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The Role of Procedural Knowledge in the Learning and
Performance of a Novel Motor Task

by

Kathryn Hughes

A thesis
presented to the University of Ottawa
in fulfillment of the
thesis requirement for the degree of
Master of Science
in
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Abstract

Knowledge base differences have been shown to account for performance differences between expert/novice athletes in a variety of sports, and have been implicated in accounting for the difficulties of physically awkward children. However, whether knowledge base differences could also account for performance differences between less extreme differences in the range of skill, such as the learning of a novel motor task, was unclear. Cognitive theory suggested a pool of general procedural knowledge is used to guide performance in novel tasks and can be accessed through perceptual recognition. This suggested that, for a novel motor task, related superior general procedural knowledge could result in superior performance. Based on the assumption that knowledge of movement-related concepts would be of benefit in a motor task, fifty-two (N=52) university students from a movement related discipline were first assessed, via a perceptual recognition task, on their general procedural knowledge related to the ability to make movement judgements. The subjects were then divided into two levels of procedural knowledge expertise (upper/lower) and learned a novel pursuit tracking task. Overall, the subjects with superior procedural knowledge were able to minimize the cost of their movement errors on the task. This suggested their knowledge base differences could be an important factor in differences in motor skill acquisition.

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Introduction

"Native intelligence is no substitute for knowledge." This was how Anderson (1982) summed up recent research on the development of expert skill in the cognitive domain. This research has provided valuable information on just what it is that separates those people who have mastered a skill such as chess (Chase and Simon, 1973) from those who are novices.

One area in which experts clearly excel is that they simply know more about their domain. Chase and Simon (1973) were able to show that chess masters have stored solutions to many problems as well as countless common board configurations as a function of their vast amount of experience in chess and thus are more readily able to recognize patterns during actual game situations. Recent research has shown similar knowledge components can also account for expert/novice differences in sport (Allard, Graham and Parsalu, 1980; Allard and Starkes, 1980; Starkes and Deakin, 1984). Underlying expertise in all areas is the ability of experts to relate information in the environment to information stored in their data base (Allard, 1982).

The research on expert/novice comparisons is valuable in that it serves to illustrate not only the obvious point that the two extremes are different, but that this difference may reflect a larger knowledge base specific to their domain whether applied to purely cognitive domains or those with a motor component. It is important to recognize, however, that in between these two extremes is a complete range of skill levels. This then raises the possibility that some performance differences between individuals at any point in this range of skill could be accounted for in the same manner.

Anderson (1982) noted that the ability to perform successfully in novel situations is the hallmark of human cognition, yet the fact remains that some people learn a new skill more readily than others. The expert/novice research findings offer the suggestion that one reason may be due to differences in one very important component brought to the novel situation: knowledge.

This idea seems easier to grasp when considering purely cognitive behavior, but can knowledge really play a role in motor skill learning and performance. This idea has received little investigation in the motor literature, however the expert/novice sport research suggests indirectly that it can. Some more direct support comes from recent theoretical literature focusing on the importance of a sound knowledge base for motor development. The general thrust of this recent literature is that there is a base of knowledge that is necessary in the development of motor skills, and furthermore, that knowledge-based differences can account for developmental motor ability differences (Newell and Barclay, 1982; Wall, Bouffard, McClements, and Findlay, Taylor, 1985). Wall, et al. (1985) noted that the learning of new skills or the modification of old ones is seen as problem solving, and this in turn depends on the integration of knowledge from a wide variety of knowledge bases.

The important question then, concerns what knowledge could be of benefit in a novel situation. While the answer naturally depends somewhat on the task, cognitive theory suggests that one particular form of knowledge, procedural knowledge, is what we depend on in novel situations. A distinction is often made between declarative (facts, beliefs, truths) and procedural knowledge (knowing how to perform cognitive functions). Procedural knowledge is seen as governing our automated skilled behavior (Anderson, 1982, 1985; Rumelhart and Norman, 1985) whether speech, motor behavior or thought, in that our knowledge is tied up in the performance of the activity. It is our vast repertoire

of procedural knowledge, acquired through past experiences, that is felt to guide us in novel situations, as this automated skilled knowledge can be generalized and directly applied to new situations (Anderson, 1982) until more specific knowledge is acquired.

One way procedural knowledge is thought to be enacted is through perceptual recognition where the appropriate procedure is automatically triggered by recognizing relevant patterns of incoming information which can then contribute to processing in a top-down context-driven fashion (Norman and Bobrow, 1982).

Rationale

The expert/novice research together with the suggestion of the importance of knowledge in motor skill acquisition indicated that to question the role of knowledge in accounting for individual differences in the learning of a novel *motor* task was justified. Cognitive theory further suggested that, for a given novel task, a proceduralized form of knowledge would be of greatest benefit, and that it would be automatically applied if a relevant situation was recognized. This last point seemed to be especially appropriate and important when considering the speed at which motor skills operate. Furthermore, the importance of procedural knowledge in general as a component of the knowledge base for motor skills has been suggested (Wall, et al., 1985; Newell and Barclay, 1982). There has been little attempt however, to empirically investigate the exact contribution of procedural knowledge to the learning of a specific task and it was therefore the general purpose of this study to do so. The general approach taken was to focus on one general knowledge concept felt to be especially important for a given novel motor task and attempt to assess its role in accounting for differences in performance on the task.

Two tasks were used in the study; one to provide an initial general procedural knowledge assessment, and a novel motor task. The two tasks were designed to tap the

same source of general procedural knowledge and therefore required some degree of similarity. On the other hand, given that the knowledge concept assessed was a general one, and to ensure there was no learning effect carried over between the tasks, the two tasks were also, of necessity, different. The novel motor task the subjects' were required to learn was a pursuit tracking task. A procedural knowledge concept that was felt could be of benefit in the movement component of the task was the general ability to judge the speed of the movement of objects. The selection of this concept at this point in the research was based on the assumption that some knowledge of movement related concepts, which would be a function of the subjects' experiences in many areas, was relevant to the control of movement.

The assessment task was a perceptual recognition task in line with Norman and Bobrow's (1982) suggestion that this would trigger the relevant procedural knowledge and involved judgements of the movement of pairs of lights. The belief that the tracking task would also trigger procedural knowledge related to the judgement of movement was based on the theoretical explanation that movements of the duration found in this task and which involve the monitoring of a movement to a specific endpoint, are generally thought to be completed through the ongoing monitoring and processing of feedback (Keele, 1968; Welford, Norris and Shock, 1969; Schmidt, Zelaznik, and Frank, 1978). This feedback (only visual will be considered here) provides the information required to make any necessary adjustments, however, it must be recognized and interpreted before it can be acted upon. This suggested that the feedback would be recognized as movement information and would tap the appropriate procedural knowledge for judging that information.

The assessment task and tracking task both required fast/accurate judgements of movement at high speeds through a recognition process, with distance and speed as

important variables. The tracking task however, required the knowledge to be used in the context of a movement. This was felt would ensure the necessary compatibility between the two tasks while at the same time providing the necessary contextual differences.

The key unknown question was whether knowledge differences would be reflected in performance differences. There are many components that contribute to performance, however the aim of this study was to attempt to isolate one and assess its contribution. The implication was that superior procedural knowledge, given a significant contribution to the task, would result in a better interpretation and use of the feedback information which, in turn, would be reflected in performance on the motor task.

Statement of the Problem

The study was designed to investigate the contribution of differences in general procedural knowledge as a factor in accounting for learning and performance differences on a novel motor task.

Statement of Hypotheses

The general hypotheses tested were that superior procedural knowledge of the judgement of motion, as assessed by the perceptual recognition task, would be reflected in

1. a faster rate of learning as measured by total response time
2. superior performance in the individual movement components of the task as measured in
 - a. non-overshoot movement time - reflecting the monitoring and response to movement feedback
 - b. overshoot movement time - reflecting the monitoring and response to movement feedback within an unanticipated event

- c. overshoot scores - reflecting the rate of occurrence of movement breakdowns

Limitations

Although the role of knowledge base differences in motor skill acquisition is in itself a very broad issue, this study was conducted within certain practical limitations.

Although cognitive theory suggests different types of knowledge, this study was limited to investigating only general procedural knowledge within the context of learning a novel task. Furthermore, while the contribution of many components to any complex task performance is acknowledged, this study was limited to the investigation of only one knowledge component assumed to be of major importance to the task. Finally, this study was limited to a population of university students from a movement-related discipline. The results of this study, therefore, must be considered within the context of these limitations before generalizations can be made.

Definition of Terms

1. BOUNDARY DISTANCE - distance between the target and the display boundary measured in the direction of movement
2. KNOWLEDGE - stored product from interaction with the environment
3. DECLARATIVE KNOWLEDGE - 'knowing that' or factual information, truths
4. PROCEDURAL KNOWLEDGE - 'knowing how' to perform cognitive functions
5. GENERAL PROCEDURAL KNOWLEDGE - interpretive procedural knowledge that is non-domain specific

Review of the Literature

This study combines research and theory from different disciplines and to help in understanding the suggested relationship between them, the literature review is divided into four general sections.

The first section deals with current research into expert/ novice comparisons which investigated the cognitive skills of experts in various domains, including sport, and suggest the importance of knowledge base differences between skill levels. The second section includes some of the current theorizing about knowledge in the cognitive psychology domain. It includes explanations of the distinction between declarative and procedural knowledge and their roles. The focus is on procedural knowledge as a form of skilled, automated knowledge, how this form is achieved and activated, and its important role in novel situations.

The third section makes the connection between knowledge and movement, highlighting current literature dealing with the role of knowledge as it pertains to motor development. The final section focuses on the motor component of movement, as it is in the context of a novel motor task that the role of knowledge was investigated. This section suggests how knowledge can be accommodated within the current theories explaining the processes involved in the motor component. This is then applied specifically to the task used in the study to show how it meets the necessary criteria suggested by both the motor and cognitive domains to enable the use of procedural knowledge in the manner suggested.

Expert/Novice Comparisons

The study of expertise in cognitive skills is a fairly recent phenomenon and has included investigations into a wide variety of domains ranging from chess to bridge, and has recently been extended to the sport domain. All have essentially questioned what makes the expert performer different from the novice.

The main source of information on experts comes from the semantically rich domain of chess. In an attempt to discover the processes underlying skill in chess, de Groot, (in Chase and Simon, 1973) found an important perceptual difference between masters and lower level players. He presented the players with a series of common board configurations for 5 seconds and then removed the pieces. The players were then asked to reconstruct the positions. de Groot found a vast superiority by the masters in the number of pieces they were able to reconstruct over the the intermediate and beginner level players. A follow-up study by de Groot presented random placement of the board pieces and again asked the players to reconstruct the configuration after a 5 second viewing period. This time no superiority in recall was found in the masters level players, making the important point that the superiority found in the first task was not simply a short-term memory ability but was related to actual knowledge of game configurations.

A further series of studies by Chase and Simon (1973) sought to further investigate the processes behind chess skill. They were able to replicate de Groot's original study by showing superiority in recall for structured board configurations. Chase and Simon concluded that underlying masters' skill is the ability to chunk the pieces into meaningful configurations.

Chase and Simon (1973) further investigated the nature of the chess master's chunking of the pieces by asking the 3 levels of players to reproduce a configuration of chess pieces presented on a second test board. A chunk was defined as those pieces moved

by the subject following one glance. The masters were able to reproduce more pieces per glance (chunk), for example 16 out of 28 pieces correctly on the first trial to 4 for the beginner, and these chunks tended to represent meaningful game configurations. Again, however, as in the 5-second recall paradigm, it was shown that when the pieces were randomly presented, reproduction was no better by the master than by the lower level players. Chase and Simon (1973) concluded that the master has stored numerous chess patterns and subsequent moves in memory and the organization of this knowledge about chess enables him to recognize familiar patterns in game situations and generate appropriate moves.

The 5-second recall paradigm has also shown expert superiority in bridge (Charness, 1979) with common bridge patterns only. In light of these findings in other skilled domains, recent studies have investigated expert/novice differences in some sports such as basketball (Allard, Graham and Parsalu, 1980), field hockey (Starkes and Deakin, 1984) and volleyball (Allard and Starkes, 1980) to determine if such 'software' components could play a role in sport skills as well.

In a 5-second recall paradigm similar to the one used by Chase and Simon (1973), expert (university players) and novice (undergraduates) basketball players were shown structured and unstructured slides of games for 4 seconds and then asked to recall the information by placing magnets representing players on a board (Allard, Graham, and Paarsalu, 1980). As was found in chess and bridge, basketball experts showed superiority in recall of structured slides only.

Allard (1982) investigated the notion of 'chunking' found in chess by having players recall schematic diagrams of basketball plays by drawing the diagram after as many 5 second looks as was necessary to complete it. The amount of information copied after each look constituted a 'chunk'. The results were similar to those found in chess in that

the experts took fewer looks to copy, made fewer errors and included a greater number of elements per look, and the nature of the chunks represented meaningful basketball structure. Allard suggested that basketball skill required players to develop rapid chunking, pattern matching and a rich data base of basketball patterns in the same way chess masters are required to do so.

Similar results were found in a study of expert/novice field hockey players (Starkes and Deakin, 1984), however slightly different results were found in volleyball (Allard and Starkes, 1980). Rapid visual search rather than chunking appeared to be an important perceptual skill underlying volleyball skill, as the expert players were much faster at detecting the presence of the ball in a slide, but were no more accurate. This was the case for both structured and non-structured slides leading Allard and Starkes to conclude that the nature of the game was such that the focus was on rapid ball detection rather than context information. It was noted however, that it could not be determined if the differences in the volleyball domain were simply actual domain differences or paradigm differences.

Generally, these results from the sport domain point to the sport expert as being no different from the chess expert. They have more knowledge about their sport and this knowledge is structured and represented differently from the novice. Underlying expertise in all areas is the ability to relate information present in the environment to information stored in their data base (Allard, 1982). As Glaser (1984) noted, experts in general not only have knowledge about their subject matter, but knowledge about the application of what they know.

