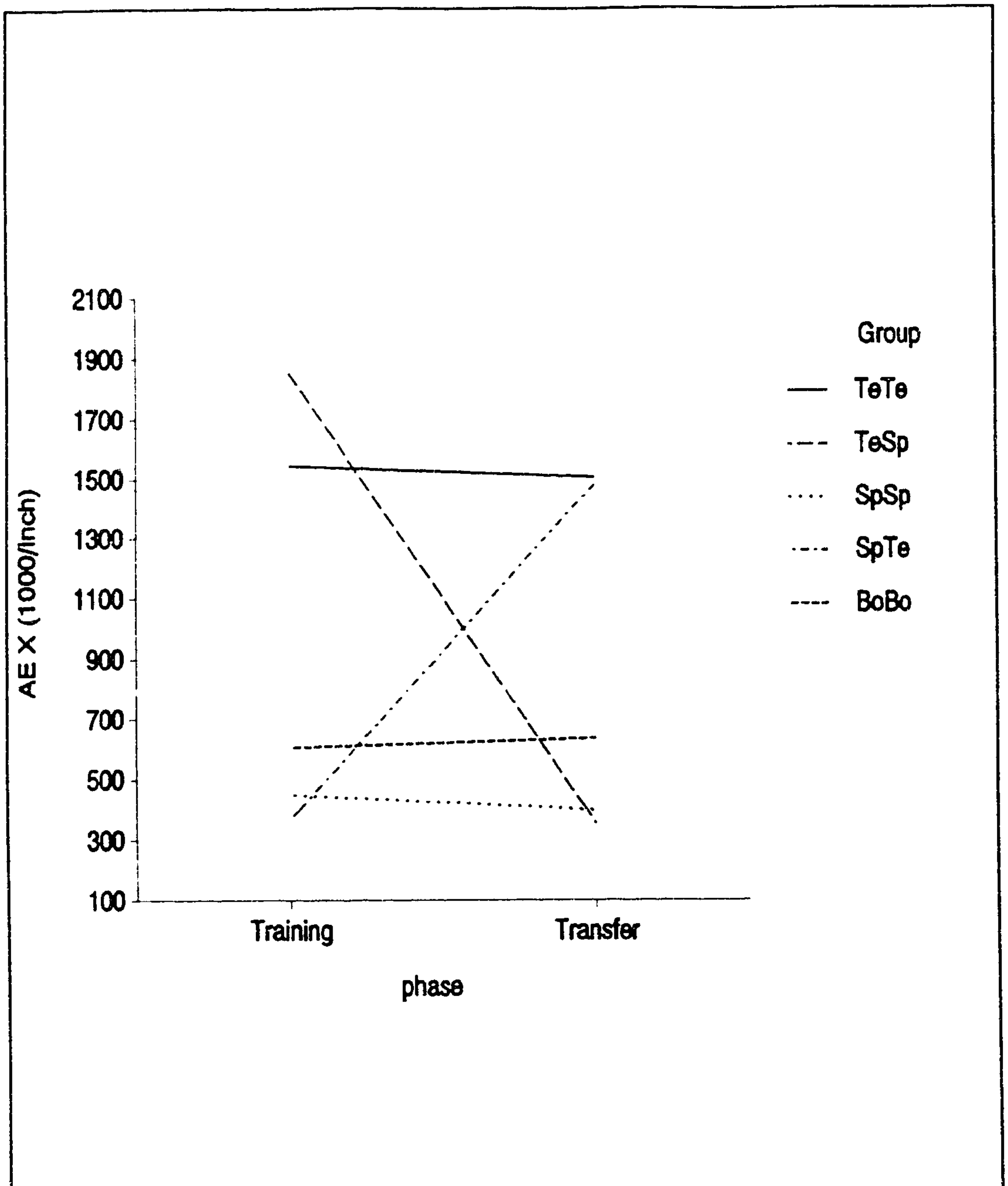

Figure 5. EXP 2. Absolute Error on the X axis for the training and transfer phases.

