44877

NAME OF AUTHOR/*NOM DE L'AUTEUR* JOHN T. CORLETT

TITLE OF THESIS/*TITRE DE LA THÈSE* DEVELOPMENTAL ASPECTS OF MOTOR SHORT TERM MEMORY

UNIVERSITY/*UNIVERSITÉ* SIMON FRASER UNIVERSITY

DEGREE FOR WHICH THESIS WAS PRESENTED/ *GRADE POUR LEQUEL CETTE THÈSE FUT PRÉSENTÉE* Ph.D.

YEAR THIS DEGREE CONFERRED/*ANNÉE D'OBTENTION DE CE GRADE* 1980

NAME OF SUPERVISOR/*NOM DU DIRECTEUR DE THÈSE* JOHN DICKINSON

DATED/*DATÉ* JANUARY 21/80 SIGNED/*SIGNÉ*

PERMANENT ADDRESS/*RÉSIDENCE FIXÉ* [redacted]

NL-91 (3-74)

DEVELOPMENTAL ASPECTS OF

MOTOR SHORT TERM MEMORY

by

John Thomas Corlett

B.Sc.(Hons), Brock University, 1973

M.Sc.(Kinesiology), Simon Fraser University, 1977

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

In The Department

of

Kinesiology

SIMON FRASER UNIVERSITY

August, 1979.

Title of Thesis/Dissertation:

DEVELOPMENTAL ASPECTS OF

MOTOR SHORT TERM MEMORY

Author:

(signature)

JOHN T CORLETT

(name)

JANUARY 21 /80

(date)

Approval

NAME: John Thomas Corlett
DEGREE: Doctor of Philosophy
TITLE OF THESIS: Developmental Aspects Of Motor Short Term Memory

EXAMINING COMMITTEE:

Chairman: Dr. E.W. Banister

Dr. J. Dickinson
Senior Supervisor

Dr. W.D. Ross

Dr. G.L. Diewert

Dr. Vito Modigliani
Department Of Psychology
Simon Fraser University

Dr. Ian Williams
External Examiner
Department of Kinesiology
University of Waterloo

Date Approved: August 16th, 1979

Abstract

Ninety school children, 30 in each of three age groups, were tested using a slide bar for their ability to reproduce linear arm positioning movements in a short term memory paradigm. Three separate experiments were conducted using the same subjects in each experiment.

The first experiment tested the effects of movement length, retention interval length, and available movement cues on reproduction of a criterion movement. Subjects reproduced longer movements with greater absolute error than shorter ones in all age groups: the effect of movement length on absolute error was greater on the youngest children. A deterioration in criterion reproduction as measured by increasing absolute error also occurred as the length of the retention interval increased from 0 to 30 seconds. Again, the effect was greater for younger children than for older ones. Having distance and location information available produced slightly less absolute error than reproduction with location information alone for all age groups. As measured by constant error, all age groups displayed a tendency to undershoot criterion movements as both movement length and retention interval increased.

The second experiment tested the ability of children to exercise cognitive control over motor behaviour in three conditions of task relevant and task irrelevant information. Relative to control conditions in which no irrelevant information was present, subjects of all ages were affected by a multiple trials design in which no directed forgetting was possible. Younger subjects were more affected than older ones suggesting an increased capacity for cognitive control in older children. In a single trials design in which directed forgetting was possible, older subjects were capable of exerting a greater degree of cognitive control than younger ones. A decrement in performance relative to controls at all ages was evident, however, indicating that even the oldest subjects are highly susceptible to proactive interference.

The third experiment showed that all subjects are affected by the interpolated activities in a retroactive interference paradigm using absolute error as the dependent measure. No significant interaction between interference and age was shown indicating that older and younger subjects are equally affected. In addition, results concerning the effect of increased original learning on retroactive interference were obtained: however, subjects in high original learning groups produced greater interference effects than those in low original learning groups.

The results are discussed in relation to both the basic concepts of motor skills learning and performance developed with adults. In general, it is concluded that those concepts are parsimonious ones, holding true for the children tested in this study. Certain results are discussed in the context of possible proactive interference inherent in the experimental designs. Practical applications to the teaching of motor skills are also discussed.

Table Of Contents

Approval			Page ii
Abstract			Page iii
List Of Tables			Page viii
List Of Figures			Page ix
List Of Appendices			Page x
CHAPTER 1	Introduction		Page 1
CHAPTER 2	Experiment 2		
	2a.	Introduction	Page 25
	i.	Movement Length	Page 25
	ii.	Retention Interval	Page 27
	iii.	Movement Cues	Page 28
	iv.	Dependent Error Measures	Page 31
	2b.	Experimental Design and Methods	
	i.	Hypotheses	Page 33
	ii.	Subjects	Page 33
	iii.	Apparatus	Page 35
	iv.	Design and Analysis	Page 38
	v.	Procedure	Page 39
	2c.	Results	Page 43
	2d.	Discussion	
	i.	Movement Length	Page 55
	ii.	Retention Interval	Page 64
	iii.	Movement Cues	Page 71
	iv.	Interaction Effects	Page 77
CHAPTER 3	Experiment 2		
	3a.	Introduction	Page 85

3b. Experimental Design and Methods

i. Hypotheses — Page 88
ii. Subjects — Page 88
iii. Apparatus — Page 89
iv. Design and Analysis — Page 89
v. Procedure — Page 91

3c. Results — Page 92

3d. Discussion — Page 98

CHAPTER 4 — Experiment 3

4a. Introduction — Page 104

4b. Experimental Design and Methods

i. Hypotheses — Page 107
ii. Subjects — Page 108
iii. Apparatus — Page 108
iv. Design and Analysis — Page 108
v. Procedure — Page 109

4c. Results — Page 110

4d. Discussion

i. Retroactive Interference Effects — Page 117
ii. Original Learning Effects — Page 119

CHAPTER 5 — General Discussion — Page 121

Bibliography — Page 128

Appendix 1 — Page 137

LIST OF TABLES

Description of Table	Page
Table 1a: Descriptive statistics of absolute error (Expt 1)	46
Table 1b: Descriptive statistics of constant error (Expt 1)	47
Table 1c: Descriptive statistics of variable error (Expt 1)	48
Table 1d: Descriptive statistics of cell means for analysis of variance of absolute error (Expt 1)	49
Table 1e: Descriptive statistics of cell means for analysis of variance of constant error (Expt 1)	50
Table 1f: Descriptive statistics of cell means for analysis of variance of variable error (Expt 1)	51
Table 1g: Analysis of variance table for absolute error (Expt 1)	52
Table 1h: Analysis of variance table for constant error (Expt 1)	53
Table 1i: Analysis of variance table for variable error (Expt 1)	54
Table 2a: Descriptive statistics of absolute error (Expt 2)	94
Table 2b: Descriptive statistics of constant error (Expt 2)	95
Table 2c: Descriptive statistics of variable error (Expt 2)	96
Table 2d: Analysis of variance table (Expt 2)	97
Table 3a: Descriptive Statistics Of Retroactive Interference Experiment (Expt. 3)	113
Table 3b: Descriptive Statistics For Original Learning Experiment (Expt 3)	114
Table 3c: Analysis of Variance Table For Retroactive Interference Experiment (Expt. 3)	115
Table 3d: Analysis of Variance Table For Original Learning Experiment (Expt. 3)	116

LIST OF FIGURES

Figure #	Description of Figure	Page
1	Information Processing Model	8
2	Human Performance Model	22
3	Slide Bar	37
4a	Absolute Error vs. Movement Length	58
4b	Constant Error vs. Movement Length	59
4c	Variable Error vs. Movement Length	60
5a	Absolute Error vs. Retention Interval	66
5b	Constant Error vs. Retention Interval	67
5c	Variable Error vs. Retention Interval	68
6a	Absolute Error vs. Movement Cues	73
6b	Constant Error vs. Movement Cues	74
6c	Variable Error vs. Movement Cues	75
7a	Absolute Error vs. Movement Length (grouping by retention interval)	82
7b	Absolute Error vs. Movement Length (grouping by movement cues)	83
8a	Absolute Error vs. Proactive Interference Design	101
8b	Constant Error vs. Proactive Interference Design	102

LIST OF APPENDICES

Appendix #	Description	Page
1	A posteriori analysis of significant main effects in Experiments 1, 2, and 3	137

CHAPTER 1

Introduction

For centuries, scientists have been concerned with human structure and its relationship to function. For example, in the early 16th century, Galileo (1564-1642) and Borelli (1608-1679) were exploring the nature of size and human motion. Like the more general studies of human structure and function, the specific study of growing children also has a long history. Between 1759 and 1776, deMontbeillard studied the growth of his son and constructed what we now recognize as growth displacement and velocity curves. Since then, the study of growth, or auxology as it is contemporarily called, has progressed greatly. The increased interest in the workings of the human body inevitably led to the study of children since they are a subject population among whose most noticeable characteristics is the rapid change which occurs in size and the ability to perform physical tasks. Several excellent reviews on the general trends of physical growth have been published. Both Thompson (1942) and Tanner (1962, 1978) among others have elucidated the fundamental tenets of size, shape, proportion, and composition as they are affected by child growth. These reviews reflect the recognition of child development as an area of major concern in human biology.