Declarative and Procedural Knowledge

A distinction is often made in the cognitive psychology domain between types of knowledge. One such common distinction is between "knowing that" and "knowing how" (Ryle, 1966) which is now more commonly referred to as 'declarative' and 'procedural' knowledge (Anderson, 1982, 1985; Rumelhart and Norman, 1985; Wichelgren, 1979). The distinction is considered to be analogous to that of data base and program in computer science terminology (Claxton, 1980). Declarative knowledge is considered to be factual information, truths, or associations (Claxton, 1979) with a prime example being knowledge of the form that "George Washington was the first president of the United States" (Rumelhart and Norman, 1985). Procedural knowledge, on the other hand, is knowledge about how to do something or how to perform cognitive functions (Anderson, 1985) as, for example, knowing how to kick a football or how to use our native language (Anderson, 1984).

Ryle (1966) in "The Concept of Mind" first discussed the two types of knowledge and noted three features which seemed to distinguish between declarative (knowing that) and procedural knowledge (knowing how). The first concerns the possession of the information itself. He noted that 'we never speak of a person having partial knowledge of a fact or truth, save in the special sense of his having knowledge of part of a body of facts or truths...on the other hand, it is proper and normal to speak of a person knowing in part how to do something i.e., of his having a particular capacity in a limited degree'.

A second distinction which is closely tied to the first, is that procedural knowledge is acquired gradually through performing the skill while declarative knowledge can be acquired suddenly. Ryle stated that 'while truths can be imparted, procedures can only be inculcated, and while inculcation is a gradual process, imparting is relatively sudden. It makes sense to ask at what moment someone became apprised of a truth, but not to ask

at what moment someone acquired a skill'. This distinction is in keeping with the belief that it is procedural knowledge that is felt to govern skilled human performance (Rumelhart and Norman, 1985; Anderson, 1982).

A third distinction noted by Ryle is that declarative knowledge can be communicated verbally while procedural knowledge generally cannot. He cited the example of a well-trained sailor being able to tie complex knots and tell if someone else is tying them correctly, but probably being unable to verbally describe how the knots should be tied. In general, declarative knowledge is considered to be accessible in that the performer has conscious access to the information while this is not the case with procedural knowledge as this knowledge is tied up in the performance of the cognitive activity. As Rumelhart and Norman (1985) noted, many things we know seem difficult to describe in declarative fashion; we know them by the way in which we do the task. Good examples come from out skilled behavior, whether it be speech, motor control, or thought.

The role of procedural knowledge in governing our skilled performance was further shown by Anderson (1984) who noted that while the use of our native language is a case of procedural knowledge, it is still possible to have access to some of the declarative information in terms of verbalizing some of the grammatical rules. In other words, it is possible to have procedural as well as some declarative knowledge about a particular domain.

Claxton (1980) noted that the declarative knowledge we may possess about certain things is essentially passive knowledge in that it does not organize itself. This is the job of the procedural knowledge which is active and operates on the declarative part in a purposeful way. In this sense, declarative and procedural knowledge can be seen as different aspects of the same knowledge (Claxton, 1980). Claxton, in fact used the term 'experiential knowledge' rather than procedural, which is automatically built into the

processes that subserve our perception, thought, feeling and action. This knowledge is derived intuitively from our dealings with the world and is inferred from our own immediate experience. This knowledge is not directly available to conscious awareness as only the products, not the processes, are observed (Claxton, 1980).

Triggering of Procedures

An important consideration regarding procedural knowledge is how it is triggered into action. One suggestion is through direct invocation, where some other procedure can determine just which procedure is required at the time and causes it to be brought into action (Rumelhart and Norman, 1985). A second method is accomplished through a triggering mechanism where the procedure, conceptualized as an active processing structure, essentially sits above a data base, looking for a pattern relevant to itself. If a relevant pattern occurs, the procedure is triggered and goes into action (Rumelhart and Norman, 1985; Norman and Bobrow, 1976).

Norman and Bobrow (1976) suggested that it is just such a processing structure that is used to direct processing in a perceptual recognition problem solving task. They felt that the traditional view of the linear sequence of processing stages in the processing of sensory information was not the complete picture in these situations. This traditional data driven, or bottom-up, analysis assumes sensory stimuli enter the sensory system, processes such as feature extraction are automatically performed, and the sensory memory is activated which then in turn provides input for the system to organize (Norman and Bobrow, 1976; Anderson, 1982).

Norman and Bobrow instead suggested that top-down or context-driven analysis was also involved in the process of, recognition of perceptual stimuli. They suggested that active memory units, the vast repertoire of knowledge gained from past experiences, have a

major role in directing processing and this idea is illustrated simply in a description of the processing in recognizing facial features. Seen apart, it may be difficult to recognize specific facial components as such, but put together appropriately, they become easily recognizable. This illustrates the importance of context or relationships between elements and it is just such a relationship that can activate the appropriate memory unit or form of knowledge, as this knowledge contains information about such relationships.

The recognition of some initial relationship, for example, the eye-nose triangle, is enough to trigger and activate the internal knowledge of facial features, which can then begin to guide the processing in a top-down fashion, checking for the other necessary relationships of features. In other words, once the initial concept of a face is triggered, missing elements are then suggested and searched for by conceptually generated processing (Norman and Bobrow, 1976).

The importance of pattern recognition, in performing many cognitive activities is acknowledged as it essentially allows us to interpret and assign meaning to the world around us (Wessels, 1982). The combination of bottom-up and top-down or context-driven processing felt to be involved in recognition is also important in that it highlights the role of context, prior knowledge (Anderson, 1982) and expectation (Wessels, 1982) in cognitive function. These effects have been shown previously in the recognition of the relationship between two pictures (Palmer, 1975), facial features (Palmer, 1975), word vs letter discrimination (Reicher, 1969) and in recognizing sentence patterns (Tulving, Mandler and Baumal, 1964). In this sense, the suggestion of Norman and Bobrow (1976) that prior knowledge can play a large role in directing pattern recognition processing is not new at all but it is important as it offers a model combining the processing structure and the stored knowledge (Rumelhart and Norman, 1985).

Proceduralizing Knowledge

The general belief is that it is procedural knowledge which governs our skilled behavior (Rumelhart and Norman, 1985; Anderson, 1982). In light of this, Anderson (1982) has proposed a framework whereby knowledge is taken to the procedural skilled level. He suggested three stages in the development of skill acquisition which are somewhat analogous to the general observations made by Fitts (1964) which are often used to describe motor skill learning.

The first stage proposed by Anderson is what is termed the declarative stage. Here the individual receives information and instruction about the skill. This information is then basically encoded as a set of facts about the skill. What is required for the subject to perform the skill at this stage is a repertoire of general interpretive procedural knowledge which will help to interpret the new skill information and generate some form of the skill. This is illustrated by Anderson with the example of students learning geometry proofs. The students initially may have no specific procedural knowledge for doing the proofs but do have a pool of general procedural knowledge for such things as perhaps solving problems in general, doing mathematics-like exercises or certain types of deductive reasoning, all of which may help the individual begin to generate some form of task specific behavior. The basic claim is that general interpretive procedures with no domain specific knowledge can be applied to some facts about the domain and produce coherent and domain-appropriate behavior (Anderson, 1982). One other important feature of the declarative stage is that verbal mediation may be used frequently.

This stage is analogous to the initial or 'cognitive' stage in skill learning proposed by Fitts (1964). Fitts stressed the importance of realizing that both adults and children begin the acquisition of new forms of skilled behavior with many existing skills which can be both general and specific. In a learning situation, such as learning to swim, the individual

receives instruction, observes, and tries out different routines which are already available, and gradually gets started in learning the new task (Fitts, 1964). Fitts also suggested that verbal mediation plays an important role in the early stages.

Anderson's second stage was termed knowledge compilation where declarative knowledge is gradually converted to procedural form. This occurs with practice and results in procedural knowledge being directly applied without the need for other, more general, and less efficient interpretive procedures. Three features associated with the knowledge compilation process are: speedup, drop-out of verbal rehearsal and elimination of piece-meal application. Anderson's study of the learning of geometry proofs indicated that after doing a series of geometry problems, there seemed to be less verbal rehearsal of the postulate, less time to recognize the appropriate postulate, and direct application of the postulate as a whole rather than separately applying the different elements.

Anderson suggested this compilation process is accomplished through two subprocesses, composition and proceduralization. Composition combines any separate procedures that may be used in a task into one single procedure, and proceduralization essentially builds in the application of the procedure to enable it to apply more directly and automatically (Anderson, 1982).

Fitts (1964) suggested the middle, intermediate stage was one of formulating specific associations and learning to respond to specific cues, as well as developing a clearer understanding of the application of the skill, with a decrease in verbal mediation. He noted that the subroutines become longer, and the skill becomes more integrated and continuous, such as in the kicking, breathing and use of the arms in swimming.

Anderson termed the final stage, the procedural stage, as one of further tuning of the skill so it is applied more appropriately, and there is improvement in the choice of method

by which the task is performed. Three mechanisms are proposed which form the basis of this tuning process; a) generalization - where procedures become broader in their range of applicability; b) discrimination - where procedures become narrower; and c) strengthening - where better procedures are strengthened and poorer ones weakened. The generalization process is seen as crucial to perform successfully in novel situations as it enables us to extract common features from existing procedural knowledge to form generalizations for use in novel situations, such as the ability to form the plural form of new words. Anderson sees the ability to generalize as a further step in skill acquisition as it requires additional learning to accomplish it. Discrimination is seen as restricting the application of procedures to the appropriate circumstances. To accomplish this, feedback is seen as important which will indicate when a procedure may have been misapplied. Anderson stressed the importance of recognizing that these final stages are intuitive and mistakes can be made.

Fitts termed the later stages of skill learning as the autonomous stage. He noted this stage may include continual, more gradual increases in efficiency and an increased ability to carry on the skill automatically or while engaged in other activities.

Knowledge and Movement

The role of knowledge in action is one that has received little direct empirical investigation, and as Newell (1978) noted, when knowledge is referred to, it is essentially nebulous. A number of early studies, although primarily stemming from the transfer of training framework, attempted to investigate the role of knowledge on motor learning and performance. These dealt with the teaching of certain mechanical principles to ascertain whether this knowledge helped in learning a motor skill where the particular principle applied.

Hendrickson and Schroeder (1941) taught 2 groups of boys the theoretical explanation of refraction, then further taught one of the groups how this principle applied to water depth changes. A third control group was given no explanation. The subjects were then required to fire an air gun at a submerged target of twelve and four inch depths. They found knowledge of the principle of refraction helped not only in transferring to the second depth but also in the first depth as well, with the added explanation of the effect of depth changes proving beneficial.

Coleville (1957) on the other hand found no differences between a group taught theory and a control group when she used three principles of mechanics pertinent to certain motor skills and three skills which utilized these principles.

Broer (1958) attempted over the course of a school term to substitute some skill learning in volleyball, basketball and softball with basic teaching of problem solving and simple mechanics for a group of seventh grade students. Superiority was found by the experimental group on subsequent tests of 8 sport skills over a control group which received only the usual skill instruction. The results of some of these early studies left the role of existing knowledge on motor skill performance unclear (Newell and Barclay, 1982).

The importance of knowledge in skill learning was alluded to by Holding (1981) when in discussing the importance of information in skill learning he stressed the need to consider information available prior to the action as well as during and after completion. Information such as knowledge of the goal of the act and some understanding of the ways through which the goal can be accomplished are seen as important. However, the fact that individuals do come to the learning situation with some advance knowledge in these areas is acknowledged but not discussed further. Rather, Holding stresses the importance of supplementing what is known by emphasizing finding effective means of conveying

information about the task (i.e., verbal instructions, demonstrations), rather than focusing on the knowledge the learner is bringing to the task.

Arend (1980), somewhat indirectly, dealt with the important role of knowledge by emphasizing the need for developing substrates to skilled movement. She noted teachers of movement often focus upon teaching the details of a particular motor skill only to discover that many students may be lacking an important substrate - the ability to move well (Arend, 1980). The development of a solid base is seen as crucial if the teaching of some complex skills can begin.

Efficient movement is seen as a functional integration of many prerequisites. For this integration to occur, Arend sees it as essential that the learner have intimate knowledge of their own physical systems, the environment, a responsive and well-tuned body, and a storehouse of cognitive plans or strategies to enable them to adapt and perform in a variety of situations.

Also seen as important to efficient movement is the ability to deal with three levels of constraints (Arend, 1980). Morphologic constraints refer to those of the neuromuscular-skeletal system and organismic variables such as age, sex, personality and experience. Biomechanical constraints refer to redundancies in the physical world (gravity, momentum, friction) and principles related to force production and absorption. Lastly, environmental constraints refer to the relative predictability of the spatial and temporal components of the environment. Arend sees the development of efficient movement as requiring the individual, through time and experience, to understand the nature of these constraints and how they may relate to and effect movement.

There has been some further recent interest, essentially stemming from a cognitive psychology framework, that is primarily concerned with the importance of knowledge in

motor development. These articles deal directly with knowledge, however, in attempting to cover the broad range of its role in development, are consequently theoretical in nature and offer little experimental evidence. They also suffer from the use of different and sometimes confusing terminology differences commonly found in the relatively new field of cognitive psychology, especially when being applied to a new domain.

Newell and Barclay (1982) emphasized the intimate relationship between knowing and doing, while noting that the neglect by the psychology domain in general of the study of action has resulted in the current theorizing about knowledge bearing little relationship to action. In an attempt to bridge this gap, Newell and Barclay presented a fairly general view of the potential types of knowledge which can be developed about the action process. They essentially posed the question: "What can a person know or come to know about his/her own actions?"

They suggested two major types of knowledge: sensitivity to those situations requiring a skilled action; and knowledge of variables or factors which affect the outcome of action. Sensitivity includes knowing action is required and understanding the movements needed to complete the act, and can be seen as involving two related elements. One is understanding the nature of the problem and the second is an awareness of the context in which the task is presented (i.e., competitive or noncompetitive context).

The second major category is knowledge of variables affecting skilled performance and includes three elements; person, task, and strategy variables. The person variable represents knowledge of one's own physical structure and of one's ongoing action. The task variable includes knowledge of task characteristics and how they can affect task difficulty and complexity which can result from either specific past experience on the task or general related experience.

The last variable is strategy which is assumed to reflect knowledge of the movement configurations which can be invoked to complete the action and may include task specific strategies or general strategies. Newell and Barclay define strategies as classes of knowledge specific to the organism-environment interactions at hand and see them as the instantiation of knowledge, with knowledge being the uninstantiated concepts. In this sense they feel the two are analogous to procedural and declarative knowledge.