Table 7

Experiment 2. UANOVA results on AE, CE, VE for the phase by group interaction (collapsed data).

Dependent Variable	F Ratio	M.S. Error	Probability	
AE X	$F(6,28)=23.40$	120703.38	$p<0.001$	*
AE Y	$F(6,28)=3.94$	14102.88	$p<0.01$	*
AE Time	$F(6,28)=14.07$	35.72	$p<0.001$	*
CE X	$F(6,28)=4.31$	410798	$p<0.01$	*
CE Y	$F(6,28)=1.19$	33565.48	$p>0.05$	
CE Time	$F(6,28)=7.02$	111.77	$p<0.001$	*
VE X	$F(6,56)=16.31$	25744.75	$p<0.001$	*
VE Y	$F(6,56)=12.30$	2338.80	$p<0.001$	*
VE Time	$F(6,56)=5.69$	26.87	$p<0.001$	*

M.S. Error = Mean Square Error, * = significant

AE on the X axis coordinate scores for TeTe, TeSp, SpSp, SpTe, and BoBo are plotted in Figure 5. Post-hoc SNK results reveal that for AE scores on the X axis the TeSp training phase were significantly different from the training phase of SpSp, SpBo, BoBo, and SpTe, as well as the transfer phase of TeBo, SpSp, SpBo, BoBo, and TeSp. The transfer phase of TeSp was different from the training phase of TeTe, TeBo, and TeSp. The SpTe training phase differed from TeTe, TeBo, and TeSp training phase and the transfer phase of TeTe, TeBo, and SpTe. Finally, the transfer phase of SpTe was different from SpSp, SpBo, BoBo, and SpTe training phase and the transfer phase of TeBo, SpSp, SpBo, BoBo, and TeSp.

There were only four significantly different comparisons for the AE Y axis coordinates involving TeSp and SpTe. The transfer phase of TeSp was different from the training phase of TeBo. Also, the SpTe transfer phase differed from TeBo, SpSp, and SpBo transfer phase.

Group TeSp, training and transfer phases differed from SpSp, SpBo, and SpTe training phase and the SpSp transfer phase on the AE for time dependent variable. The training phase of SpTe was found to differ from the training phase of TeTe, TeBo, BoBo, and TeSp as well as the transfer phase of TeTe, TeBo, SpBo, BoBo, TeSp, and SpTe. The transfer phase of SpTe differed from the training phase of SpSp, SpBo, SpTe and the transfer phase of SpSp. Figure 6 illustrates the mean AE data for time.

The CE scores for the X axis coordinates differed in group TeSp from training to transfer. The training and transfer phases of SpTe on the CE for time also differed. No other comparisons for CE reached the $p<0.05$ level.