While many of the characteristics of physical growth are obvious, the progress of psychological development is sometimes more subtle. It is no less dynamic, however. Just as a book cannot be judged by its cover, the potential of an individual for physical performance is defined by more than physical characteristics alone. This is particularly important when considering children whose learning as they grow represents a large contribution to their ability to perform motor skills.

The study of learning has occupied a prominent place in psychological research since the late 19th century and, before that, in the minds of philosophers since ancient times. Learning theories and the experimental attempts to validate or disprove them can trace their lineage to the early writings of Ebbinghaus (1885), Thorndike (1898), and Pavlov (1927). However, it was Watson (1920) who may be thought of as the first advocate of the first major learning theory, Connectionism. He, and those who followed his lead such as Guthrie (1959), Hull (1943), and Skinner (1953, 1957), did much to advance the concepts of how human conditioning and learning occurs, based on one of the major underlying premises that these phenomena occur as the result of the contiguity of stimulus and response. Indeed, the behaviourist approach still dictates today much of how we perceive learning to take place although our thinking on the subject has been modified.

Connectionism is not without its limitations, however. There are many examples of learning which are very difficult if not impossible to explain within a strict S-R framework, for example, latent learning. These limitations spawned the second great school of learning theory, Cognitivism. Led by Tolman (1932, 1949), traditional cognitive learning theory stressed the importance of the individual's ability to organize and process stimuli before a response is elicited, arguing that responses do not always simply follow stimuli reflexively.

Despite the concern of both Connectionism and Cognitivism with explaining behaviour, studies of learning largely neglected the details of how the motor patterns of which the observed behaviour was comprised were learned. This neglect was summarized best by Guthrie who described the rats in Tolman's maze as being "buried in thought", totally unable to move anywhere if required to learn only on Tolman's terms. It is only relatively recently that the ways in which we learn to perform motor skills have been investigated as thoroughly as the ways that verbal skills and problem solving have been studied. To this end, new conceptual frameworks for dealing with motor learning and performance have evolved (for example, the information processing approach, to be discussed later). These new points of view are admirably suited to research with children and could provide much needed insight into growth and physical performance. Unfortunately, research into the developmental aspects of motor skills has not taken advantage of the available techniques, opting for a more product-oriented, or result oriented view rather than investigating and ultimately understanding the processes subserving those results.

Growth, manifesting itself in the size, shape, and proportionality characteristics of the performer, is only one factor producing changes in performance. Many other considerations such as sense acuity, perception, and intelligence have been summarized by Singer (1975). Some of these parameters have been investigated as they change with age. For example, Hodgkins (1973) and Eckert and Eichorn (1977) have shown that simple reaction time decreases during child growth by about 50% between the ages of 6 and 19. Singer (1969) has reported differences in discrimination reaction time between third and sixth graders and demonstrated that performance on complex perceptual motor tasks such as stabilometer balance and rotor pursuit also improves between the third and sixth grades.

However, simple changes in performance say nothing about learning. The increments in motor performance which result from growth are, at least in part, due to the fact that the criteria of success of such tasks favour larger children. Maturation must not be confused with learning, a process of relatively permanent change in behaviour as the result of experience or practice. Although maturational effects confound our ability to interpret learning effects when gross motor tasks are used, many studies of this nature have been done. For example, learning of throwing skills at various ages has frequently been investigated (Dusenberry, 1958; Wild, 1938).

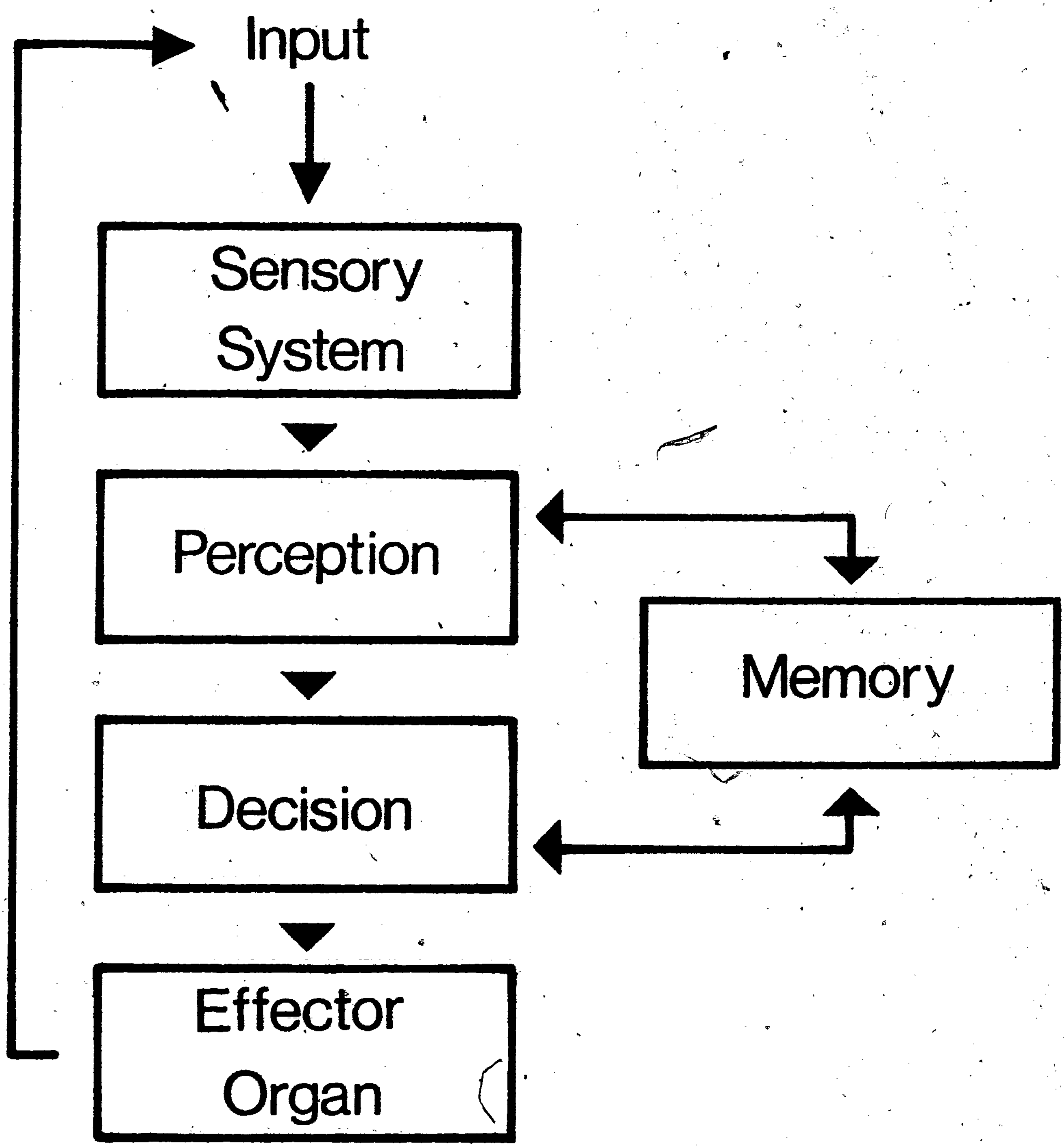
Motor skills research with adults has moved away from simply concerning itself with the products of many complex neuromuscular occurences. Running, jumping, and throwing are the culminations of processess within the performer, not monolithic events. Recognizing this, researchers such as Kay (1957) proposed that the performer be treated as an information processor and this approach to the study of motor performance has greatly influenced research since its inception.