In essence, Newell and Barclay suggest more emphasis needs to be placed on experiential factors such as strategy and knowledge in further attempts to assess the factors contributing to motor skill development.

The knowledge-base approach was also taken by Wall, Bouffard, McClements, Findlay, and Taylor (1985) in suggesting a more holistic model of motor development to aid in understanding the problems of the physically awkward. A large portion of their theoretical paper deals with the role of knowledge in action and their subsequent speculation that the physically awkward children may be behind their peers in terms of their knowledge base.

Wall, et al. suggested three major types of knowledge are acquired through experience that increases with development: declarative and procedural knowledge which are somewhat analogous to that suggested by Newell and Barclay, and an third type which they term affective.

Declarative knowledge is considered as the storage of information about something, factual information stored in memory which can influence the development and execution of skilled action. From a developmental perspective, they suggest this declarative knowledge about action is initially acquired through countless data-driven interactions between the person and the environment. This knowledge is further modified and restructured into coherent packets of knowledge.

Procedural knowledge is seen as underlying the skilled performance and underlies all aspects of action from the perceptual to the execution stages. In that sense, an action sequence is viewed as the instantiation of procedural knowledge about action.

Affective knowledge refers to an individual's subjective feelings such as competence and confidence, and is also acquired by continually interacting with the environment and its people (Wall, et al. 1985). Wall, et al., as was the emphasis for Newell and Barclay (1982), also include metacognitive knowledge as an important type of knowledge to be included.

The basic premise of Wall, et al. is that the development of knowledge about action allows for the more accurate use of deliberate conscious control in the acquisition of skilled action, and it is here that the physically awkward may be experiencing problems. The learning of new skills or the modification of old ones is seen as problem solving, and this in turn depends on the integration of knowledge from a wide variety of knowledge bases (Wall, et al., 1985). They suggest that as individuals increase their knowledge bases, their conscious control of action will become more accurate and efficient in a broader array of situations. For example, individuals who have acquired a wide array of automatized skills (procedural knowledge) will be more flexible in their response to different task demands; and accurate declarative knowledge about performance environments may also facilitate skilled action in them (Wall, et al., 1985). They conclude that the problems of the physically awkward may be better understood through assessments made using a knowledge-base conceptual framework. The development of such an assessment is suggested as the next problem to be tackled.

These last references, then, while not providing empirical evidence do suggest generally how knowledge of many kinds could play an important role in the development of motor skills.

Motor Component

A theoretical model that has been used extensively in the study of human motor performance is the information processing model, which attempts to explain how information is used in perceiving, deciding and organizing an action. The model, as applied to motor skills, has three basic components: a perceptual mechanism which organizes incoming stimuli, a decision mechanism which then selects a plan of action, and the effector mechanism which organizes the appropriate response. It is this last component, the effector mechanism, that will be discussed here.

Fitts (1954) first applied information theory in an attempt to explain the information capacity of the motor system which he defined as including the visual and proprioceptive feedback loops that permit a subject to monitor his own activity. Fitts proposed a relationship between the length of time taken to complete a movement (MT) and the required accuracy (target width) and distance (amplitude) of the movement. To investigate this relationship, subjects were required to tap alternately back and forth between two metal plates of equal size with a metal stylus for 15 seconds and an average time for each discrete movement was calculated. Fitts was able to vary the difficulty of the task by changing the combination of target width and movement amplitude and presented a total of 16 target conditions.

Fitts found that movement time increased uniformly as movement amplitude increased or target width decreased. From his results, Fitts proposed a logarithmic relationship between MT, A and W which was expressed mathematically as $MT = a + b \log_2(2A/W)$ and is now referred to as Fitts' Law. Movement time is constant for any given ratio of A and W and subsequent changes in A or W that change the ratio of the relationship will result in a change in MT. The value of $\log_2(2A/W)$ is thought to reflect the difficulty of a particular movement and is referred to as the Index of Difficulty (ID), reflecting the

amount of information to be processed. The general rationale behind Fitts' Law, then, is that the system is a processor of information and as the amount of information to be processed increases as indicated by an increase in the Index of Difficulty, the time required to process and complete the movement increases.

Fitts' Law has been shown to have wide generality in the study of movement control. It has been found to hold for discrete tapping tasks (Fitts and Peterson, 1964) as well as for serial, for tasks other than tapping such as pin transfer (Fitts, 1954), with children (Kerr, 1985; Sugden, 1980), and across age groups (Welford, Norris and Shock, 1969).

Processes Underlying Fitts' Law.

a) Feedback

The generality of Fitts' Law led to attempts to explain the underlying processes that could explain the relationship. Central to the interpretation of Fitts' Law is the idea of visual or proprioceptive feedback and the need to monitor movement in order to meet the required accuracy (Kerr, 1982; Marteniuk, 1976). A major concern, however, was whether feedback, particularly visual, could be used for very rapid motor skills where only a very small amount of time is available to monitor performance.

Posner and Keele (1968) in an attempt to investigate the role of visual feedback in rapid movements, trained subjects to move a stylus to a circular target at movement times varying from 150 to 450 msec. On the subsequent test trials, half were performed without visual feedback as the lights were turned off. They found that the accuracy of the movement was only affected for the movements of 260 msec or more whereas movements under 190 msec were unaffected. Posner and Keele concluded that the minimum duration for the processing of visual feedback from a movement appeared to be between 190 and 260 msec.

Keele (1968) then suggested a feedback interpretation of Fitts' Law based on the importance of visual and kinesthetic feedback. The interpretation, applied to visual feedback, was related to Posner and Keele's (1968) previous findings defining the minimum time required to process visual feedback. A movement is seen as essentially a series of corrections, and the relation between speed, accuracy and distance is determined by the time required to process feedback and make corrections in the movement (Keele, 1968). Movement time is seen as being a function of the number of corrective movements necessary and the minimum amount of time required to process the feedback related to each correction.

Welford, Norris and Shock (1969) found that when speed was related to the actual scatter of the landing on the targets, there were some departures from the fit of the Fitts' equation. They found movement times were differentially affected when amplitude was varied and the target width was held constant, with target width showing the greater effect. They hypothesized that there are two control processes that should be distinguished: a) a faster one concerned with distance-covering and b) a slower one for 'homing' onto the target. The former process is regarded as essentially a 'motor' control, shown in ballistic movements to no specific target, and the latter as implying an additional process of visual control. They concluded that the accuracy of a movement may be more dependent on some absolute appreciation of the end position of the movement and independent of its amplitude.

b) Impulse-Variability

Schmidt, Zelaznik, and Frank (1978) have offered an alternative explanation for Fitts' Law based on impulse variability and applied to single aiming movements. Schmidt, et al. felt that the general explanations for Fitts' Law were based on the very optimistic view of a subject's abilities in processing feedback information, with accuracy depending on the

quality and speed of movement corrections. They proposed instead, that the motor system output is contaminated by 'noise' (within-subject-variability) which is in turn related to the nature of the movement. They suggest that the variability of movement is proportional to the amount of force used. Central to the model is the notion of the generalized motor program and their assumption that single aiming movements may be generally preprogrammed (Schmidt, et. al., 1978). The model suggests that the generation of such a movement includes an initial impulse for acceleration which is essentially the aggregate of forces applied to the limb in the direction of the target. The velocity of the movement after the initial impulse has stopped is directly proportional to the impulse. The implication is that any variability in the impulse will result in proportional increases in the variability of the velocity after the acceleration phase (Schmidt, et al. 1978). This in turn affects the movement accuracy, as, since the movements are felt to be preprogrammed, movements with too much or too little impulse acceleration will consequently either travel too far or fall short of the target. In effect, the theory suggests that the limitation in subject's MT is an indirect result of his inability to be accurate due to variability in the force-production and time-production mechanisms.

In short summaries of a series of experiments, Schmidt, et al. (1978) provided some support for some of the basic assumptions of their model. The assumption that force and its variability are proportional was supported when subjects showed more variability in force production as the amount of force they were required to produce on a lever increased. A further experiment showed a linear relationship between within-subject variability of the impulse duration and movement time when subjects were asked to make a series of oscillating movements of a lever over 16 different combinations of movement amplitude and movement time. In a final experiment, subjects made single aiming movements on nine movement conditions of amplitude and movement time. The results gave some support to the basic premise of the model, namely that the variability of the movement endpoint is linearly related to the ratio of amplitude and movement time.

Schmidt, et al. (1978), while emphasizing the promising findings related to their model, do acknowledge a few problems that are not accounted for. One such important problem stems from their results on the final experiment. The three movement times used were 140, 170, and 200 msec., and the results for the conditions using 200 msec. showed lower variability in movement endpoint. They suggest this could be explained by the possibility the subjects were able to use visual feedback and correct movements in progress. This time frame would be in line with the findings of Posner and Keele (1968), but more importantly, suggests that movements of this duration may not necessarily be programmed as was assumed by the model. They conclude with the hypothesis that their model may be limited to those movements that are preprogrammed, which they still assume may exceed 200 msec., but that it breaks down when movements are long only when the subject is monitoring endpoint accuracy. They suggest that the Fitts model may still be the best description of the relationship of amplitude, width, and movement time for visually guided movements. As such, their model seems to account more for the possible explanations of the source of movement variability.

All of these theories then, while differing in many respects, do highlight one common important feature: the important role that visual feedback can play in the monitoring of an ongoing movement in order to meet the required accuracy, at least for movements of a minimum of 200 msec. duration and where the endpoint accuracy must be monitored.

Recognition in the Monitoring of Visual Feedback.

An earlier section in this review highlighted the importance of stimulus or pattern recognition in making sense of the world around us. At this stage, it is important to establish the role of this important process in the performance of motor skills. The suggestion in the previous section of the important role of the monitoring of visual feedback in movement control raises the question as to what is contained in the visual

information received from a movement and why it is of use. The perhaps somewhat obvious answer is that feedback must be interpreted and recognized to be of value. Marteniuk, (1976) in applying the information processing model to motor skills notes that an important sensory ability in movement is the ability to recognize information which must be compared to past experiences. Marteniuk also noted that this process is involved in recognizing environmental activity as well as proprioceptive feedback from a movement, and involves first receiving the feedback from the movement, comparing it to some memory of past similar experiences for interpretation, and then through the subsequent recognition of the feedback, it can be acted upon. The importance of recognition in movement, particularly related to feedback information, is given further support with the recognition schema found in Schmidt's schema theory (1975). The recognition schema is felt to generate the expected sensory consequences of a movement and then is used to monitor the movement for this feedback.

Thus, motor skills, as would be expected, do appear to use recognition in the same manner as non-motor skills, in that information from the environment or from feedback must be interpreted and recognized, and this process relies heavily on past experience and information.

The Pursuit Tracometer,

The step-input pursuit tracometer, or 'stressalyzer' was developed at the National Research Council in Ottawa (for a description of the task see methodology section). It has been used extensively in assessing the cognitive-motor performance of many different populations ranging from the elderly (Normand, Kerr, Metivier, in press), Down's Syndrome subjects (Kerr and Blais, 1985; Blais and Kerr, 1986) to subjects under conditions such as sleep deprivation (Buck, 1975). Past results have shown that Fitts' Law does hold for this task (Buck, 1981).

A phenomenon in motor skills that Fitts' Law is felt to explain is the speed-accuracy trade-off, in that to maintain a constant processing rate, speed and accuracy must be traded off against each other. This also means, however, that the individual, when performing a task, can exert some control over the way to respond and could change the relative contribution of the control processes underlying the movement (Schmidt, 1982). While it is acknowledged that there is room for such a trade-off with the tracometer, the general thrust of the task is to become more efficient, and this cannot be accomplished by an overemphasis on either speed or accuracy at the expense of the other.

The movement error rates (where targets are overshoot) found in previous studies are fairly constant for similar populations and conditions ranging from 30-40% (Buck, 1976, 1981), showing both the difficulty of the task and that generally, subjects are responding with a combined speed-accuracy strategy that seems to be inherent to the task.

The high error rates are important for another reason in that they indicate the high proportion of movements that can be assumed to have been completed using visual feedback as indicated by the recorded adjustments. The movements made without recordable adjustments do leave open to question the possibility they could be completely preprogrammed, however this seems unlikely for a few reasons. First of all, even the shortest of possible movements on the task is still long enough to use visual feedback (Keele, 1968); and the theories presented earlier generally point to the use of visual control when endpoint accuracy must be monitored. This latter point is in fact one of the important features of the tracometer. The subject must correctly align the pointer with the target before the next target is presented, therefore the subject cannot simply make an error and then proceed, but instead, must continue to monitor the movement and make the necessary adjustments until exact alignment is achieved.

The tracometer then, is a fairly difficult and complex motor task, which requires both precision and speed on the part of the performer who, in turn, must continually monitor performance to successfully meet the task demands.

Method

Subjects

The subjects were 52 undergraduate students at the University of Ottawa in the Department of Kinanthropology. The subjects received class credit for their participation in the study, however the decision to participate was voluntary. There were 26 males and 26 females tested.

Apparatus

There were two separate tasks used in this experiment, one to provide an assessment of procedural knowledge related to the judgement of movement, and one to provide the motor skill learning assessment.

The apparatus used to assess the subjects' procedural knowledge consisted of a computerized matrix board, an IBM personal computer and a reaction time button. The matrix board consisted of 42 rows of 121 light emitting diodes (LED) 1 cm apart and covered with a transparent hard plastic top. The matrix board was connected to the IBM personal computer. The software used was the "Movement Analysis Program" which was written in the Department of Kinanthropology at the University of Ottawa. The entire MAP computer program consisted of four separate tasks of which only 2 were used for this experiment; a) simultaneous movement, and b) sequential movement.