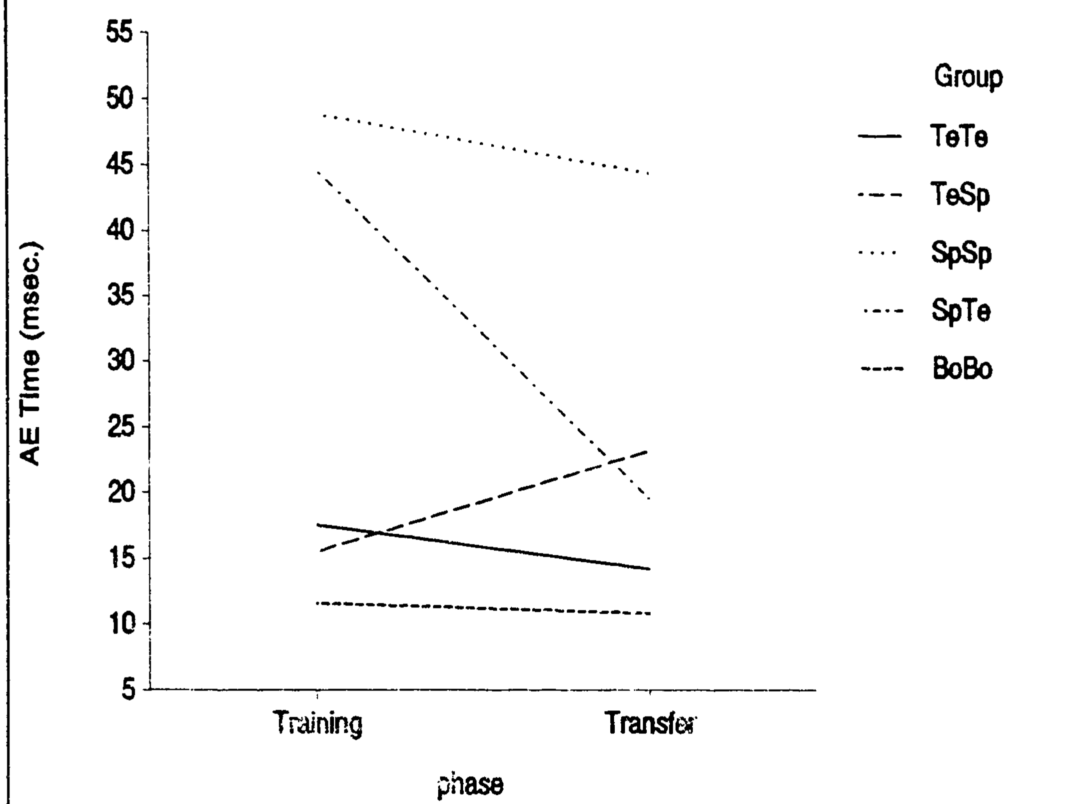

Figure 6. EXP 2. Temporal Absolute Error for the training and transfer phase.

The SNK results on the VE scores yielded a number of differences. For deviations on the X axis the training phase of TeSp differed from SpSp, SpBo, BoBo, and SpTe training phases and the transfer phase of TeBo, SpBo, SpBo, TeSp, and SpTe. The transfer phase of TeSp and training phase of SpTe were found to be different from groups TeTe, TeBo, and TeSp training phase and groups TeTe and SpTe transfer phase. The transfer phase on SpTe was different from the transfer phase of SpSp, SpBo, BoBo, and SpTe as well as the transfer phase of TeBo, SpSP, SpBo, BoBo, and TeSp.

The post-hoc results for VE on the Y axis were the same as that for the X axis except the comparison of the training phase of SpTe and transfer phase of TeTe failed to reach significance. VE scores for the X axis coordinates are displayed in Figure 7.

The training phase of TeSp was found to be different than the training phase of SpSp for VE on time. Group SpTe training phase differed from all other groups' training phase and all groups' transfer phase including its own. The SpTe transfer phase differed from the transfer phase of SpSp and the training phase of TeBo, BoBo, and SpTe. The means for VE on time are displayed in Figure 8.

Retention Data. A two-way (Groups by Day) MANOVA was done on AE and CE scores from the retention tests.