The view of man as an information processor represents a considerable departure from more well-established Connectionist interpretations of behaviour. The study of learning, or perhaps more properly behaviour, has a longstanding tradition of stimulus-response contiguity approaches. Such issues as drive, motivation, and habit strength have been central to our understanding of the learning process since the early part of the 20th century (Hill, 1963). However, the Hullian and Skinnerian approaches in the estimation of some observers failed to ascribe sufficient cognitive abilities to humans. As Keele (1973) states, ".....learning often occurs without the contiguity between environmental stimulus and behavioural response". It is an information processing viewpoint which stresses the ability to store, retrieve, and manipulate information. As such, it provides an excellent vehicle with which to study attention, perception, memory, and decision making. To understand how this is accomplished, examine the model in Figure 1 which is a synthesis of several constructs in the literature (for example, Welford, 1968) and which will serve for illustrative purposes.

Each of the model's components represents an hypothetical stage of motor performance. The stimulus pattern impinges upon the sensory system and, as the result of the actions of each of the subsequent steps, the input is converted to output which, in the case of almost all performance, is muscular contraction. Although such a model can be made very simple or very complex (indeed, the cybernetic features can become extremely complicated), Figure 1 with its basic perceptual, memory, and decision stages is useful in discussing motor performance.

To fully appreciate child growth and development as it affects motor performance, it is necessary to understand what roles are played by both the physical and psychological factors. Although the role of physical characteristics has come under

FIGURE 1: AN INFORMATION PROCESSING MODEL


Input
Sensory System
Perception
Memory
Decision
Effector Organ

scrutiny in several growth studies both in Canada and abroad, at the present time there is little information available on the ability of children to learn and perform tasks in situations where the physical characteristics of the performer do not significantly affect the outcome. Such knowledge could be obtained using existing experimental techniques common to the information processing approach to motor skills. This study is devoted to identifying the changes which happen during child growth in the ability to learn and perform simple motor tasks in which the contribution of size is minimized.

Postman and Keppel (1968) in their examination of the literature in the field of verbal learning identified five principal areas into which the major research findings could be classified. These areas were acquisition, organization, retention, interference, and transfer. Unfortunately, as Adams (1971) stated: "...compared to the study of skills, the histories of verbal behaviour and conditioning over the same period is a scientific story to be envied". Adams is probably correct. It would be difficult to construct such a concise summary of the literature in the area of motor skills as Postman and Keppel have prepared in verbal learning. The history of motor skills research is characterized by diversity of experimental techniques and by varying degrees of emphasis on the importance of practical applications of the findings. In establishing a fundamental body of knowledge in a specific area of motor skills, it would be desirable to emulate the rigor and logic exemplified by the history of verbal learning. Since the developmental aspects of the motor system have not been extensively investigated from a behavioural point of view in a systematic fashion, the opportunity to set off on the right foot exists. Of the five research areas outlined in verbal learning by Postman and Keppel, all are applicable to motor learning. The concept of response organization in recall is not as readily transferable to motor skills research since free recall often does not have a practical place in the performance of motor tasks. A motor task usually requires a specific sequence of its "list" components to be meaningful. An attempt to test free recall of movements is not really a motor task at all but rather a largely "verbal" classification task. Nevertheless, there are some motor tasks with flexibility in sequencing (for example, dance steps) to which organization is an important factor.

The remaining four areas - retention, transfer, interference, and acquisition - are all readily adaptable to the realm of motor skills and there is a need to establish a data base in developmental terms in all five areas. A central issue to all of the areas in condideration is the concept of memory since all are directly or indirectly measured as a function of something remembered or forgotten either in the short or long term.

It is useful at the outset to state that, as an anatomical or physiological entity, memory has never been identified although much research in this area has been undertaken. As the knowledge of the molecular events responsible for the function of the human body increased, numerous theories were advanced in the attempt to explain the way in which memory "worked". Disruptive techniques such as electroconvulsive shock (ECS) provided evidence that there was an electrical component of memory (for example Chorover and Schiller, 1965). However, the retrograde effects of ECS are short-lived and research emphasis shifted toward identifying a "memory molecule" which could serve as a long term store, a system which better accounted for the common wisdom surrounding memory. This common wisdom regarding the stability of long term memory (a stability not considered present in the electrical properties of the nervous system) was given some credence by the demonstration that inter-animal transfer of memory was possible (although the evidence was not thoroughly convincing). In both Planaria (McConnell, 1962) and rats (Babich, Jacobson, Bubach, and Jacobson, 1965), some transfer of memory to a recipient animal was shown when homogenates of brain tissue from a trained donor animal were injected into the recipient. While the results of these studies were far from conclusive, they did stimulate interest in the possible nature of chemical memory storage. DNA (Gaito, 1966), RNA (Hyden and Eghazi, 1968), and protein (Flexner, Flexner, and Roberts, 1967) have all been suggested, somewhat reduntantly, as likely candidates, and, while the evidence for any of them is suspect (particularly in the case of DNA), some combination of them in terms of gene activation theory does provide some insight into the molecular basis of learning and memory.

Relatively more success has been achieved experimentally by treating memory as a behavioural construct. The understanding first of verbal learning and more recently of motor learning has been advanced largely by successfully using memory as an explanatory device by which different aspects of behaviour could be investigated. Since the concepts of memory and forgetting are inextricably linked, a main thrust of research has been concerned with uncovering the mechanisms which act on memory to cause forgetting. These premises developed in studies of verbal learning have served as the basis on which research into the same phenomena in motor learning have been based. It is now conventional to treat memory not as an homogeneous entity but as two separate components called short term memory and long term memory. Sperling (1960) presented a case for a third component a short term sensory store distinct from short term memory, but that distinction need not be made here since it is unclear that such a store exists for motor memory. There are several lines of reasoning which point to a behavioural difference between short term memory and long term memory. First, there is clinical evidence. Milner, Corkin, and Teuber (1968), Corkin (1968), and Wicklegren (1968) reported the case of a post-surgical patient who, for verbal material, had no memory longer than ten seconds, although his recall during the ten seconds after exposure to the material was normal, suggesting a separation of short term memory and long term memory. Interestingly, in those same studies, motor skills, unlike verbal ones, did show improvement from day to day indicating that differences exist between the storage of verbal and motor skills in long term memory.

In addition to the clinical evidence, other experimental work also demonstrates the separation of the two stages of memory. Peterson, Hillner, and Saltzman (1962) showed that recall of verbal material was better in the short term when learning was done under massed practice conditions. However, recall of similar material in the long term was better if learning had occurred under distributed practice conditions. The apparent difference in the way that memory representations are achieved in the short and long term supports a two stage model of memory. Numerous other studies have addressed themselves to an additional line of reasoning which supports the two stage theory (for example, Underwood, 1965; Kolers, 1966). They have shown that errors in recall following short term retention intervals are of an acoustic kind, that is, similar sounding words are confused with each other. However, following longer retention intervals, the errors in recall are of a semantic nature, with words of similar meaning being substituted for those originally learned. This implies that a difference in memory representation occurs between the short and long term, again supporting the delineation of the two stages.

Of the two hypothesized stages, short term memory is the more frequently investigated today, largely because of experimental convenience, but also because information stored in long term memory is highly resistant to such phenomena as forgetting. The properties of long term memory were often studied during the early years of memory research (see Stelmach, 1974), leaving short term recall as fertile research ground in recent years. In addition, the dynamic processes of memory occur during the short term when material is first being assimilated and the research effort has justifiably concentrated on these dynamic processes.

Although many of the basic concepts in verbal learning and memory have been adapted to the motor domain, the ensuing proliferation of data generated has been only infrequently collected using children as subjects. Generally, studies performed on children have stressed the visual system. For example, Hagen (1967) and Druker and Hagen (1969) examined the developmental trends in processing task-relevant and task-irrelevant information and concluded that young children do not disregard the uninformative information in a visual stimulus array as well as older children. In addition, they found that there is an age dependent improvement in the scanning of an array for relevant information. Sroufe (1971) and Krupski and Boyle (1978) suggested a reason for this, stating that young children maintain a less stable state of attention during short term memory tasks. Haith, Morrison, Shiengold, and Mindes (1970) and (Haith, 1971) have shown developmental changes in short term visual memory. Having been shown four geometric figures for 150 msec, 5 year olds could recall only two after a brief retention period whereas adults could regularly recall all four successfully. The authors suggested that older children and adults employ a rehearsable verbal code during such memory tasks while younger children employ a non-rehearsable visual code. Similarly, Conrad (1971) and Flavell, Freidricks, and Hoyt (1970) proposed that rehearsal strategies change with age.