The simultaneous movement task (task a) consisted of two LEDs being illuminated simultaneously, one 2 cm above the other. Adjacent LEDs then illuminated in rapid succession giving the appearance of the lights travelling horizontally across the board. The two LEDs travelled simultaneously but over unequal distances up to a maximum distance

of 40 cm across the matrix board. There were four subtasks within the simultaneous movement task where the speed and distance at which the LEDs travelled in relation to each other was varied. The determination of the speeds at which the LEDs travelled was based partly on four standard reference speeds which were built into the program. The reference speeds were 40, 50, 60, and 70 LEDs/sec. and every pair of lights included at least one presented at one of the reference speeds. The speed of the second LED was then determined by the subtask condition. The four subtask conditions were a) one dot catches up to the other, b) dot does not catch up, c) overtaking and d) crossing over. (See Appendix A for complete subtask descriptions)

The sequential movement task (task b) was also comprised of four subtasks with the speeds of sequentially presented lights, travelling unequal distances in unequal times, varied. In this case a baseline of 10 LEDs illuminated close to the subject and the lights fell vertically towards the baseline from a maximum height of 40 cm. There was 3/4 second between presentation of the two LEDs. The same four reference speeds used in task a were also used on task b to determine the speed of LED A. The four subtask conditions were movements in a) equal time and equal distance, b) equal times and unequal distances, c) equal distance and unequal time, and d) unequal distance and unequal time. (See Appendix A for more complete descriptions)

The apparatus used as the novel motor task was the step-input tracometer (Buck, Leonardo and Hyde, 1981) which consists of two components; a tracking unit and a control unit. The tracking unit consists of a control wheel and the target display. The target display consists of five positions, 41 mm apart, which can be illuminated and are set in a semi-circular fashion. Each target is 2.4 mm in diameter. The subjects are required to align the cross on the pursuit pointer with the current target, defined as the one being illuminated, by rotating the control wheel (see Figure 1). The control wheel

operates in an indirect fashion in that turning the wheel to the left moves the pointer to the right, and turning the wheel to the right moves the pointer to the left. The alignment must be maintained for an uninterrupted period of 200msecs after which the target is extinguished and a new target illuminated.

The task is self-paced in that the subject is required to align the pointer correctly before the trial continues. One trial consists of 100 random target presentations with the limitation that each of the 20 between target movements (10 moving left, 10 moving right) occurs five times. The control unit controls the target presentation and measures the subject's responses. It contains a cassette recorder for storing data and a digital second counter to enable the experimenter to provide immediate knowledge of results for the subject in the form of total number of seconds to complete each trial.

The following data were obtained from each trial; a) total response time, b) correct reaction time, c) non-overshoot movement time, d) overshoot movement time e) error score, and f) overshoot score. Total response time represented the average total time to make a single response. Reaction time represented the time from the presentation of the illuminated target to the initiation of the movement. Movement time represented the time from the initiation of the movement to the successful alignment with the target. Overshoot movement time included movements where the subject went beyond the target before successful alignment whereas non-overshoot movement time was calculated only for those movements with no overshoots. Overshoot score was the percentage of overshoot errors per trial while error score was the percentage of directional errors, i.e., movements initiated in the wrong direction, per trial.

The difficulty of the task was varied across four movement distances (41 mm, 82 mm, 123 mm, 164 mm), and four levels of directional probability. When resting on target 1, the probability that the next movement would be to the right was 100%,

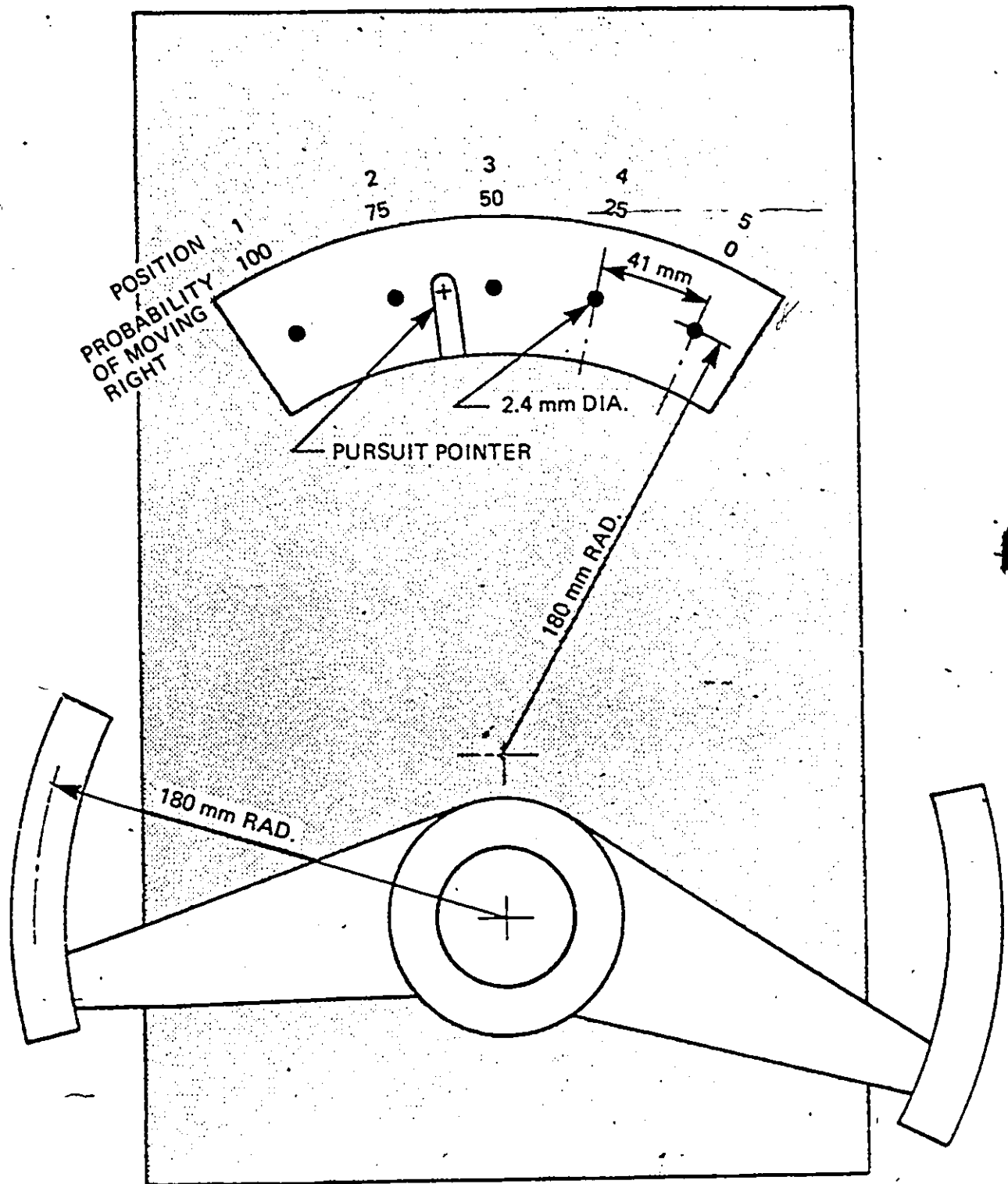


Figure 1: Pursuit Tracometer

however, when resting on target 4 the probability of moving right was 25% but the probability of moving left was 75%.

Procedure

All subjects completed a single test session consisting of the movement analysis test followed by the pursuit tracking task. The entire testing session for each student lasted approximately one hour.

1) Movement Analysis

The subjects were seated in front of the matrix board which was tilted to approximately a 30 degree angle to allow for easier viewing of the lights. Each subject completed both subtasks (a) and (b), however, the order of presentation of the subtasks was alternated for each subject.

The task instructions were given verbally to the subject (see Appendix B) and they were shown the reaction time button which was used only to encourage quick answers and the time calculated was not part of the results analyzed.

The subjects' answers were recorded by the experimenter in the computer which then sounded a beep to signal to the subjects the initiation of the next pair of lights. To further aid viewing of the lights, the movement analysis test was performed in a darkened room.

One trial consisted of one pair of lights and for both subtest (a) and (b) the subjects were given eight practice trials, two at each of the four different conditions and at speeds slower than what would be seen during the test trials. The test itself, for both subtests (a) and (b), consisted of a random sequence of 64 trials with the 16 possible conditions

occurring four times. Therefore, for the movement analysis portion of the testing session, each subject performed 128 trials with the entire session lasting approximately 20-30 minutes.

2) Pursuit Tracking Task

The subjects then were asked to perform eight successive trials on the tracometer with intertrial pauses of approximately one minute. This portion of the testing session lasted approximately 25-30 minutes. The subjects were seated in front of the tracking unit and the chair was adjusted so the subject would not have to look up at the target display. The task instructions were given verbally to the subjects (see Appendix B). Following each trial feedback in the form of time taken to complete the trial was given to the subject. Following the completion of the eight trials, the subjects were asked subjectively, whether they felt they had emphasized both speed and accuracy equally or favoured one over the other. This was done to provide some information should the results suggest the possibility of a speed-accuracy trade-off.

At a later date, a short questionnaire concerning some background information, which was felt may be useful in providing some information on possible sources of knowledge related to judging movement, was then given to the subject (see Appendix C).

Design and Analysis

The analysis of the data included three components; a) an analysis of the assessment task data separately, b) a series of correlations between the assessment task performance ranking and tracometer performance ranking; and c) analysis of tracometer performance separately.

1. **ASSESSMENT TASK:** The number of errors each subject made on both task (a) and task (b) across the 4 occurrences of each sub-condition was submitted to a task x occurrence (2 x 4) ANOVA to determine:

- a. if task a and b were of different levels of difficulty,
- b. if any learning occurred.

Following this, using the split-half technique, the subjects were divided into two groups (upper/lower) based on performance on the assessment task, and the total number of errors each subject made was submitted to a group x occurrence (2 x 4) ANOVA to determine

- a. if the performances of the 2 groups was different,
- b. if any learning occurred.

2. **CORRELATIONS** - A series of Spearman-rank correlations was conducted to investigate the relationship between assessment task ranking based on the number of errors, and tracometer performance ranking. Assessment task ranking was correlated with:

- a. overshoot movement time,
- b. non-overshoot movement time,
- c. overshoot rate,

from trial 1 to investigate any initial relationship, and then with the same variables from trial 8 to investigate any change in the relationship over the course of learning the motor task.

3. **TRACOMETER VARIABLES** - Using the two groups formed based on the assessment task performance, a series of ANOVAS was performed on the tracometer data to compare the performances of the two groups to determine if superior procedural knowledge was a factor in performance.

- a. **TOTAL RESPONSE TIME:** A group x trial (2 x 8) ANOVA to compare the overall performances of the groups on the task and to investigate the rate of learning of the task.
- b. **CORRECT REACTION TIME:** A group x trial x probability (2 x 8 x 4) ANOVA to compare the reaction times of the groups over the trials and across the 4 levels of probability.
- c. **NON-OVERSHOOT MOVEMENT TIME:** A group x trial x distance (2 x 8 x 4) ANOVA to compare the time taken to complete movements without overshoots over the trials and across the 4 distances.
- d. **OVERSHOOT MOVEMENT TIME:** A group x trials x distance (2 x 8 x 4) ANOVA to compare the time taken to complete movements made with overshoots over the trials and across the 4 distances
- e. **ERROR RATE:** A group x trials x probability (2 x 8 x 4) ANOVA to compare the rate of errors made in initiating movements in the wrong direction over the trials and across the 4 levels of probability.
- f. **OVERSHOOT RATE:** A group x trials x boundary distance (2 x 8 x 4) ANOVA to compare the rate of overshoot errors made over the trials and across the 4 boundary distances.

Results

Preliminary Analysis

The initial analyses dealt principally with the results obtained from the movement analysis task designed to provide the procedural knowledge ranking of the subjects for use in the motor performance analysis.

The task x occurrence ANOVA to determine if task (a) and (b) were of equal difficulty yielded a significant main effect for task, $F, (1,102)=8.04, p<.05$. Task (b) proved to be the more difficult with an error rate of 10% as compared to a rate of 7% for task (a).

Following this initial analysis and due to the significant main effect of task, the subjects were first ranked according to their total number of errors from task (a) and task (b) combined, and then ranked separately based on their performance on task (a) and then on task (b). These different rankings were then compared to ascertain whether they were measureably different as such differences might have necessitated treating the tasks separately in further analysis.

The comparison found that when the split half technique was applied on each of the rankings to form an upper and lower group, 75% of the subjects remained in the same group for task (a) and task (b). This was felt to be sufficient to justify the use of the ranking, and subsequent upper/lower groups, based on the subjects' combined error total for task (a) and task (b).

The group x occurrence ANOVA with repeated measures on the last factor, to establish whether the performances, in terms of errors, of the upper and lower groups was different, indicated that the upper group was superior to the lower group, $F(1,102)=47.27, p<.01$, or in other words, their procedural knowledge was superior to that of the lower group. The error rates were 5% for the upper group and 11.6% for the lower group. Furthermore, the lack of an occurrence main effect or a group x occurrence interaction indicated that no significant learning took place in either group during the testing procedure.

A summary of the results from the preliminary analysis of the procedural knowledge assessment task is presented in Table 1.

Table 1: Total Number of Errors for each Group by Task and Occurrence

Group	N	Task a				Task b			
		Occurrence							
		1	2	3	4	1	2	3	4
upper	26	50	32	33	37	74	69	74	77
lower	26	109	97	96	105	122	115	128	102

Note. Each occurrence represents 36 trials per subject or 936 total trials per group.

Main Analysis

The intent of the main analysis was to consider the relationship of procedural knowledge, as related to movement judgements, to performance on a motor task requiring those judgements.

Correlation Coefficients

The first analysis used to investigate this relationship was a series of Spearman-Rank correlations between the subjects' error totals on the assessment task and the major variables of interest on the tracometer where a relationship was hypothesized; non-overshoot movement time (NOMT), overshoot movement time (OMT), and overshoot rate. The correlation coefficients for all comparisons are presented in Table 2.

Table 2. Correlation Coefficients between Task Rankings

	Variable					
	OMT		NOMT		Overshoots	
	Tr 1	Tr 8	Tr 1	Tr 8	TR 1	Tr 8
errors	.300*	.293*	.214	.073	.015	.094

* $p < .05$

Note: Tr = Trial

The correlation coefficients of the assessment task ranking with OMT on trial 1 ($r=.300$) and trial 8 ($r=.293$), although both fairly low, were the only significant ($p < .05$) correlations. This suggests some relationship between the ranking in terms of procedural knowledge and the time taken to complete movements with overshoots.