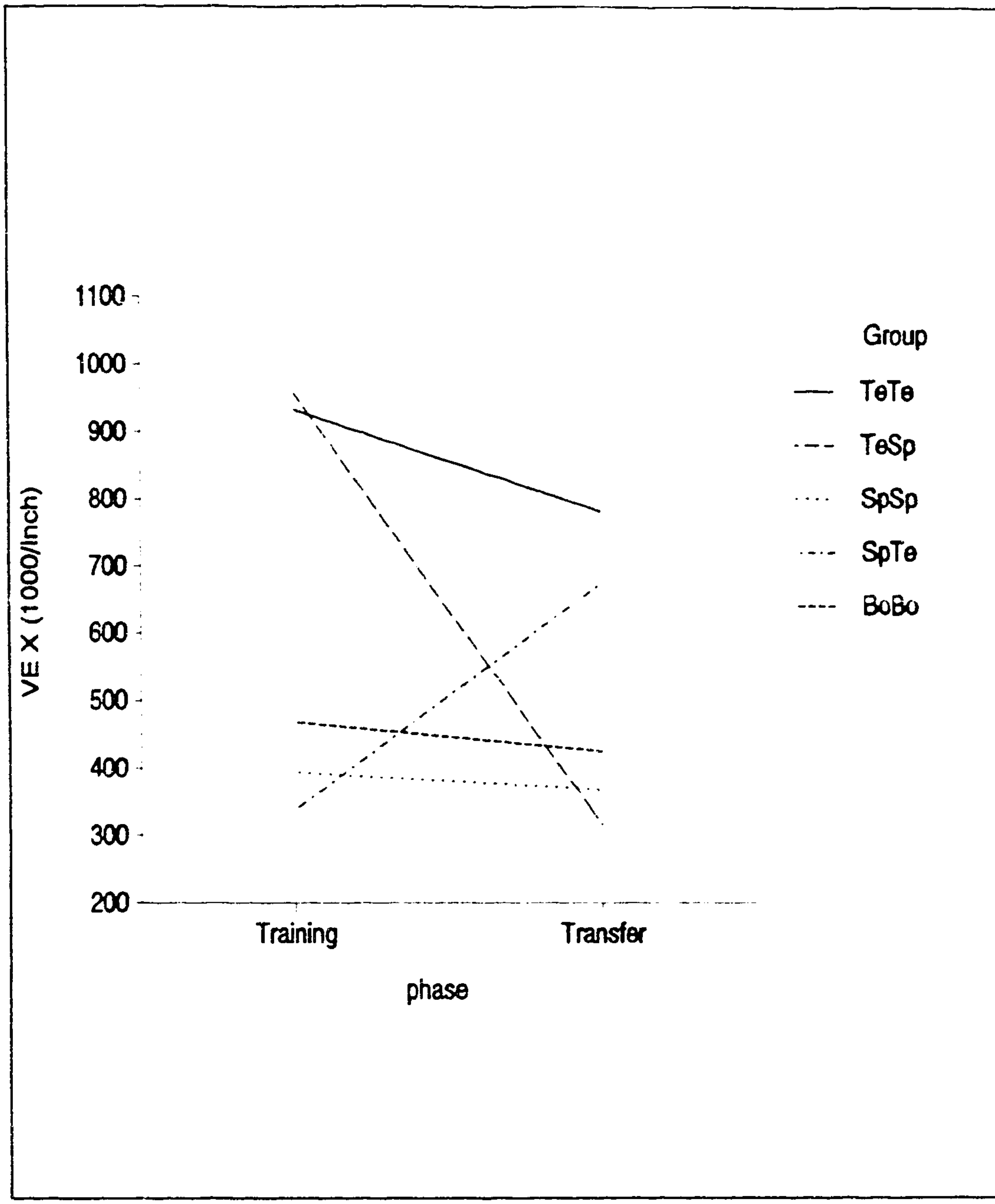

Figure 7. EXP 2. Variable Error on the X axis for the training and transfer phases.