Specifically, the ability to recode from the visual system to the auditory system improves during development. Such improvements can be induced in young children if the appropriate instructions are given (Keeney, Canizzc, and Flavell, 1967; Weist and Crawford, 1977).

Not only are the recoding abilities of children subject to aging trends, but so are the organizational strategies used within a given storage mode. Niemark, Slotnick, and Ulrich (1971) presented a categorizable set of pictures to children of different ages. They found a greater tendency to categorize with age although even sixth graders did not categorize as much as adults. Also, the recall cf pictures showed increasing degrees of subjective organization with age. Tulving (1962) has shown with adults the importance of response organization during short term recall of verbal material.

The point arises that the differences in the short term recall of visual material may not be strictly a memory phenomenon but perhaps a sensory one. However, Sheingold (1973), using a partial report method found no age differences in the intake of visual material. Differences occurred only when recall was delayed. Such findings indicated that receptor properties develop more rapidly than the processing capacity which makes use of sensory stimuli.

The concern with the processing of visual information is not unfounded. Vision plays an important role in the development of skills by children. Reiber (1968) had 5, 7, and 9 year olds perform a pinball propelling task and reported differences between age groups in the ability to perform the task only when visual input was not available. Smothergill (1973) showed no age differences in the ability to localize targets visually. However, if the target was presented, then removed, 9-10 year olds were better than 6-7 year olds in delayed recall of the target position. In addition, visual presentations were remembered by both groups better than proprioceptive presentations. The importance of visual information processing is not to be underestimated.

Recently, some researchers have concentrated, not on any particular sensory mode (though certainly one or more sensory modes are involved in any performance test), but rather on general aspects of short term memory experiments using children as subjects. For example, of interest in terms of sampling subjects, the correlational relationship between intelligence and short term memory has been examined by Cohen and Sandberg (1977). They presented evidence that intelligence is a good predictor of short term memory performance in recall for most recent items but not in recall for first or long term items. The data suggest that intelligence may be related, though not necessarily causally, to performance. However, it is not always possible to have intelligence data on children and it is best to use as large a sample as is manageable and match groups on other criteria (e.g. age) to minimize the potential differences in results caused by intelligence differences. However, given that short term memory requires certain central processing activities, it is likely that intelligence and short term memory are inextricably linked and that selection on the basis of intelligence would serve no useful purpose.

Many studies have investigated the relationship between verbal ability and short term memory performance. Fitzgerald (1977) demonstrated that performance on short term memory tasks by 4 and 5 year olds was at least partially dependent on verbal labelling abilities and Brown (1977) emphasized this importance by showing that highly similar pictures were confused by children even when distinct verbal labels were available. Presumably such confusion disappears as verbal abilities are refined during child development.

Spatial and temporal order information in short term memory of 3 and 6 year olds have been studied by Alton and Weil (1977) and Anooshian and Wilson (1977). Subjects improve as they age in their ability to organize temporally so as to take advantage of cues available in the sequential characteristics of the material to be learned. In addition, older subjects, unlike younger ones, could simultaneously encode temporal and temporal and spatial information. However, subjects of 5 and 6 years old could be confused in their recall of spatial location by the nature of the travel observed between two objects, perhaps due to the inability to reject task-irrelevant information.

Turning to a more process oriented view of short term memory, Emmerich and Ackerman (1978) tested first and fifth graders on a 30 item set of pictures presented either randomly, in blocked categcries, or in categories sorted by the subject. Recall was either free, cued, or constrained. The results showed that children's recall, unlike adults, was influenced by retrieval conditions and not by encoding. Interestingly, Longsleth and Zoltan (1978), in a test-retest of grades 1 and 2, showed that age effects were two times as great on original learning than on retention itself, implying that the original coding processes are perhaps more important than indicated by Emmerich and Ackerman.

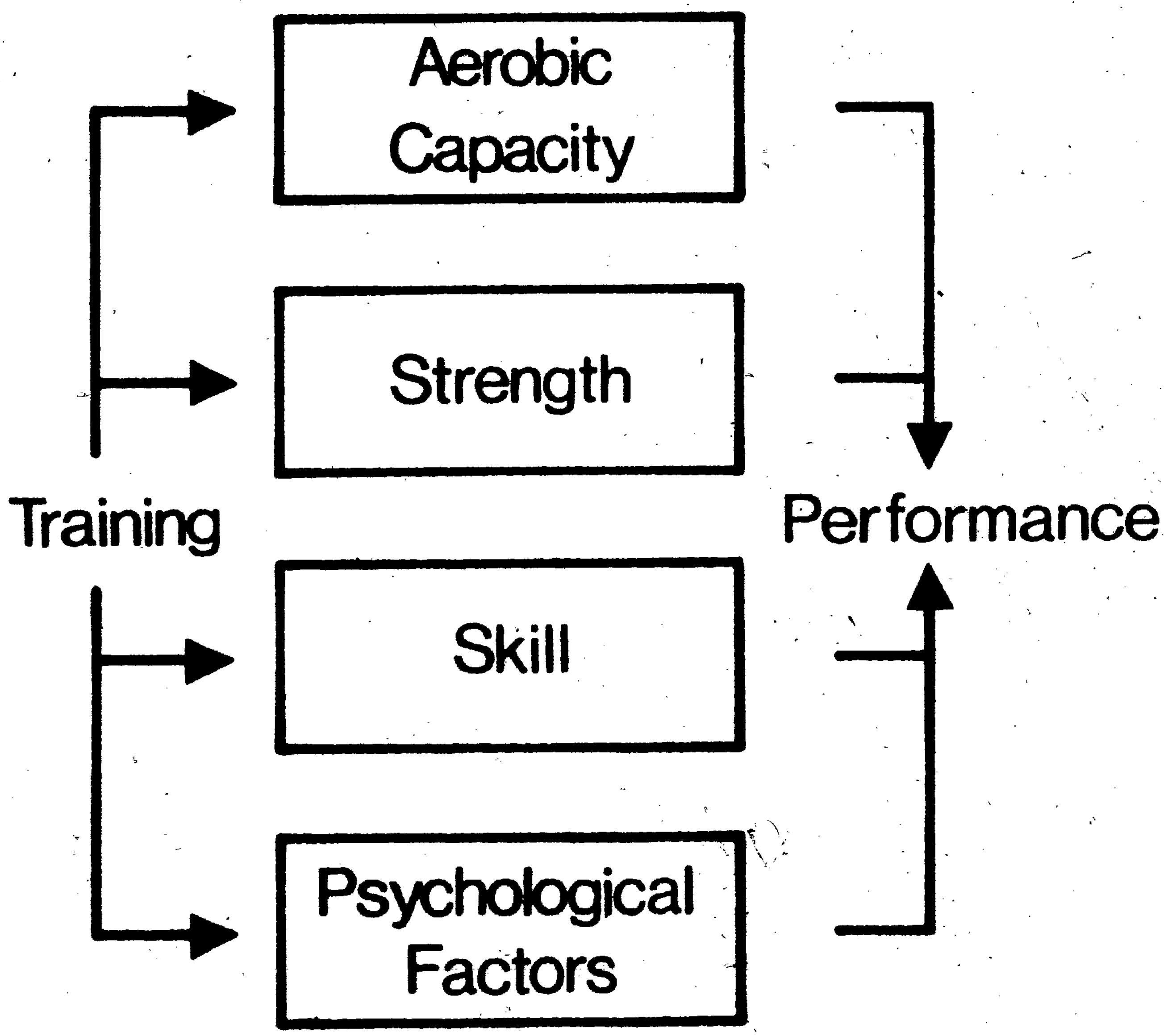
Regarding the various sensory modes in relaticn to each other, Fishbein, Decker, and Wilcox (1977) in a study of children in grades 1, 2, and 4 reported that older children were better at recognizing gecmetric forms than younger ones but that there was no difference between intramodal and cross-modal recall.