Tracometer Data Analysis

The second component of the main analysis involved analyses of the tracometer data only with the groupings determined by performance on the assessment task. The resulting two groups ($N=26$ per group) formed using the split-half technique, separated the subjects into two levels of expertise in general procedural knowledge related to the judgement of movements and will be referred to as the upper and lower groups. The purpose of this portion of the analysis was to determine if performance in the individual components of the motor task was in any way a reflection of these knowledge differences.

The group means and standard deviations for the main variables are presented in Table 3.

Table 3: Means (msecs) and Standard Deviations for Main Variables

Group	TRT		CRT		NOMT		OMT	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
upper	1308	12	343	2.2	926	7.8	1360	12.1
lower	1346	11.1	353	2.5	955	8.3	1462	14.7

Note. TRT-total response time, CRT-correct reaction time, NOMT-non-overshoot movement time, OMT-overshoot movement time.

Each variable was submitted to further analysis and the results for each will be discussed individually.

Total Response Time

The performance curves of the two groups for the average total time to make a single response is illustrated in Figure 2, and although the upper group's TRT was consistently faster, this difference was not significant.

The group x trial ANOVA indicated a significant main effect for trial only, $F(7,350)=67.95, p<.05$, in essence a learning effect. This is reflected in a steady decrease in time over the eight trials at an equivalent rate for both groups and is illustrated in Figure 2. Post hoc analysis showed a significant difference between trials one and two and between trials 2 and 3 indicating both groups had essentially learned the task by the third trial.

Correct Reaction Time

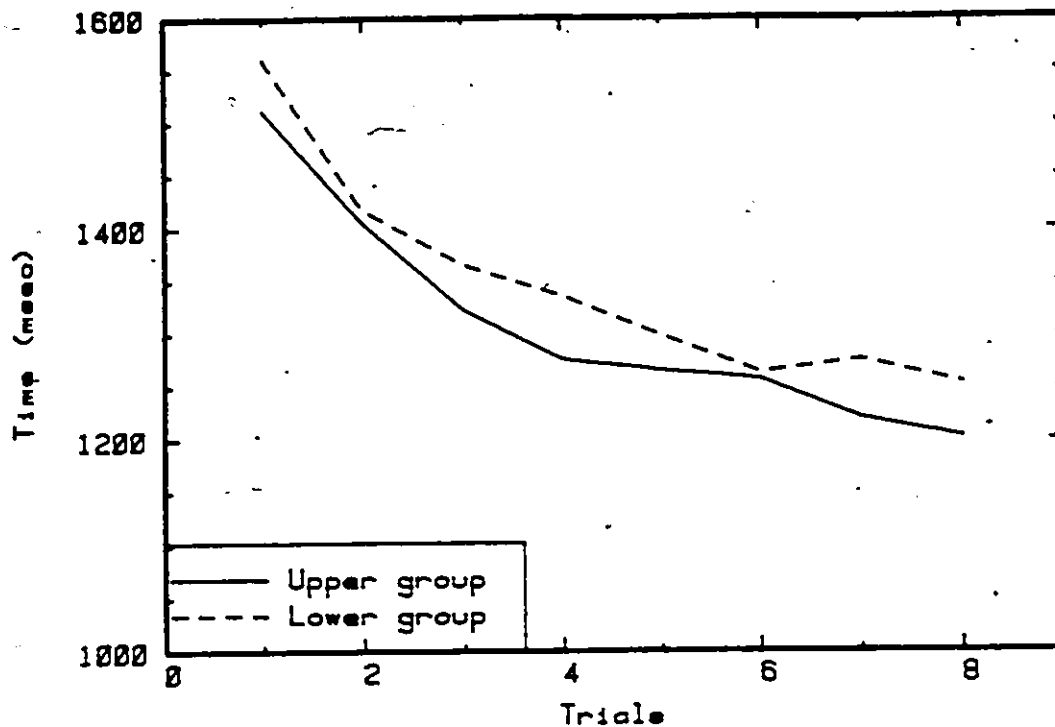


Figure 2 Total Response Times over Trials

The analysis across the eight trials was not possible due to missing scores, therefore the trials were paired and a group \times block \times trials \times probability ($2 \times 4 \times 2 \times 4$) ANOVA was performed. Significant main effects were found for block, $F(3,150)=150.56$, $p<.01$, and probability, $F(3,150)=236.97$, $p<.01$. The main effect of probability reflected the difference in difficulty between the levels of probability, and the main effect of block was a result of the steady decrease in time over the blocks. Further analysis showed a significant difference between each successive block.

The group \times block interaction was also significant, $F(3,150)=3.18$, $p<.05$, and is illustrated in Figure 3. An analysis of the simple main effects showed this was due to initial superiority by the upper group in the first block.

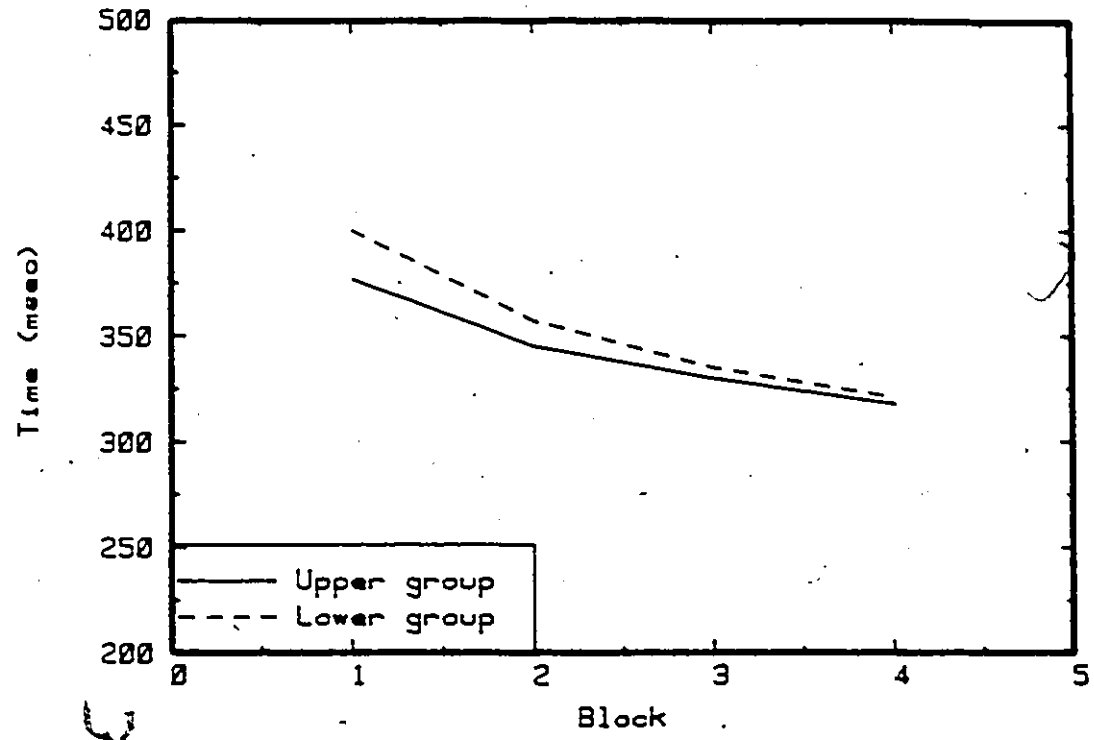


Figure 3: Correct Reaction Time over the Four Blocks

Error Score

The error rates for both groups, representing movements initiated in the wrong direction, are presented in Table 4.

Table 4: Error Rate(%) across Trials

Group	Trial							
	1	2	3	4	5	6	7	8
upper	26.0	25.5	26.8	20.4	23.9	22.6	24.4	20.6
lower	23.7	21.7	24.8	19.5	22.0	21.2	23.4	24.4

An analysis of the error rate showed no group differences which is a reflection of the similarity of actual values in Table 4. Main effects were found for trials $F(7,350)=5.63$, $p<.01$; as well as a main effect for probability $F(3,150)=360.38$, $p<.01$.

Non-Overshoot Movement Time (NOMT)

Group data for NOMT across the eight trials are illustrated in Figure 4 and seem to suggest at least an initial superiority by the upper group, in that their performance was consistently faster over the first 5 trials. The group x trial x distance ANOVA yielded significant main effects for trial, $F(7,350)=33.77$, $p<.01$, and for distance, $F(3,150)=1023.48$, $p<.01$. The group x trial interaction was also significant, $F(7,350)=2.06$, $p<.05$ (see Figure 4), as was the three-way group x trial x distance interaction, $F(21,1050)=1.59$, $p<.05$.

An analysis of the simple main effects of the group x trial interaction was unable to pinpoint the exact source of the interaction effect, therefore further analysis was attempted on the three-way group x trial x distance interaction in the hope that it would help in the interpretation of the two-way interaction. This interaction showing the groups' performances across the eight trials for the four distances is illustrated in Figure 5.

While again the exact source was not pinpointed, the graphs do suggest a general trend of superiority by the upper group across the initial few trials at each distance, but more so for distances 2 and 3. This then suggests, that, overall, the general initial trial superiority of the upper group was likely responsible for the interaction effects.

Overshoot Movement Time (OMT)

Due to the relatively low number of movements made with overshoots at the longer distances, the group x trials x distance ANOVA was possible only for the shortest distance

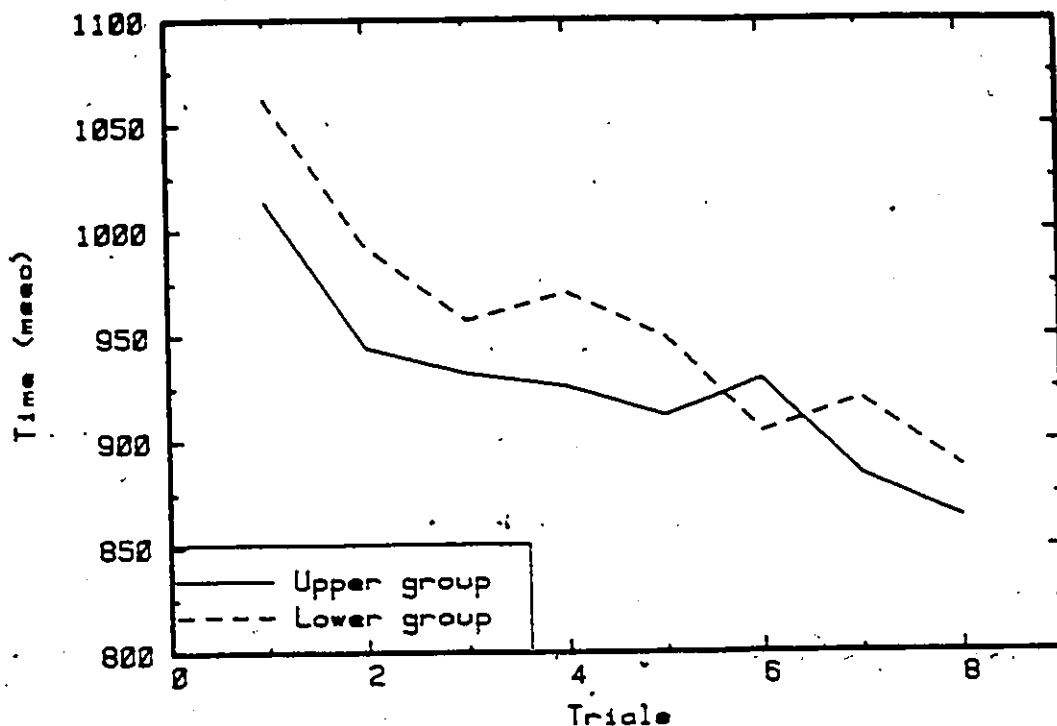
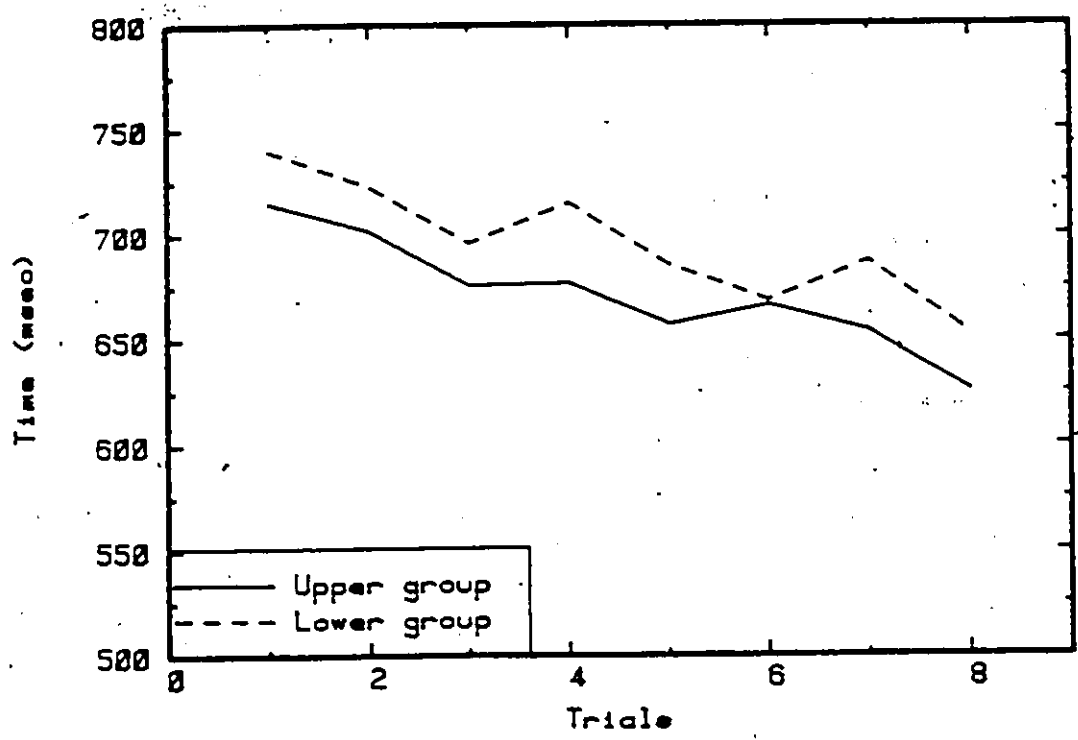