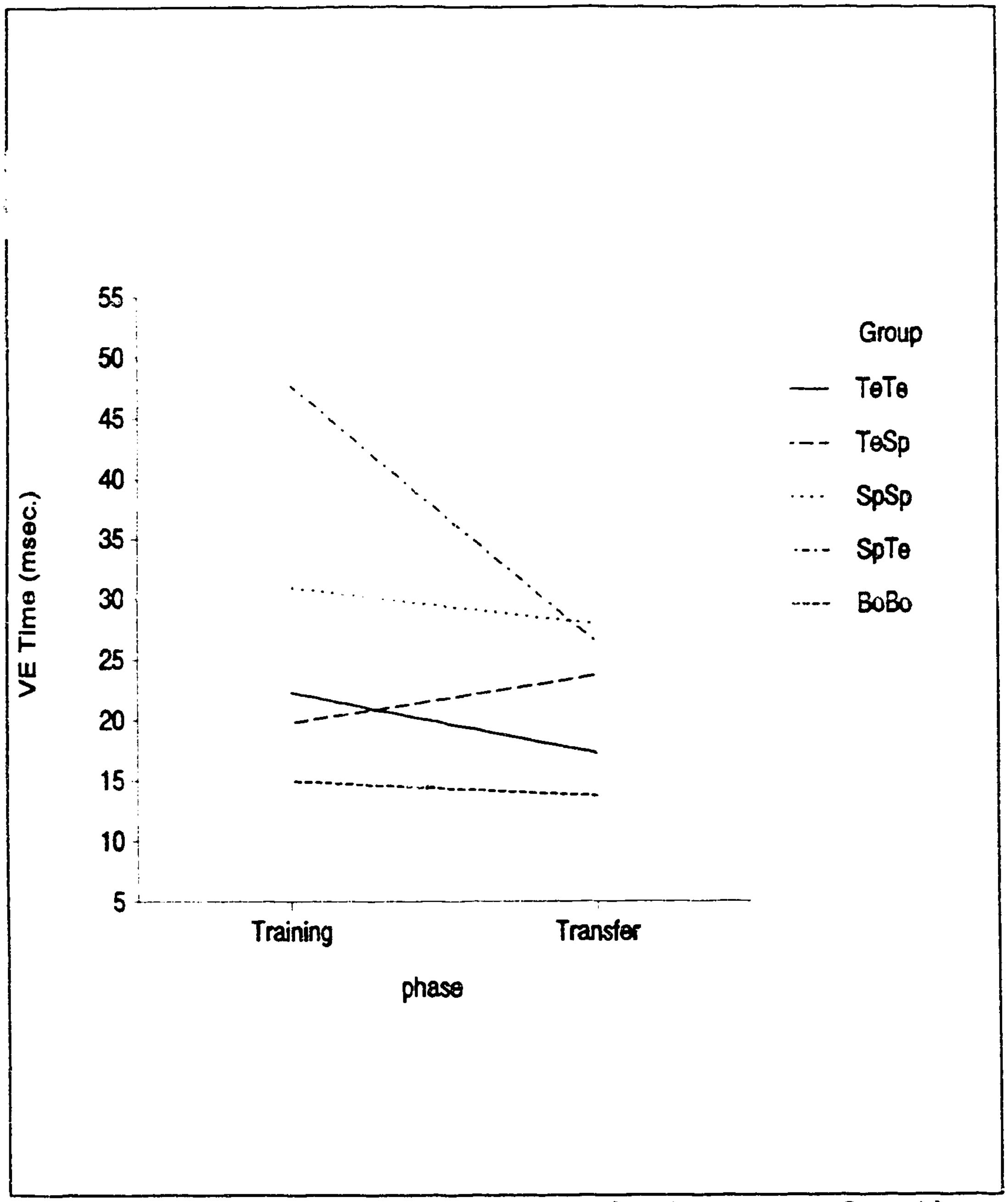

Figure 8. EXP 2. Temporal Variable Error for the training and transfer phases.

There was a significant Day $F(14,86)=3.652$, $p<0.001$ main effect. The MANOVA of the VE scores reached significance for both main effects, Day $F(6,142)=2.839$, $p<0.05$ and Group 15,216)=1.743, $p<0.05$. All other MANOVA's failed to reach significance at the $p<0.05$ level.

Subsequent UANOVAs revealed significant Day main effects for AE scores on the X axis $F(2,48)=10.68$, M.S. Error=549977.50, $p<0.001$; AE on time $F(2,48)=9.20$, M.S. Error=239.37, $p<0.001$; CE on the X axis $F(2,48)=4.47$, M.S. Error=1022666.94, $p<0.05$; CE on time $F(2,48)=15.30$, M.S. Error=676.57, $p<0.001$; VE on the X axis $F(2,72)=5.17$, M.S. Error=39357.93, $p<0.01$; and VE on the Y axis $F(4.73)=4.73$, M.S. Error=6643.68, $p<0.05$. A significant Group main effect was obtained using the VE scores for time $F(5.72)=3.26$, M.S. Error=50.80, $p<0.05$.