Clearly, children are capable of successfully using many different sensory modes during short term memory tasks though, for the most part, the literature has concentrated on the visual system.

In motor skills the proprioceptive mechanisms are of prime concern. As Rarick (1978) stated: "Very little research of consequence has been done ...... in the age range 5 to 15 years". Perhaps the largest deficiency in motor development is in the area of the properties of the motor system itself. It is in this direction that research focus is required.

It is useful when dealing with an event such as motor performance to construct a model which describes conceptually the relationships between the hypothesized components of the performance system. A modification and elaboration of a model from Corlett, Calvert, and Banister (1978) is shown in Figure 2. Previous studies using such models (e.g. Corlett, 1977) have concentrated on the mathematical relationships between physical training and performance of such predominantly aerobic tasks as running and cycling. In the current study, the relationships between the skilful characteristics of the performer and performance of a motor task are examined.

FIGURE 2: A MODEL OF HUMAN PERFORMANCE


Aerobic Capacity
Strength
Skill
Psychological Factors
Training
Performance

To isolate the skilful aspects of performance as completely as possible, it is necessary to eliminate or minimize the contribution of other factors, specifically the physical traits and level of "physical fitness" of the performer. Other considerations such as the psychological state of the performer (e.g. level of motivation) and stability of task characteristics between subjects must be taken into account as well. The experimental designs and apparatus detailed here are manifestations of the need to deal as much as possible with skill rather than other confounding factors such as speed, strength, and aerobic capacity. These designs are concerned with those aspects of motor development research deemed most important by Rarick. Specifically, they are designed to investigate the ways in which children use proprioceptive information.

The literature reveals a number of features concerning the information processing ability of children as they mature. Most of the research has studied the visual system: however, these findings combined with what is known of the motor system allow the formation of several hypotheses regarding the developmental aspects or motor short term memory. The major hypothesis around which all of the experiments in this study revolve is that as children grow older, their ability to process proprioceptive information increases. Working in the realm of short term memory, this gives rise to several specific hypotheses which form the basis of the experiments described later in the text. In addition, important hypotheses tested using adults as subjects have not been tested using children. Therefore, within each age group, several hypotheses arise independent of maturation effects. These will be described where appropriate in the following chapters.

CHAPTER 2

Experiment 1

A. Introduction

i. Movement Length

Laabs (1973) presented evidence that the central tendency effect described by Leuba (1909) was apparent in arm positioning tasks commonly used in motor skills research. The principle states that short movements tend to be overshot while long movements tend to be undershot. Laabs' subjects moved a lever over an arc of 120° with movement endpoints falling in one of three sectors (40-60°, 61-80°, and 81-120°). Movements were also grouped on the basis of their extent, short ones being 10, 15, and 20 cm, long ones being 25, 30, and 35 cm. On the basis of algebraic (signed) error comparisons, short movements were reproduced overly-long (that is, a positive algebraic error) while long movements were reproduced overly-short (a negative algebraic error), following a 12 second retention interval.

Several studies preceded that of Laabs and provided essentially the same information. Lloyd and Caldwell (1956) and Marteniuk, Shields, and Campbell (1972) gave supporting evidence of the central tendency effect on the basis of algebraic, or constant, error. Nevertheless, the latter study showed no differences in variable error and suggested accordingly that limb position receptors are qualitative and provide equally accurate location information independent of the extent of the movement. One study stands in contrast to those just mentioned. Stelmach and Wilson (1970) reported no significant effect on mean constant error for rotational arm positioning between 25° and 125°.

Stelmach, Kelso, and McCullagh (1976) had subjects perform an horizontal arm positioning task in which the movements terminated in one of four sectors of a 160° arc. Although the main effect of sectors was found to be significant for all dependent error measures used (algebraic error, mean squared error, and within-subject error), examination of means by both simple observation and post hoc statistical analysis provides an unclear picture as to the nature of the sector effect.

Methodological differences (for example, linear movements vs. rotational movements) and different emphases placed on reported dependent error measures makes it difficult to be certain what the effect of movement extent is on the accuracy of reproduction of criterion movements. With children, development of movement skills appears to proceed in a proximal-distal fashion, that is, movements close to the body centre line are learned before mcvments away from the centre line (Cratty, 1967). Extrapolating from this, one might speculate that longer movements placing the endpoint farther from the centre line would be more subject to error upon reproduction than shorter ones for which the endpoint is more proximal. There is little evidence for this in the literature, however. Only Stelmach (1970) has reported that rotational positioning errors are less nearest the vertical and increase as the movement endpoint moves off-centre.

ii. Retention Interval

In 1959, Peterson and Peterson (see also Brown, 1958) reported the results of what has become the fundamental short term memory experiment upon which much subsequent research has been based. They presented their subjects with a list of nonsense syllables, then tested their recall at various retention intervals following presentation. They found that, with increasing length of the retention interval (from 0 to 18 seconds) subjects were capable of recalling fewer of the list components. They argued that this constituted evidence in support of trace decay in the short term.

The Peterson and Peterson experimental paradigm was adapted to motor short term memory in 1966 by Adams and Dijkstra who stressed that more power would be added to empirical laws obtained from verbal learning experiments if they could be shown to hold for other responses classes. Their subjects moved a freely sliding element along a metal bar to a stop one, three, or five times, then waited for up to three minutes before attempting to recall the movement. The results which showed absolute error increasing as the retention interval lengthened, supported the trace hypothesis (Brown, 1958), that is, the original learning trial(s) leave a "memory trace" which decays with time as did the verbal material of Peterson and Peterson. In addition, Adams and Dijkstra illustrated a reduction in absolute error for a given retention interval when more "reinforcing trials" (an allusion to the S-R analogy seen by Adams) were given.

iii. Movement Cues

One important procedural consideration must be addressed to properly appreciate data collected during motor short term memory experiments using limb positioning tasks. Laabs (1973), although certainly not the first to do so (see Leuba, 1909), presented evidence suggesting that a number of different potential movement cues were available to subjects during linear arm positioning experiments. His data showed that distance and location cues were differentially affected by filled and unfilled retention intervals. Distance cue errors increased during increasing retention interval length (a trace decay) but were unaffected by interpolated activities. On the other hand, location cue errors were comparatively resistant to unfilled retention intervals but increased following retention intervals filled with interfering activities. Since Laabs' study, equivocal evidence has been presented which leaves the nature of distance and location cues anything but clear.

Consistent findings indicate that location (that is, movement endpoint) cues are capable of being rehearsed when the opportunity is available. Among the studies corroborating the findings of Laabs (1973) regarding the nature of location cues are Marteniuk (1973), Diewert (1975), and Stelmach, Wallace, and McCracken (1976). That there is a rehearsable code subserving location is consistent with what is known of proprioceptive mechanisms (for example, see Kelso and Stelmach, 1976). Unfortunately, the findings for distance cues are highly ambiguous and leave the Laabs' delineation of distance and location in some doubt. For example, while Posner (1967) and Moxley (1974) found no ability of subjects to rehearse and retain distance information in short term memory, Marteniuk (1973) and Diewert (1975) found the opposite to be the case.

Diewert and Roy (1978) investigated the nature of coding strategy for memory of distance information by differentiating between two possible means by which subjects could rehearse distance. The first was the use of location to code for distance whenever possible. The second was the use of a counting strategy whereby distance is calculated from velocity and time. Their results show that, when possible, subjects used location to code for distance rather than a counting strategy although the former demanded processing capacity while the other did not. Nevertheless, counting did provide a means by which distance could be accurately retained. Therefore, even in the face of unreliable location information, distance was a rehearsable movement cue.

Location information seems to be an important component of distance information, a view in line with known nervous system physiology which has identified no receptors for distance per se (Kelso and Stelmach, 1976). This does not mean that distance information is not available: it may well be derived from other sources (for example velocity and time) and it has been proposed that the major difference between distance and location information is the level at which they are processed. Although the theoretical relationship between distance and location is not fully understood, it is important to bear in mind that any data collected using a slide bar will be affected by the kinds of cues available to the subjects.

iv. Dependent Error Measures

In addition to the interpretation difficulties in arm positioning experiments caused by movement length and movement cues, further complications common to all studies of motor behaviour are present in the form of the uncertainty surrounding the validity and meaning of dependent error measures. Stelmach (1974) has stated that the "indiscriminate use of these variables probably accounts for some of the confusion in the short term motor memory literature".