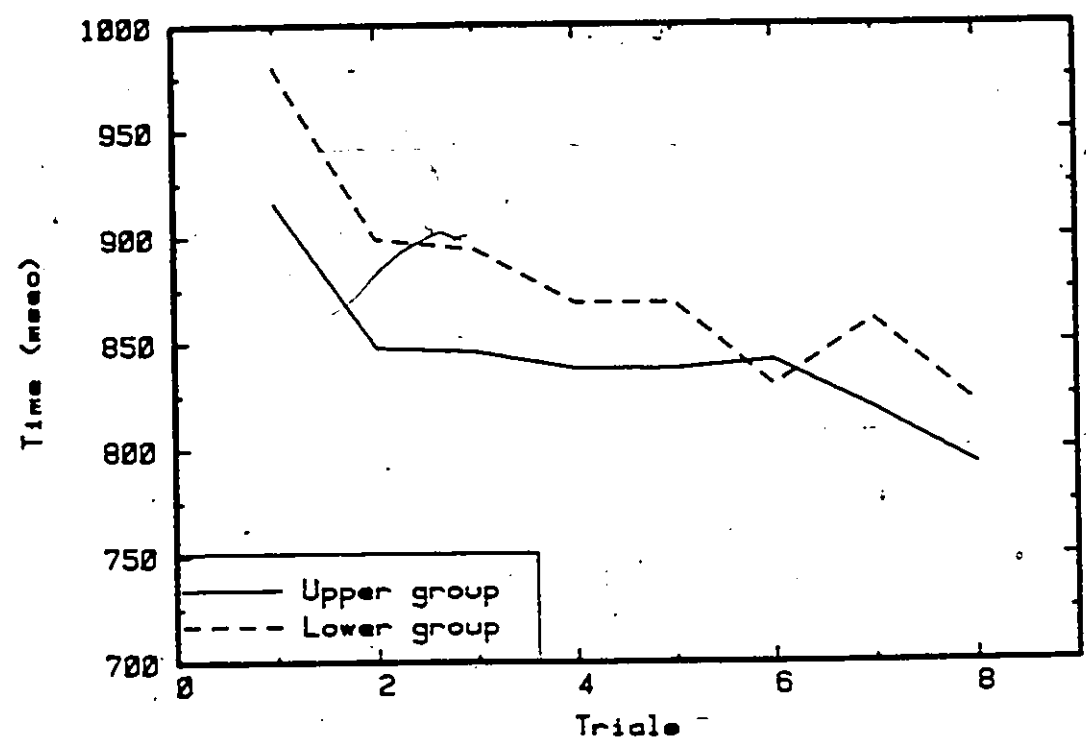
Figure 4: Non-Overshoot Movement Time Across Trials

(41 mm). The analysis indicated significant main effects for group $F(1,50)=4.16, p<.05$, and trial, $F(7,350)=12.09, p<.01$. The group effect reflected the significantly superior performance by the upper group as clearly illustrated in Figure 6a. The general decrease in time by both groups over the course of the trials is responsible for the trial effect.

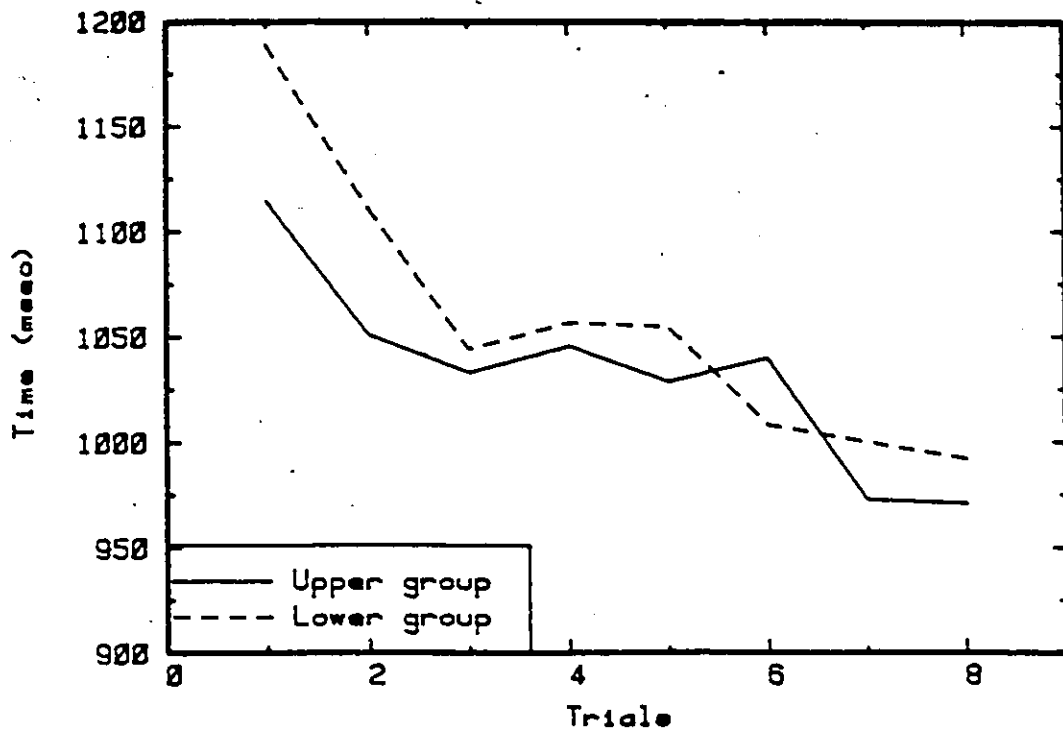
Although no analysis was possible on the remaining three distances (82 mm, 123 mm, 164 mm) Figure 6 also illustrates the groups' performances for these distances. The figures reflect a similar general trend of upper group superiority at least for the initial trials, and interestingly, also for the last trials.



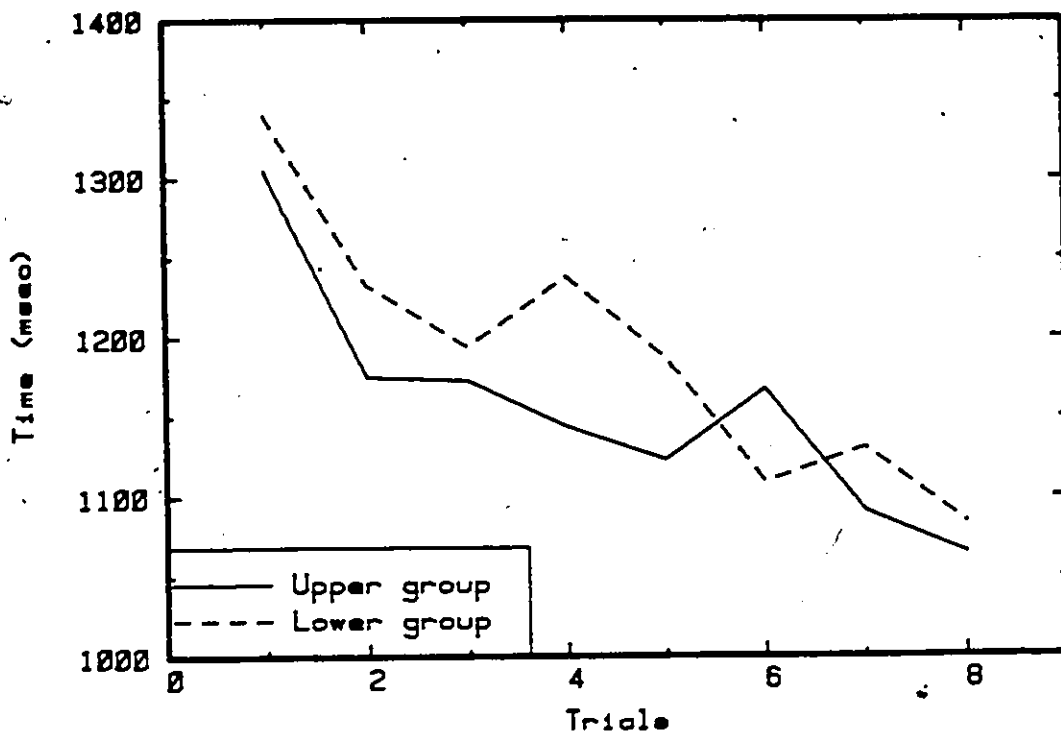
a) NOMT - Distance 1



b) NOMT - Distance 2

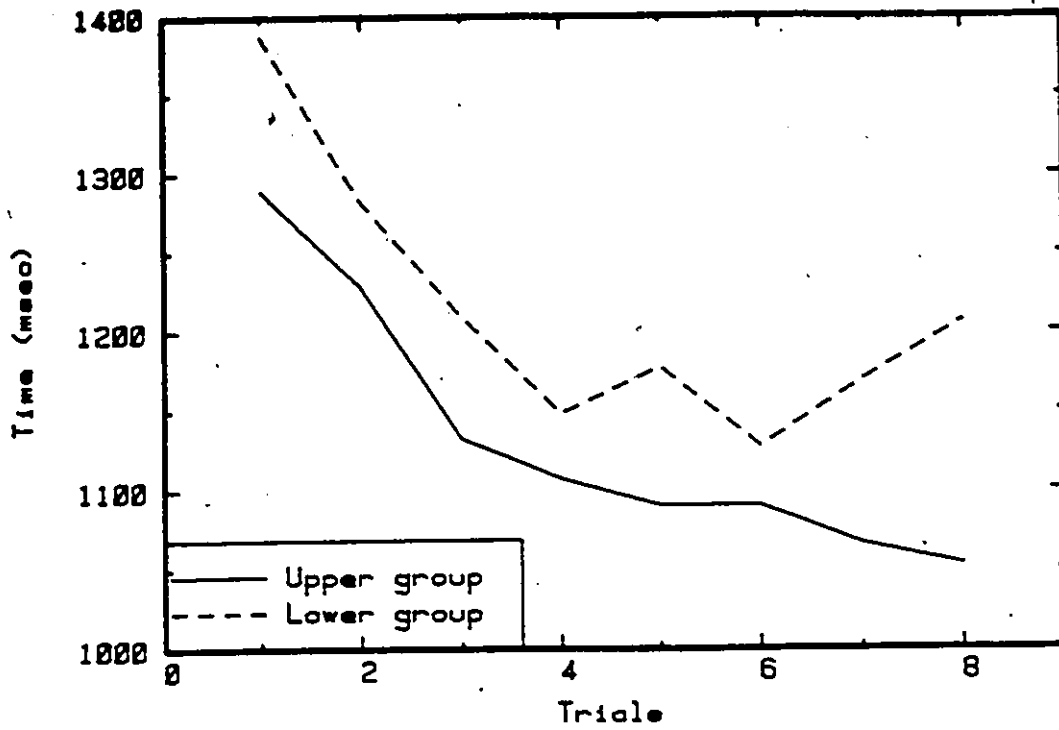


c) NOMT - Distance 3

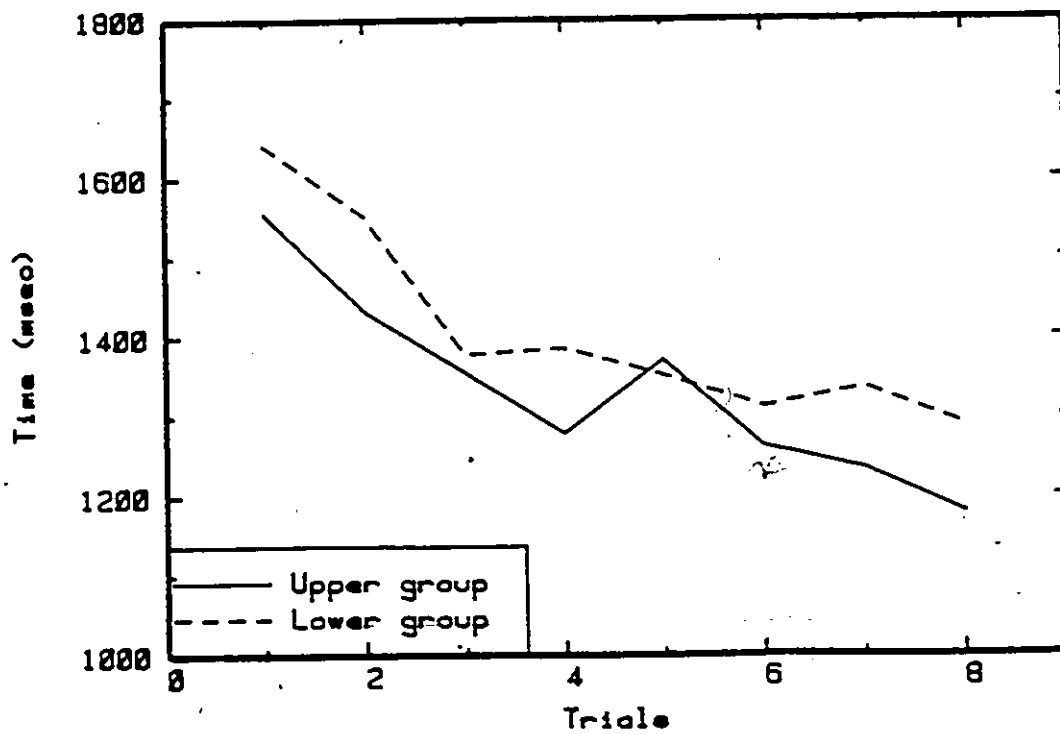


d) NOMT - Distance 4

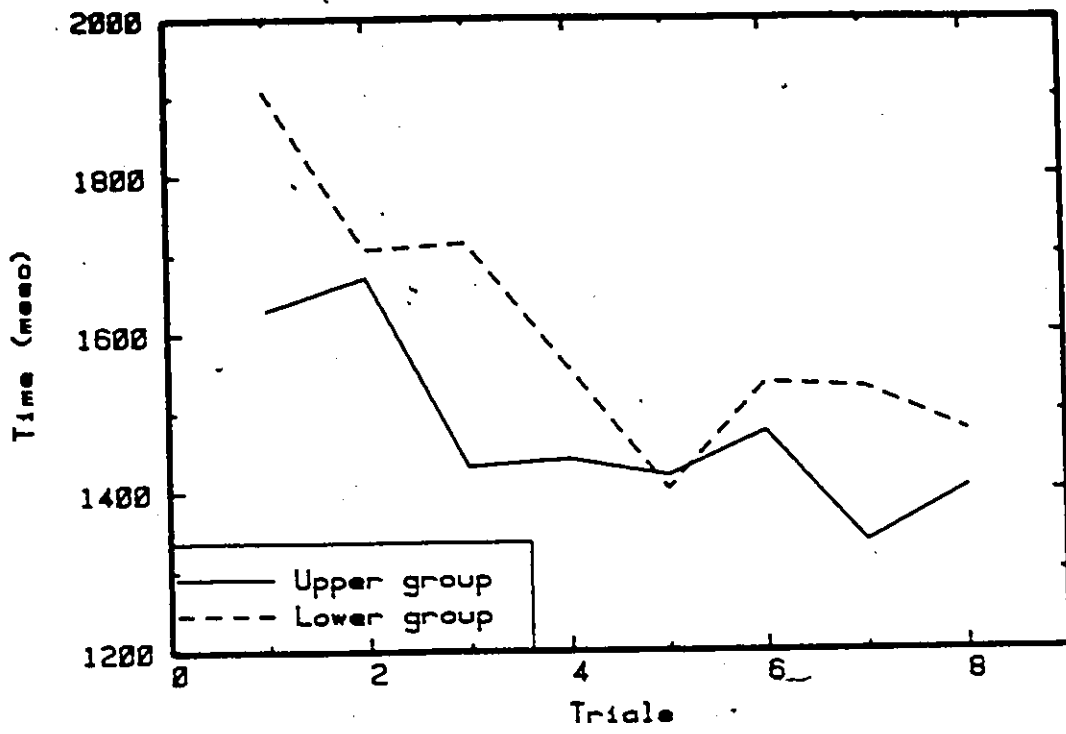
Figure 5 Non-overshoot Movement Times across Trials by Distance