Post-hoc SNK revealed that for AE on the X axis, CE on the X axis and VE on the Y axis the first retention test was different from similar data obtained during the second and third retention tests. For AE on time the last retention test was different from the first two tests. The first retention test VE scores for the X axis coordinates were different from the last retention test. All three retention days were significantly different from each other for the time CE scores. Group SpTe differed from TeTe, SpSp, SpBo, BoBo and TeSp when the VE scores from the temporal parameter were considered. Mean retention scores are presented in Table 8.

Table 8

Experiment 2. Mean Retention Scores

	Retention		
Dependent Variable	Test 1	Test 2	Test 3
AE X	1983.203	1313.520	1147.111
AE Time	40.102	33.181	23.064
CE X	-1604.894	-1058.067	-849.345
CE Time	-30.773	-10.913	6.347
VE X	804.102	715.335	639.559
VE Y	318.720	266.766	259.294

DISCUSSION

The results from Experiment Two indicated that the transfer of learning from spatial only and/or temporal only information is asymmetrical. These results mirror those found by Hicks (1974) when subjects were required to learn a printing task with either the left or right hand prior to opposite hand transfer.

The asymmetrical transfer is evident in the results which indicate that subjects who train using spatial information and then transfer to temporal information do not maintain performance levels on the spatial parameter. The SpTe subjects performance in transfer does not reach the same level as those groups who have experienced spatial information at some time during the experiment. In fact they perform at the same level as groups who never experienced spatial information. Conversely, subjects who had temporal information during training, and then transfer to spatial information maintain their performance on the temporal component of the task. Apparently, subjects maintain what they learned about the temporal component of the task, when they transfer to spatial information (see Figures 5,6 and 7).

Salmoni et al. (1984), Schmidt et al. (1989), Swinnen et al. (1990), and Winstein and Schmidt (1990) claim that if learning is to be inferred the effects of the KR treatments should persist during a no-KR retention test. A second way to indicate that learning has taken place requires subjects to perform some novel variation of the task (Magill et al., 1991; Wulf and Schmidt 1989). The present experiment does not utilize either one of these, but uses instead the more complete A to B or B to A transfer paradigm. The use of the A to B or B to A paradigm provides an additional way to determine the effects of spatial and temporal information in the learning of a motor skill.

Subjects in the TeSp group only received temporal information for the training phase. However, when the subjects were transferred to the spatial information condition they maintained their level of performance on the temporal component of the task. The transfer phase for the subjects in the TeSp group was a form of a no-KR retention test as outlined by Salmoni et al. (1984). The subjects received spatial information but no temporal information during the transfer phase. The fact that the subjects could maintain their performance on the temporal component of the task in the absence of temporal information indicates that the subjects learned the temporal component of the task.

The data obtained from the retention tests does not support the conclusion that learning has taken place. Although there was no Phase by Group interaction there was a significant Day main effect. The Day main effect indicated that the groups retention scores were effected in the same way regardless of the type of information they received. The results obtained from the data collected during the retention tests would seem to indicate that the significant differences as a result of the Day main effect could be due solely to practice or experience with the task. That is, subjects increased their performance on the retention tests due to practice and not the different types of information they had available to them in the learning situation.

There is an apparent contradiction in the results which relates to the question of relative permanence of the effects of spatial and temporal information in the learning of the task. On one hand, in Experiment Two the subjects in the TeSp group were able to maintain their performance on the temporal component of the task in the absence of temporal information indicating that learning had taken place. On the other hand, the no-KR retention test seems to alter the task demands to a point where the subject's data would not support the conclusion that learning has taken place. Positive results with respect to the inference of learning as a result of subjects performance on a no-KR retention tests have been obtained in other studies (e.g. Schmidt et al., 1989; Swinnen et al., 1990; Winstein and Schmidt, 1990).

GENERAL DISCUSSION

The results from Experiment One and Two indicate that when subjects have spatial and temporal information available they can use both types of information to reduce errors on a multidimensional task (i.e. a task which requires subjects to learn more than a single component). The results of the first experiment indicate that subjects use both spatial and temporal information to improve performance on the spatial and temporal components of the task. They seem to able to use this information either independently or together without interference.