Although all three of absolute, or unsigned, error, constant, or signed, error, and variable, or mean squared, error, have been regularly reported, their relative merits are in dispute. Shutz and Roy (1972) took the extreme stand that absolute error was nothing more than a combination of constant and variable errors and, as such, provide no useful information worth reporting. This is in contradiction to writers who have used absolute error as the basis upon which to build theoretical concepts (for example, Schmidt, 1975). Laabs (1971) has made the same point, stating that when variability is small, the following relationship holds true:

$$\text{Average AE} = \sqrt{CE^2 + VE^2}$$

To bolster the inadequacies of the individual measures, several composite measures have been proposed. For example, Henry (1974) suggested the use of a single error measure similar to that previously mentioned. This error term is of the form:

$$E^2 = CE^2 + VE^2$$

In addition, Roy (1976) suggested that all error measures (E, absolute error, constant error, and variable error) be analyzed in a multivariate analysis of variance.

The final word on this fundamental problem has not been written. At the present time, since no literature in motor short term memory of children is available, it seems advisable to report all of absolute, constant, and variable errors, bearing in mind their inherent deficiencies. In this way, data collected using children as subjects will, in the initial stages, be available for comparison with previously-reported adult data which is expressed in terms of all three dependent measures.

B. Experimental Design And Methods

i. Hypotheses

1. All error measures increase as the length of the retention interval increases. Such a finding would be taken as support for the position that there is a trace decay of memory acquired during learning.

2. All error measures increase as the length of the criterion movement increases. Such a finding would be taken as support for a proximal-distal theory of motor development.

3. All error measures are less under reproduction conditions in which both distance and location are available than when location alone is available. Such a finding would be taken as support for the utility of distance as a movement cue during linear arm positioning tasks by children.

ii. Subjects

Subjects participating in all experiments were students of the same public school in the Burnaby, B.C. school board. Permission to test these students was obtained from school board officials following their scrutiny of the research proposal for the study. Prior approval was obtained from the Department of Kinesiology Graduate Studies Committee.

Thirty children in each of three age groups were tested. The mean ages of the three groups were 5.8 years, 8.9 years, and 12.5 years. Fifteen each of boys and girls at each age were tested. Six children were left handed: for these subjects, test protocols were maintained as for right handed ones except that movements were performed with the left hand in the opposite direction to those made by right handed subjects. Three left handers were kindergartens, two were grade 3's, and one was a grade 6.

These age divisions corresponded to grades Kindergarten, 3, and a combined class of grades 6 and 7. The design of the study was cross-sectional in nature, meaning that children were tested only once with the means for each of the age groups serving as a prototype for children of that age. A longitudinal or mixed longitudinal design was not feasible for this study due to the time constraints imposed by such studies.

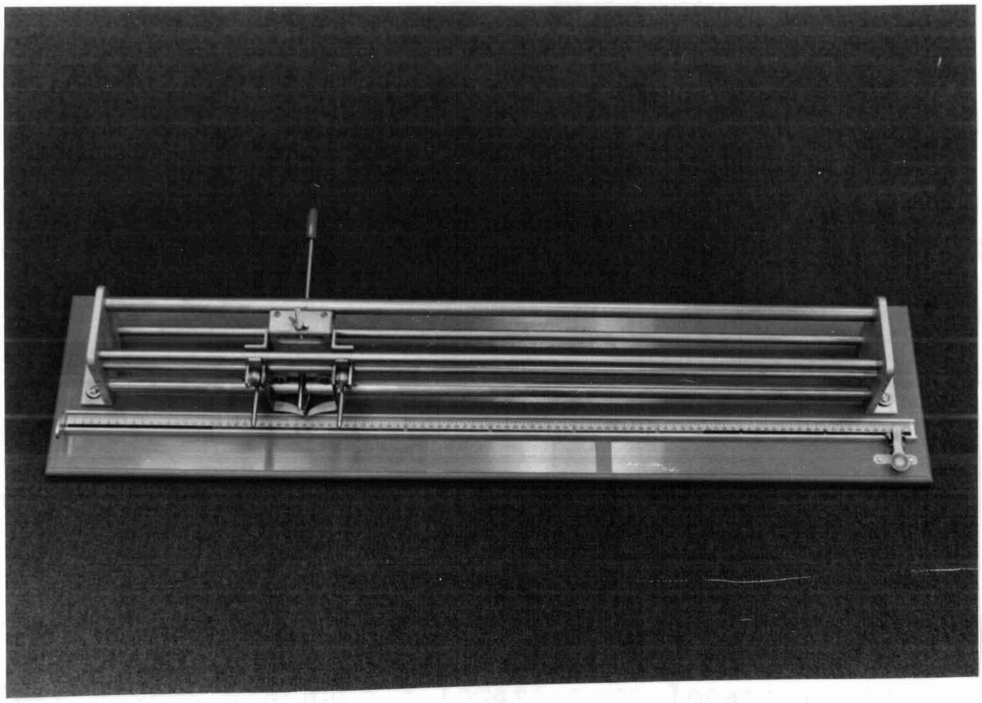
No attempt to categorize subjects on the basis of physical or psychological maturity was deemed plausible although such techniques are available. For example, physiological age can be determined via skeletal age and psychological age can be determined in numerous ways such as the M-space concepts presented in the neo-Piagetian framework by Gerson and Thomas

(1977). For this study, it was assumed that chronological age is a good predictor of physical or psychological age for the population and it is less controversial to defend the use of it, accepting its inherent variance characteristics, than to defend the methods by which other maturity indices are estimated for each member of the sample.

iii. Apparatus

The apparatus used for all experimentation in this study was a slide bar, depicted in Figure 3. It was situated on a table in a quiet room in the subjects' school. Subjects sat in front of the slide bar and opposite the experimenter. Subjects performed linear arm positioning tasks by moving a low friction slide along a tubular steel bar. The experimenter constrained the length of the movement during learning trials by fixing a moveable stop at a predetermined point along the track. The experimenter moved the stop out of the way during reproduction trials requiring the subject to move without constraint. If both the starting position and the end point of the learning trial were used for the reproduction trial, the subject had both distance and location information available. For some movements, distance was rendered an unreliable cue by changing the starting position from that of the learning trial and requiring the subject to move to the same end point during the reproduction trial. Therefore, subjects

FIGURE 3: SLIDE BAR APPARATUS



were asked to reproduce previously learned movements with both distance and location cues available, or location cues alone, available. Subjects performed the tasks with eyes tightly shut to eliminate visual input and subjects were allowed to visually acquaint themselves with the apparatus before experimentation began.

iv. Design and Analysis

Experiment #1 provides data for the performance of a linear arm positioning task for children in each of the age groups. Each subject performed 18 criterion movements whose order was randomly assigned. The 18 movements were comprised of combinations of the following conditions:

3 retention intervals of 0, 15, and 30 seconds, 2 recall conditions, either distance + location or location alone, and 3 movement lengths of 10, 20, or 40 cm. (Performing all possible conditions results in 3 x 2 x 3 = 18 movements).

Four attempts at each endpoint were tested. Raw data was collected on previously prepared data sheets. Raw data scores were converted to scores for absolute error, constant error, and variable error in the computational section of the computer statistical package used. The generated error scores were subjected to descriptive statistical analysis and analysis of variance using programme BMDP2V of the Biomedical Computer Programs P-Series (Dixon and Brown, 1977). The design tested by the statistical analysis was a 3(ages) x 3(movement lengths) x 3(retention intervals) x 2(movement cues) factorial design with repeated measures on all but the first factor. Trials effects were not of interest in this study and were not analyzed. In addition, initial analyses for each age group were performed to ascertain whether sex differences at any age between boys and girls existed. When no statistically significant differences at any age between boys and girls were found, sex was no longer considered in subsequent analyses.

v. Procedure

An introductory talk was given to each group as a whole, after which each subject was removed from class to be tested individually in the room provided by school authorities. Subjects were allowed to acquaint themselves with the surroundings after being seated at the table and were asked for their date of birth at this time. The following set of familiarizing instructions were given:

"This is the apparatus we will be using to do our experiments. It is called a slide bar and it works like this. This part, the slide (demonstrate) moves along this metal rod. Why don't you try it with your right (left) hand? Move at your own speed and in one continuous movement (TRIAL).