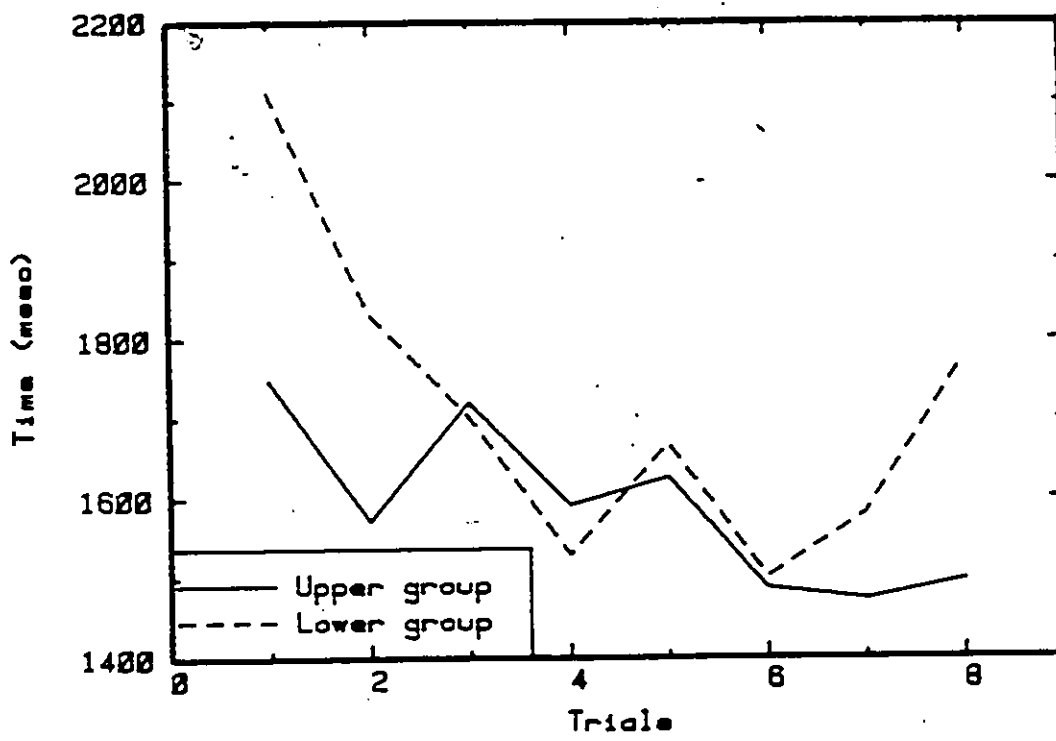
a) OMT - Distance 1



b) OMT - Distance 2



c) OMT - Distance 3



d) OMT - Distance 4

Figure 6: Overshoot Movement Times across Trials by Distance.

A further 2 x 8 (group x trial) analysis of variance with repeated measures on the last factor was then done with the distances collapsed. The trends suggested in Figure 6 were confirmed, as the analysis yielded a significant main effect for group, $F(1,50)=5.60$, $p<.05$. This effect is clearly illustrated in Figure 7 showing the upper group's superior performance across the trials. The main effect of trial was also significant $F(7,350)=21.04$, $p<.01$.

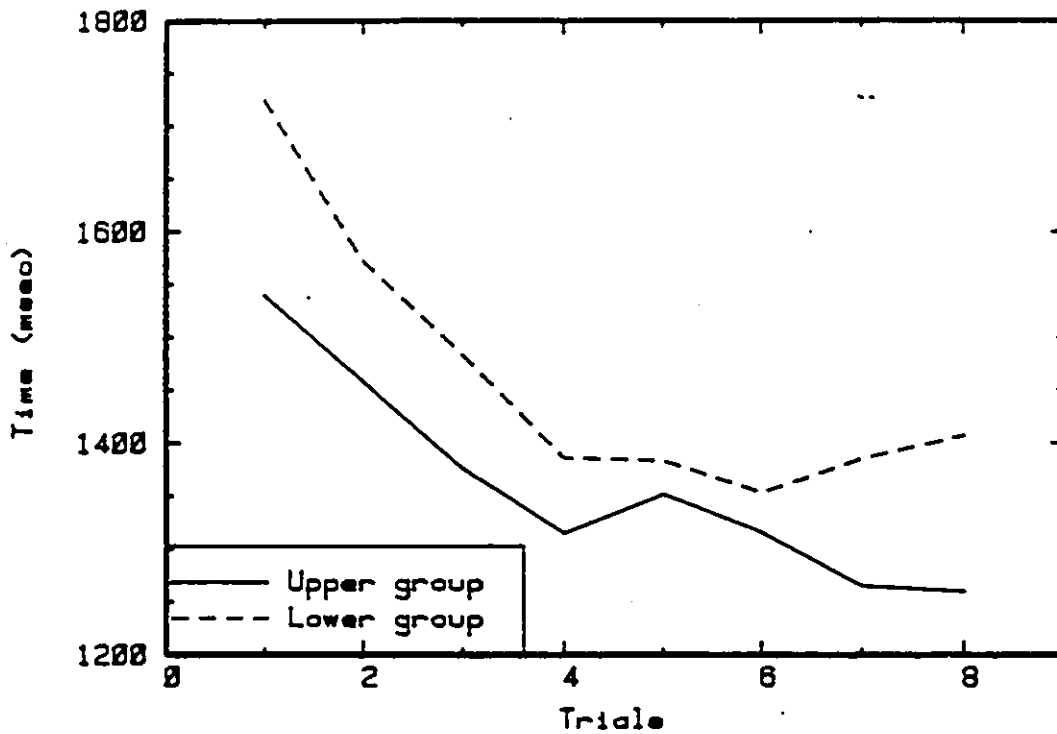


Figure 7: Overshoot Movement Time across Trials

The low positive but significant correlation between assessment task rank and Trial 1 OMT is consistent with the OMT differences found and seems to reflect an upper group superiority especially in the early trials. The slightly lower but significant correlation

observed between assessment task rank and trial 8. OMT, however, does not appear to reflect a relationship that remained over the trials.

Overshoot Score

The rate of overshoots for both groups is presented in Table 5. An analysis showed no differences between the groups, but showed main effects for trials on overshoot rate, $F(7,350)=6.70$, $p<.01$, as well as a main effect for boundary distance $F(3,150)=101.38$, $p<.01$. The analysis of overshoot rate also produced a significant group \times distance interaction which is reflected in the group means shown in Table 6.

Table 5: Overshoot Rate(%) across Trials

Group	Trial							
	1	2	3	4	5	6	7	8
upper	28.9	27.9	26.0	24.8	22.5	22.1	22.3	24.1
lower	29.7	25.0	25.9	24.8	22.0	23.8	24.8	24.6

Table 6: Group Means by Boundary Distance for Overshoot Rate

Group	Boundary Distance			
	1	2	3	4
upper	16.1	24.6	26.9	31.7
lower	15.7	21.7	27.2	35.8

An analysis of the simple main effect did not pinpoint the source of the interaction, however, as indicated by the means, the lower group appeared to have increasing difficulty with movements as the distance of the target from the boundary increased (e.g., boundary distance 4).

Upper/Lower Thirds

A further reorganization of the groups was then performed in an attempt to investigate the possibility that a majority of subjects may have been grouped around the center thereby reducing the possibility of group effects. Two groups were then formed consisting of essentially the upper and lower third of the assessment task ranking with each group consisting of 17 subjects.

An analysis was then completed for the tracometer data using these groups, which subsequently produced no different results with one exception. In an attempt to combine enough data necessary for an analysis the trials factor was collapsed into four blocks of two trials. This was sufficient to provide enough data for an analysis of overshoot movement time that included distance one and two. Significant main effects were found for group $F(1,32)=4.55$, $p<.05$, block $F(3,96)=18.63$, $p<.01$, and distance $F(1,32)=133.55$, $p<.01$. The group effect was due to the superior performance by the upper third group and reflects a similar pattern found in the analysis of overshoot movement time distance one as discussed earlier. Table 7 shows the group means for the four blocks for the two shortest distances.

Table 7: Upper/Lower Third Group Means for OMT (Distance 1 and 2)

Group	Block			
	1	2	3	4
upper	1341.5	1208.5	1191	1145
lower	1488	1298.5	1270	1258.5

Subject Questionnaire

The questionnaire which was felt might provide some information for possible sources of knowledge related to movement judgements, provided some descriptive background on the subjects in each group.

Both groups had similar physics and biomechanics backgrounds with an average of 1.68 years for the upper group and 1.88 years for the lower group. There was a slight difference in the average number of years driving with the upper group having an average of 5.18 years as opposed to an average of 4.6 years for the lower group. Also, while 86% of the lower group had some previous experience with video games, only 55% of the lower group had had previous experience. Finally, as to be expected, both groups were heavily involved in competitive sports and both groups included sports as a major hobby.

Discussion

The general purpose of this study was to investigate knowledge base differences and their contribution to the learning and performance of a novel motor task. The specific hypotheses tested were that superior general procedural knowledge related to the judgement of movement, through more efficient monitoring of the movement, would result in a) a faster rate of learning, and b) superior performance in the movement components of the task which required that knowledge. The basic premise of these main hypotheses was based on the notion that subjects access a pool of general procedural knowledge in order to guide performance in novel situations (Anderson, 1982); which in this case would be triggered through the visual feedback and monitoring of the movement.

The first hypothesis, related to the rate of learning, was subsequently rejected. The hypothesis relating to superior performance on the movement components of the task was confirmed for overshoot movement time (OMT) and was partially confirmed for non-overshoot movement time and for overshoot rate. The hypotheses that were confirmed indicate some support for the idea that knowledge base differences can contribute to performance differences on a novel task.

It is perhaps necessary at this point, before beginning the main discussion, to make a few general comments about the assessment task itself. The task was intended to discriminate between levels of general procedural knowledge related to the judgement of movement. The analysis of the subjects' performances on the task indicates that it did clearly distinguish between procedural knowledge levels and that this assessment was not contaminated by learning on the recognition task. The fact that task a (simultaneous

movement) and task b (successive movement) appear to represent different levels of difficulty would perhaps suggest that they may be assessing slightly different components of the procedural knowledge. The close similarity in ranking on the two tasks, however, suggests that overall the same general knowledge is required and, therefore, the combined ranking of the subjects from the two tasks may provide a final rank based on a more general level of expertise and was the ranking used on the task.

It was felt that, when faced with a novel task, superior procedural knowledge could provide an advantage in learning the task. The total response time data, which reflects overall performance and combines all variables, however, shows that although their performance was consistently poorer, the lower group was able to learn the task at the same rate as the upper group. In this case then, superior general procedural knowledge does not seem to have been enough of an advantage to enable the upper group to learn the task faster. The results from the breakdown of the task into its component parts do, however, show some interesting patterns relating to task performance:

The hypotheses predicted a difference in performance only for the movement components of the task. As the decision components of the task (correct reaction time and error scores) did not require the procedural knowledge being tested no significant differences were anticipated. Therefore the lack of any major group differences in correct reaction time, with the exception of block one, and error score, was expected.

The difference found in correct reaction time on the initial block showing the upper group to be superior is somewhat difficult to interpret in light of the fact that it was not hypothesized. One point, however, that may be important to consider is that it is unlikely that one knowledge concept such as the one under study would be isolated or separate from other concepts that may often be required in similar contexts. In other words, it is possible that the procedural knowledge in judging movement may be used

in contexts that may also require quick reaction times. Similarly, the upper group's skill at dealing with feedback may have allowed them to spend less time pre-planning their movements. This, however, is only speculation at this stage. Instead, the fact that there were not major correct reaction time differences between the groups is in itself important in that it indicates that the assessment task was not simply separating those subjects with fast reaction times from those who may have been slower.

The movement components of the task, non-overshoot movement time, overshoot movement time, and overshoot score, were where the group differences were expected as it was here that the general procedural knowledge would be of use in the monitoring of the movement. The results show, however, that those with superior procedural knowledge in judging movement, generally took the same amount of time to complete their movements when the movements were made correctly, however, this may reflect, as well, the ability to pre-plan rather than simply an ability to respond to movement feedback. The results also show, that those with superior procedural knowledge made the same number of movement errors (overshoots) as those with poorer procedural knowledge.