The results obtained in the second experiment indicate that the relationship between spatial and temporal information present in a learning situation may not be a simple one. The asymmetrical transfer indicates that subjects benefit from the use of spatial and temporal information in different ways.

One possible reason for the asymmetrical transfer lies in the form of the spatial and temporal information. The temporal information was given to the subjects in the form of KR. That is, subjects received verbal, terminal, augmented, feedback consistent with the definition of KR espoused by Salmoni et al. (1984). The spatial information about the response was available to the subject during and after the movement through the subjects' own sensory system. The subject could see the apparatus, target, and his/her own hand when performing a response. That is, visuo-spatial information was always available to the subjects.

In most experiments when subjects are provided with KR about their performance on a spatial dimension, they are blindfolded or have the visuo-spatial information occluded (e.g. Bilodeau et al., 1959; Ramella, 1983a; 1983b; 1982; Trowbridge and Cason, 1932). The subjects in Experiments One and Two used their own sensory system to obtain the spatial information necessary to perform the spatial component of the task. Results from the transfer phase of Experiment Two indicate that the subjects were unable to maintain their performance on the spatial component of the task when that spatial information was no longer available.

Subjects in the second experiment were only able to maintain their performance on the spatial component of the task when they had spatial information available to them. Subjects seemed to use the spatial information to guide their performance but did not engage in the processing necessary to retain performance on the spatial dimension in the absence of spatial information. That is, the task demands when spatial information was available did not seem to encourage the subjects to learn the spatial component of the task.

It is also possible that what is learned is different when visuo-spatial information is available to the subjects. Proteau, and Cournoyer (1990) and Proteau, Marteniuk, Girouard, and Dugas (1987) provided data which would seem to indicate that subjects actually learn to use visuo-spatial information to perform a task. That is, subjects learn to use visual-spatial information to perform the task rather than learning the actual movement. Further research is needed to determine the role of vision in the learning of a motor skill.

The subjects in the temporal groups in the two experiments presented here received temporal information in the form of KR on a 100% relative frequency schedule. The subjects received KR on every trial in the training and transfer phases of the experiment. The guidance hypothesis would predict that the 100% relative frequency should impair the no-KR retention. This prediction was supported somewhat by the data from the retention tests of the two experiments reported here. Subjects in the retention tests did not yield data which would indicate that they maintained their performance on the task due to the KR treatments.

The guidance hypothesis may be able to explain the results of the present experiment in terms of the retention tests scores. However, the asymmetrical results obtained from the subjects in the TeSp group in

Experiment Two indicate that the subjects learned something about the temporal component of the task. Therefore, the asymmetrical transfer results from the second experiment do not support the guidance hypothesis as an explanation of how information functions to effect learning.

Magill et al. (1991) found that when subjects were required to perform a coincidental timing task, verbal KR was redundant with visual information as measured by both a no-KR retention test and a transfer test. That test required subjects to perform a novel variation of the task. Further, Schmidt (1988) stated that KR as a form of feedback is studied most often because it is easily controlled in experiments. He goes on further to state that the study of KR may not be the most ecologically valid way to study the role of sensory information in learning. However, Schmidt claimed that the results obtained from studies using KR could lead to a better understanding of how error correction information functions in a learning situation. In the present study it follows that visuo-spatial information should promote learning. As the results of the present experiments are somewhat mixed in terms of no-KR retention and A to B or B to A transfer, further research is needed to clarify the relationship between the possible types of information available to a performer in a learning environment.

There are two main implications of the results obtained from the second experiment with respect to learning. First, subjects yielded data which indicate that learning has occurred when a paradigm other than the KR paradigm was used. Second, data from retention tests may not always indicate the relative permanence of the KR treatment effects and therefore learning. Caution should be used when discounting the effects of information during acquisition solely due to null effects on no-KR retention tests.