You are going to be making all your movements with your eyes closed. Try another one with your eyes tightly shut this time. Be sure you can't see (TRIAL).

It is very important that you keep your eyes shut during all the movements: when I tell you to 'close your eyes', shut them and keep them shut until I tell you to open them again. Do you have any questions so far? (If so, repeat the instructions).

Some of the movements will be made from the starting position I give you to a stop that I will move to a place along the metal rod (demonstrate). Let's try a movement to the stop. Sit with your hands on the desk in front of you. Close your eyes. I will place your hand on the moveable slide and when I say 'move to the stop', move the slide to the stop. Then place your hand back on the desk. (TRIAL, 18cm).

Open your eyes. After you have learned a movement by moving to the stop, I will ask you to repeat it after a waiting period. Sometimes I will start you in the same place and ask you to make the same movement again but without the stop in place to help you. Other times, I will start you in a different place and ask you to move to the place where the stop was. Let's try one of each kind. (TRIALS, 22 cm for distance plus location; 12, then 24 cm for location alone).

Do you understand everything so far or would you like to go over the instructions again?" (repeat if necessary).

When the experimenter was satisfied that the subject fully comprehended what was required, the experiment proceeded as outlined in the following instructions specific to Experiment 1.

"We are going to do a series of movements. I will tell you how to perform each movement before we begin each one. Begin and end each movement with your hands placed on the desk in front of you. Each time we do a movement, I will give you these instructions:

First, I will say 'close your eyes'. Then, I will place your hand on the slide. When I say "move to the stop", move the slide to the stop. After you have made the movement, place your hand back on the table and remember to keep your eyes shut. When I replace your hand on the slide, I will say either 'make the same movement' which means that you will start in the same place and move the same distance to the place where the stop was, or, I will say 'move to where the stop was' which means that you will be starting in a different place but will move to where the stop was. Then, follow the instruction, whichever one it is. Then place your hand back on the table. You will have four tries at recalling each movement and I will give you instructions on how to make the movement each time. After the fourth try, I will say 'open your eyes' and you can open them then. Do you have any questions?" (If so, repeat the instructions).

Four pupils were subjectively deemed not to have fully complied with the instructions: data for these subjects was discarded although they were tested to avoid any problems with their peers.

Upon completion of the testing, subjects were informally quizzed concerning any rehearsal strategies which they might have developed. Subjects were asked: "How did you try to remember the movements while you were waiting to repeat them?". The few subjects who were unable to respond were further prompted with the question: "Did you remember how far you moved or where you moved to?". Responses were recorded on the subject's data sheets.

C. Results

Basic descriptive statistics for each of the factors tested at each age group are given in Tables 1a (absolute error), 1b (constant error), and 1c (variable error). Cell means and standard deviations from the analysis of variance provided in Tables 1d (absolute error), 1e (constant error), and 1f (variable error).

The main effects of age, movement length, retention interval length, and available movement cues were all statistically significant for all three dependent error measures (Table 1g). In addition, the following interaction effects were statistically significant (Table 1h):

*1. movement length by age for all dependent error measures with error increasing as movement length increased

2. retention interval length by age for all dependent error measures with error increasing as retention interval length increased

3. movement length by retention interval length for all dependent error measures

4. movement length by retention interval length by age for all dependent error measures

5. movement length by retention interval length by available movement cues for all dependent error measures

6. retention interval length by available movement cues for absolute error and constant error

7. movement length by available movement cues for constant error and variable error

8. retention interval length by available movement cues by age for absolute error and constant error

9. movement length by retention interval length by available movement cues by age for all dependent error measures

A posteriori analysis of significant main effects on absolute error was conducted using the method of Scheffe as described by Ferguson (1976). Results of these analyses are shown in Appendix 1.

TABLES 1A,B,C,D,E,F,G,H,I.

DESCRIPTIVE STATISTICS AND ANALYSIS OF VARIANCE DATA FOR EXPERIMENT 1

Table 1a: Descriptive statistics of absolute error (Expt 1)

	GRADE 6		GRADE 3		KINDER	
MOVEMENT LENGTH	X	SD	X	SD	X	SD
10 CM	3.49	1.26	4.06	1.21	4.85	1.19
20 CM	3.48	1.24	4.31	1.31	5.05	1.30
40 CM	3.83	1.36	4.66	1.29	5.52	1.28
RETENTION INTERVAL						
0 SEC	3.04	1.26	3.85	1.27	4.20	1.19
15 SEC	3.39	1.30	4.15	1.26	5.11	1.25
30 SEC	4.15	1.49	5.03	1.38	6.13	1.36
MOVEMENT CUES						
D + L	3.61	1.34	4.24	1.30	5.02	1.31
L ALONE	3.68	1.43	4.44	1.31	5.28	1.36

Table 1b: Descriptive statistics of constant error (Expt 1)

MOVEMENT LENGTH	GRADE 6 X	GRADE 6 SD	GRADE 3 X	GRADE 3 SD	KINDER X	KINDER SD
10 CM	-0.02	0.36	-0.20	0.28	0.48	0.29
20 CM	-0.86	0.41	-0.59	0.36	-0.08	0.39
40 CM	-1.59	0.90	-1.41	0.86	-1.00	0.91
RETENTION INTERVAL						
0 SEC	0.19	0.61	0.41	0.55	0.76	0.62
15 SEC	-0.35	0.77	-0.15	0.78	0.42	0.61
30 SEC	-2.28	1.19	-2.16	1.06	-1.45	1.05
MOVEMENT CUES						
D + L	-0.25	0.32	-0.10	0.66	0.44	0.41
L ALONE	-1.37	1.00	-1.18	0.66	-0.62	0.91

Table 1c: Descriptive statistics of variable error (Expt 1)

MOVEMENT LENGTH	GRADE 6 X	GRADE 6 SD	GRADE 3 X	GRADE 3 SD	KINDER X	KINDER SD
10 CM	1.93	0.38	1.93	0.29	2.43	0.18
20 CM	1.86	0.41	2.08	0.27	2.42	0.26
40 CM	1.99	0.89	2.17	0.30	2.57	0.25
RETENTION INTERVAL						
0 SEC	1.74	0.41	1.97	0.38	2.19	0.40
15 SEC	1.86	0.61	2.07	0.41	2.46	0.26
30 SEC	2.17	0.76	2.28	0.70	2.77	0.21
MOVEMENT CUES						
D + L	1.92	0.61	2.09	0.41	2.44	0.20
L ALONE	1.94	0.81	2.13	0.66	2.50	0.41

Table 1d: Descriptive statistics of cell means for analysis of variance of absolute error (Expt 1)

CELL	GRADE 6		GRADE 3		KINDER	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
L1T1C1	2.88	1.16	3.57	1.21	3.54	0.85
L2T1C1	2.75	1.14	3.84	0.91	3.49	0.86
L3T1C1	3.13	1.32	3.78	1.21	4.50	1.09
L1T1C2	3.20	1.34	3.67	1.08	4.40	1.09
L2T1C2	3.00	1.34	4.04	1.15	4.46	1.14
L3T1C2	3.27	1.38	4.23	1.03	4.75	1.22
L1T2C1	3.57	1.66	4.09	1.07	4.95	1.23
L2T2C1	3.37	1.69	4.06	1.17	4.93	1.29
L3T2C1	3.22	1.53	4.32	1.08	5.38	1.29
L1T2C2	3.23	1.46	3.81	1.35	4.90	1.28
L2T2C2	3.03	1.35	3.84	1.28	5.09	1.43
L3T2C2	3.89	1.47	4.77	1.32	5.37	1.25
L1T3C1	4.09	1.53	4.56	1.27	5.76	1.19
L2T3C1	4.37	1.35	4.81	1.21	6.28	1.44
L3T3C1	5.09	1.70	5.14	1.17	6.37	1.21
L1T3C2	3.97	1.65	4.68	1.33	5.51	1.16
L2T3C2	4.36	1.42	5.25	1.33	6.11	1.30
L3T3C2	5.18	1.60	5.71	1.54	6.72	1.48