Where they did differ greatly, was in the time taken to complete movements when mistakes (overshoots) were made, at least for the two shortest distances. Although the effect of longer distance, on the overall difference found in overshoot movement time was impossible to determine statistically, the pattern for the two farther distances suggest the same trend. The incidence of an error or unpredicted event (an overshoot) was far costlier for the lower group in terms of time and this difference is confirmed by the correlations which also suggest some relationship between general procedural knowledge assessed and the magnitude of movement errors. The advantage of superior general procedural knowledge in the monitoring of movements in this case, although not sufficient to produce differences in performance (TRT). seems to

be reflected in the ability to respond to an unanticipated event and minimize the cost of errors.

The question could be asked at this stage then, as to why there were not larger differences in the performances of the two groups as hypothesized. One important consideration is the contribution of other components to the task along with the particular procedural knowledge component considered. As Wall, et al. (1985) noted, the learning of new skills depends on the integration of knowledge from a wide variety of knowledge bases. There are many different components to performance on any task, and while this study aimed to isolate one felt to be especially important, there are clearly other components that contributed to performance.

One of the aims of this study was to investigate different levels of expertise, however, when dealing with less extreme ranges, differences may not manifest themselves as clearly or as strongly especially when dealing with more general concepts and skills. The likelihood of finding major group differences, therefore, was undoubtedly reduced for this reason: the group studied was relatively homogeneous in terms of procedural knowledge.

Another possible reason can be the fact that, overall, the subjects performed exceptionally well on the novel motor task. For example, the overshoot rates for both groups were exceptionally low compared to previous studies using this task on normal populations (Buck, 1976, 1981). The group differences cannot be explained simply as a speed-accuracy trade-off, as both groups, when questioned at the end of the session, generally indicated that they were emphasizing both speed and accuracy and did maintain similar error and overshoot rates.

Furthermore, the subjects in the study were all physically active as was clear from the questionnaire and all were majoring in a university program that related to motor activity. It is, therefore, possible that the subjects' vast experience on motor tasks affected the differences found on the assessment task when the knowledge was applied in the context of an active movement. Consequently, more task specific knowledge and skills could be brought to the task than could be assessed, perhaps reducing the dependence on more general knowledge. The exact effect of the vast motor experience of both groups is difficult to determine from this study alone, but is perhaps an important consideration for further study. The same general knowledge base can be tapped in different ways (i.e., verbally, visually, kinesthetically, etc.) and the use of a population with a broader base of related movement knowledge and less motor skill experience would be useful.

These possibilities seem relevant when re-examining some of the patterns of the results which, descriptively at least, suggest that overall the performances of the two groups did follow the anticipated direction. This was the case for total response time and non-overshoot movement time which both show a general tendency for the upper group's performance to be better than the lower group. These descriptive differences should be considered together with some of the differences suggested by the significant interactions. One important aspect of this pattern which is important to note, is that, while the results did not support the hypothesis that superior procedural knowledge would result in a faster rate of learning, descriptively there is some suggestion of an initial advantage for the upper group. Overall, the consistency of the pattern of results in the expected direction seems to suggest that the effect of the narrow experience base of the subjects, the contribution of other task components, and a small range of expertise may be important considerations. The fact remains, however, that important differences in performance, although small, were found.

This study then, adds some empirical support to the growing belief (Newell and Barclay, 1982, Wall, et al., 1985, Arend, 1980) that knowledge-base differences can be another contributing factor to individual differences in motor performance, and may not be limited to accounting for only extreme skill differences. At the very least, this study suggests that this area certainly merits further empirical investigation.

Summary and Conclusions

This study provides some support for the hypothesis that differences in knowledge base can contribute to differences in novel motor task learning and performance. When subjects were ranked on the basis of their general procedural knowledge in judging movement, those rated as possessing superior knowledge were able to minimize the cost of their errors made although the factor which was significant (OMT) was not a large enough component of the total response to produce a major difference in overall performance. This, together with the stated limitations of the study which limit generalizations of the findings at this early stage, emphasizes the importance of continued study.

Recommendations

The findings of the present study suggest some considerations for further investigation into the role of knowledge base differences in motor skills.

- 1: The investigation of the role of knowledge base differences across a more varied experience base is important.
2. Attempts to capture a more complete assessment of task relevant knowledge would contribute to a greater total understanding of the relative contribution of the various components.

3. Further work on improving the assessment of knowledge as related to movement, is important. The assessment of any knowledge is complex, yet if this line of research is to have any practical application, accurate assessment is vital.

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Appendix A

MOVEMENT ANALYSIS PROGRAM TASKS

SIMULTANEOUS MOVEMENT (TASK a)

Task Description	Light Speeds (LED's/sec)		Distance Travelled (cm)		Viewing Time (secs)	
	a	b	a	b	a	b
	a) dot a starts off behind dot b, both move off simultaneously and reach end point together	40	26.6	40	26.6	1
	50	33.3	40	26.6	0.8	0.8
	60	40	40	26.6	0.66	0.66
	70	46.6	40	26.6	0.57	0.57

General Idea:
catching up

b) dot a starts off behind dot b; both move off simultaneously, dot a does not catch dot b	40	40	30	30	0.75	0.75
	50	50	30	30	0.60	0.60
	60	60	30	30	0.50	0.50
	70	70	30	30	0.43	0.43

General Idea:
not catching up

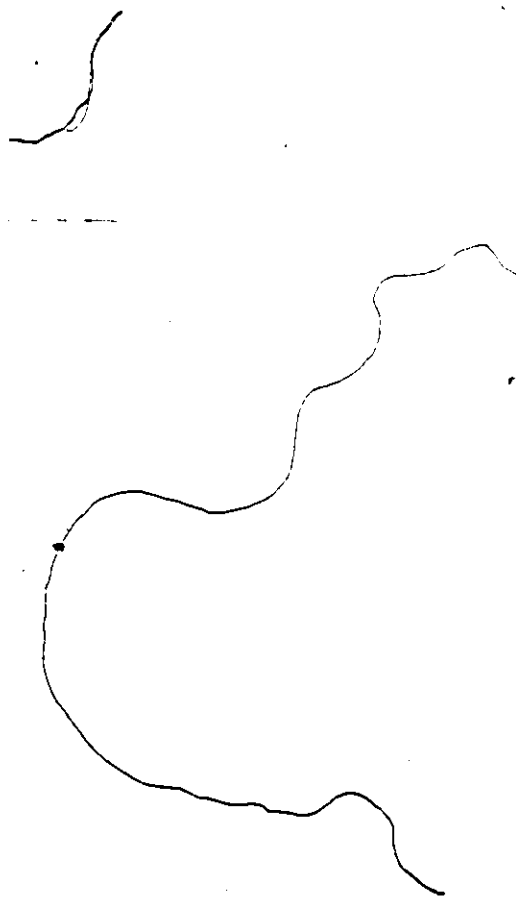
c) dot a starts off behind dot a; both move off simultaneously and dot a passes b	40	23.5	40	23.5	1	1
	50	29.4	40	23.5	0.8	0.8
	60	35.2	40	23.5	0.57	0.57
	70	41.1	40	23.5	0.57	0.57

General Idea:
overtaking

d) both a and b

start off at the						
same time, move	40	20	40	20	1	1
towards one another						
from opposite dir-	50	20	40	20	0.8	0.8
ections, cross over						
and stop at the	60	20	40	20	0.66	0.66
same time but one						
travelled farther	70	20	40	20	0.57	0.57

General Idea:
crossing-over



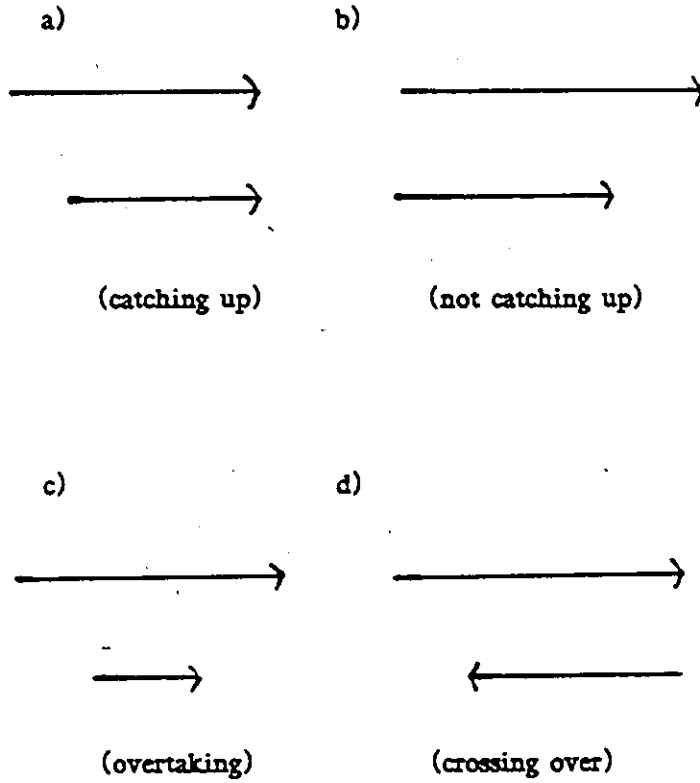
SEQUENTIAL MOVEMENT (TASK b)

Task Description	Light Speeds (LED's/sec)		Distance Travelled (cm)		Viewing Time (secs)	
	a	b	a	b	a	b
a) dot a moves down to baseline in rectilinear path, disappears, dot b moves down in the same time	40	40	40	40	1	1
	50	50	40	40	0.8	0.8
	60	60	40	40	0.66	0.66
	70	70	40	40	0.57	0.57
General Idea: equal time/ distance						
b) dot a moves down, disappears, dot b starts lower down but takes same time	40	26.6	40	26.6	1	1
	50	33.3	40	26.6	0.8	0.8
	60	40	40	26.6	0.66	0.66
	70	46.6	40	26.6	0.57	0.57
General idea: equal time/ unequal distance						
c) dot a travels down, disappears, dot b begins at same height but reaches baseline faster	40	60	40	40	1	0.66
	50	75	40	40	0.8	0.9
	60	90	40	40	0.66	0.75
	70	105	40	40	0.57	0.64
General Idea; equal distance/ unequal time						
d) dot a travels down, disappears, dot b starts lower than a and takes less time than a	40	23.3	40	26.6	1	1
	50	29.4	40	26.6	0.8	0.8
	60	35.2	40	26.6	0.66	0.75
	70	41.1	40	26.6	0.57	0.64

General Idea:

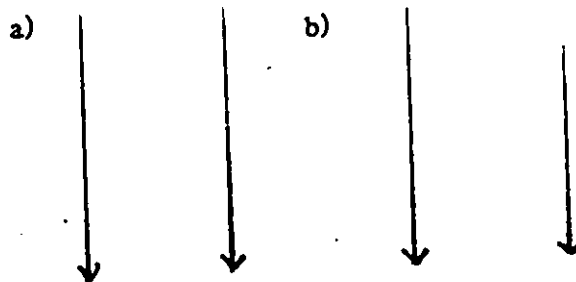
unequal time/
unequal distance

1) Simultaneous Movement



RANGE OF VIEWING TIME: .43 - 1 second

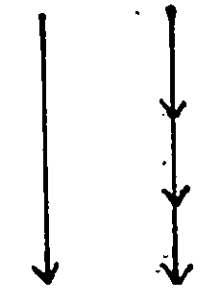
2) Sequential Movement



(equal time/distance)

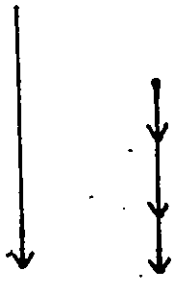
(equal time/unequal distance)

c)



(equal distance/
unequal time)

d)



(unequal time/
unequal distance)

Appendix B

TASK INSTRUCTIONS TO THE SUBJECTS

Movement Analysis Task

There are two parts to the task. For the first part, you will see two lights moving across the board. As soon as the lights have disappeared, I want you to tell me if you think they were travelling at the same speed. If you think they were, answer 'yes'; if you don't think they were the same speed, tell me which light was faster (a) or (b) where (a) is the top light and (b) is the bottom light. Hold the reaction time button and press it at the same time as you answer - try to answer as quickly as you can. One pair of lights is one trial and a 'beep' from the computer will signal the start of the next trial. There will be 8 practice trials and then 64 experimental trials. The second part of the task is basically the same as the first, except the lights will be moving vertically and will not be simultaneous. After the second light disappears, tell me which one was faster or if they were the same speed. Light (a) is the first light and (b) is the second light. Again there will be 8 practice trials and 64 experimental trials.

Tracometer

This machine measures your ability to respond to a stimulus by measuring the time you take to react to a light (reaction time) and the time you take to perform the task, i.e. to move towards the target light (movement time). This machine also measures errors (starting in the wrong direction) and overshoots (overshooting the target light). The

wheel and pointer go in opposite directions which means that when you want to move the pointer to the right, you turn the wheel to the left and vice versa. There is a cross on the pointer. To turn off the target light, you have to cover the light with the cross for an uninterrupted period of 200 milliseconds, otherwise the light will not turn off. The display shows five target lights that will appear one at a time. No other target will appear before you complete a successful alignment. The task is to move the pointer towards the target light and to align it for a period of 200 msec for the light to turn off and for the next one to appear. Try to accomplish the task as fast and as accurately as possible. One trials consists of 100 target movements and the experiment consists of 8 trials (800 target movements). There will be a short rest after each trial. Do not grasp the wheel too tightly and don's forget to blink. At the end of each trial the total time in seconds taken will be given and you are to try to reduce that time on subsequent trials.

Appendix C
SUBJECT QUESTIONNAIRE

NAME/NOM:

AGE:

SEX/SEXE:

BIRTHDATE/DATE DE NAISSANCE:

1. List all the physics courses you have taken including high school. Faites la liste de tous les cours de physique que vous avez suivies y compris ceux de l'école secondaire.
2. Have you taken the biomechanics course? Avez vous suivie un cours de biomechanique?
3. Do you drive a car? If so for how long? Est-ce que vous conduisez une voiture? Si oui, pendant combien d'années?
4. Do you play video games? Jouez-vous à des jeux de video?
 - a. never/jamais
 - b. seldom/rarement
 - c. sometimes/quelquefois
 - d. often/souvent
 - e. regularly/régulièrement
5. List the major sports you have played competitively, at what level and for how long. Indiquez tous les sports compétitifs auxquels vous avez participé, les niveaux ou vous avez joué, et pendant combien d'années.

6. List any special hobbies of any kind you have. Enumerez vos passe-temps preferes.