Finally, the issue of additivity must be dealt with. It would be difficult to determine if subjects could use spatial and temporal information in an additive way. The results from the first experiment indicate that subjects could use spatial information in addition to temporal information. This was evident by the lack of interference between the two types of information when they were provided together. For example, performance during the training phase for subjects who received spatial and temporal information alone was the same as the performance on those dimensions for the subjects who had both types of information available. In this sense subjects could independently use one type of information in addition to another type of information without interference.

To determine if the types of information were additive would require a single dependent measure. That is, in the experiments presented here, the task performance was defined by the score on both the spatial and temporal parameters. The dependent variables for these two parameters were different in that one was measured in milliseconds and the other in thousandths of an inch. As a result there is no single measure of overall task performance. Therefore, it would be difficult to determine the nature of the additivity as each type of information would contribute only to error scores on their own dimension. An overall measure of task performance would be needed to determine additivity. If there was such a measure, the nature of the additive contribution of spatial and temporal information in the learning of a task could be determined.

Summary

The importance of information in motor learning has been explicitly stated in the two prominent theories of motor learning. Adams (1971), in the closed loop theory of motor learning, proposed that information in the form of KR was necessary for the development of perceptual and memory traces for the movement. Schmidt (1975), in a similar fashion, claimed that KR was necessary in the development of the recognition and recall schema. Although the two theories oppose each other in control mechanisms (i.e. Adams closed loop control and Schmidt open loop control) they both require KR information to learn a movement. Specifically, it is the error correction properties of the KR which are thought to promote learning in these theories. However, if it is the informative contribution to error correction in KR which effects learning then it would seem to follow that one needs to understand more fully the role of information in learning.

Both Adams' and Schmidt's motor learning theories incorporate some type of memorial representation of the movement. The work of Proteau and Cournoyer (1990) and Proteau et al. (1987) indicates that the problem of motor learning may not be only restricted to the development of a memory for the movement. Subjects may actually learn how to use sensory information to complete a movement task. The question of what is learned may not be restricted to the acquisition of a memorial trace representing the movement, but may also relate to how subjects learn to use sensory information in a learning situation. Therefore, the role of information available to the subjects before, during and after the movement should be incorporated into motor learning theory.

The two experiments presented were designed to determine the relationship between two types of information present in a learning situation. Of interest, was the role of the information content incorporated within the presentation of KR and not the presentation of KR as an independent variable.

The first experiment presented here also investigated the role of spatial and temporal information on the learning of a motor skill. The results indicate that subjects can use spatial and temporal information independently and without interference. Subjects can use spatial or temporal information to learn a particular component of the task whether or not the information was presented by itself or with the other type of information. The self paced task allowed subjects sufficient time to process the essential information.

Subjects in the second experiment showed evidence of asymmetrical transfer. The subjects who began with spatial information could not maintain their performance on the spatial parameter when transferred to the temporal KR information condition. The reverse was not true for subjects who received temporal KR information first. They were able to maintain there performance on the temporal component of the task when transferred to the spatial information condition.

The asymmetrical transfer found in Experiment Two is interesting for two main reasons. First, it speaks to the relationship of spatial and temporal information in the learning of a motor skill. Second it provides evidence from a paradigm other than the KR paradigm, that indicates that learning has taken place.

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Appendix A

Table 9

Definition of Terms

Term	Definition
Absolute Error (AE)	The average absolute deviation of a set of scores from a target value; a measure of overall error (Schmidt, 1988: p. 72).
Constant Error (CE)	The average, with respect to sign, error of a set of scores from a target value (Schmidt, 1988: p. 73).
Retention	The persistence or lack of persistence in performing. A test of memory (Schmidt, 1988).
Training	A number of trials with a specified treatment in which subjects are able to acquire a task.
Transfer	The gain (or loss in the capability of responding on one task as a result of practice or experience on some other task (Schmidt, 1988: p. 371).
Variable Error (VE)	The standard deviation of a set of responses about the subject's own average score; a measure of response consistency (Schmidt, 1988: p. 73).