Note: L1=10 cm, L2=20 cm, L3=40 cm
T1=0sec, T2=15 sec, T3=30 sec
C1= D + L, C2= L ALONE

Table 1e: Descriptive statistics of cell means for analysis of variance of constant error (Expt 1)

CELL	GRADE 6		GRADE 3		KINDER	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
L1T1C1	-0.08	0.32	0.11	0.30	0.32	0.49
L2T1C1	0.24	0.31	0.53	0.22	0.64	0.47
L3T1C1	1.09	0.38	1.27	0.32	1.75	0.72
L1T1C2	-0.03	0.355	0.07	0.27	0.53	0.74
L2T1C2	-0.88	0.39	-0.56	0.27	-0.16	0.76
L3T1C2	0.82	0.37	1.09	0.25	1.52	0.83
L1T2C1	-0.07	0.41	0.07	0.25	0.65	0.91
L2T2C1	-0.38	0.44	-0.18	0.27	0.35	0.91
L3T2C1	-1.79	0.39	-1.47	0.25	-0.87	1.02
L1T2C2	0.69	0.36	0.83	0.32	1.35	0.77
L2T2C2	0.36	0.35	0.57	0.33	1.12	0.85
L3T2C2	-0.89	0.33	-0.69	0.28	-0.10	1.10
L1T3C1	0.39	0.33	0.50	0.29	1.13	0.92
L2T3C1	0.64	0.34	0.74	0.26	1.50	1.50
L3T3C1	-2.30	0.39	-2.30	0.30	-1.46	0.94
L1T3C2	-0.91	0.31	-0.76	0.29	-0.16	1.23
L2T3C2	-4.80	0.30	-4.61	0.29	-3.92	1.24
L3T3C2	-6.68	0.37	-6.59	0.33	-6.36	1.37

Note: L1=10 cm, L2=20 cm, L3=40 cm
T1=0sec, T2=15 sec, T3=30 sec
C1= D + L, C2= L ALONE

Table 1f: Descriptive statistics of cell means for analysis of variance of variable error (Expt 1)

CELL	GRADE 6		GRADE 3		KINDER	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
L1T1C1	1.72	0.32	1.91	0.30	2.02	0.38
L2T1C1	1.74	0.31	2.03	0.22	2.06	0.39
L3T1C1	1.69	0.36	1.87	0.31	2.22	0.55
L1T1C2	1.87	0.35	1.96	0.27	2.28	0.50
L2T1C2	1.62	0.39	1.94	0.27	2.19	0.55
L3T1C2	1.82	0.37	2.09	0.25	2.37	0.60
L1T2C1	1.93	0.41	2.07	0.25	2.47	0.64
L2T2C1	1.81	0.44	2.02	0.28	2.38	0.62
L3T2C1	1.80	0.39	2.13	0.25	2.52	0.70
L1T2C2	1.89	0.36	2.03	0.32	2.42	0.58
L2T2C2	1.76	0.35	1.97	0.33	2.39	0.65
L3T2C2	2.01	0.35	2.21	0.28	2.56	0.68
L1T3C1	2.09	0.33	2.20	0.29	2.69	0.72
L2T3C1	2.14	0.28	2.24	0.25	2.78	0.86
L3T3C1	2.30	0.34	2.30	0.27	2.82	0.90
L1T3C2	2.08	0.39	2.23	0.30	2.66	0.68
L2T3C2	2.10	0.31	2.29	0.29	2.74	0.85
L3T3C2	2.31	0.37	2.40	0.33	2.92	0.95

Note: L1=10 cm, L2=20 cm, L3=40 cm
T1=0sec, T2=15 sec, T3=30 sec
C1= D + L, C2= L ALONE

Table 1g: Analysis of variance table for absolute error (Expt 1)

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	p
MEAN	31027.6	1	31027.6	1238.95	<0.01
A	604.9	2	302.4	12.08	<0.01
ERROR	2178.8	87	25.0		
L	651.1	2	325.6	373.79	<0.01
L X A	33.9	4	8.5	9.72	<0.01
ERROR	151.6	174	0.87		
T	55.95	2	28.0	63.41	<0.01
T x A	7.7	4	1.9	4.38	<0.01
ERROR	76.7	174	0.4		
L x T	16.0	4	4.0	13.80	<0.01
L xT x A	17.6	8	2.2	7.56	<0.01
ERROR	101.1	348	0.3		
C	2.2	1	2.2	5.19	0.03
C x A	0.6	2	0.3	0.71	0.49
ERROR	37.5	87	0.4		
L x C	0.1	2	0.1	0.23	0.79
L x C x A	1.8	4	0.4	1.67	0.16
ERROR	46.8	174	0.3		
T x C	57.5	2	28.7	203.39	<0.01
T x C x A	2.2	4	0.6	3.94	<0.01
ERROR	24.6	174	0.1		
L x T x C	23.3	4	5.8	32.70	<0.01
LxTxCxA	8.8	8	1.1	6.16	<0.01
ERROR	62.0	348	0.2		

Note: A=age, L=movement length, T=retention interval, C=cues

Table 1h: Analysis of variance table for constant error (Expt 1)

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	p
MEAN	428.7	1	428.7	73.39	<0.01
A	155.0	2	73.4	13.09	<0.01
ERROR	521.1	87	6.0		
L	1800.6	2	900.3	3900.6	<0.01
L X A	6.8	4	1.7	7.38	<0.01
ERROR	40.6	174	0.04		
T	1228.3	2	614.2	10672.0	<0.01
T x A	1.3	4	0.3	5.52	<0.01
ERROR	10.2	174	0.1		
L x T	2444.6	4	611.2	15698.7	<0.01
L xT x A	1.3	8	0.2	4.21	<0.01
ERROR	13.7	348	0.04		
C	10.2	1	10.2	374.24	<0.01
C x A	0.1	2	0.05	1.47	0.24
ERROR	2.40	87	0.03		
L x C	11.5	2	5.8	254.0	<0.01
L x C x A	0.1	4	0.03	0.78	0.54
ERROR	3.9	174	0.02		
T x C	125.2	2	62.6	1243.93	<0.01
T x C x A	0.6	4	0.2	3.91	0.02
ERROR	8.9	174	0.1		
L x T x C	639.9	4	159.2	4727.86	<0.01
LxTxCxA	0.6	8	0.1	2.35	0.02
ERROR	11.9	348	0.03		

Note: A=age, L=movement length, T=retention interval, C=cues

Table 1i: Analysis of variance table for variable error (Expt 1)

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	p
MEAN	7622.2	1	7622.2	2380.56	<0.01
A	83.6	2	41.8	12.54	<0.01
ERROR	290.0	87	3.3		
L	53.1	2	26.5	172.11	<0.01
L X A	3.5	4	0.9	5.64	<0.01
ERROR	26.8	174	0.2		
T	1.7	2	0.8	23.84	<0.01
T x A	0.6	4	0.1	4.30	<0.01
ERROR	6.1	174	0.03		
L x T	0.3	4	0.1	3.04	0.02
L xT x A	1.2	8	0.1	5.85	<0.01
ERROR	8.6	348	0.01		
C	1.4	1	1.4	49.24	<0.01
C x A	0.1	2	0.04	1.52	0.22
ERROR	2.4	87	0.02		
L x C	0.7	2	0.3	18.17	<0.01
L x C x A	0.1	4	0.03	1.67	0.16
ERROR	3.1	174	0.02		
T x C	3.5	2	1.7	79.48	<0.01
T x C x A	0.2	4	0.02	2.37	0.054
ERROR	3.8	174	0.02		
L x T x C	0.5	4	0.4	26.17	<0.01
LxTxCxA	0.5	8	0.06	3.94	<0.01
ERROR	5.2	348	0.02		

Note: A=age, L=movement length, T=retention interval, C=cues

D. Discussion

i. Movement Length

Collapsed over all conditions of age, retention interval, and available movement cues, there is a statistically significant difference due to movement length for all three dependent error measures. These results are portrayed graphically in figures 4a (absolute error), 4b (constant error), and 4c (variable error), in which the mean dependent measures for all ages together are plotted against movement length. In addition, the dependent error measures for each individual age group are simultaneously plotted.

A posteriori analysis reveals that the effect of movement length is not uniform over the three age groups. No significant differences between 10 and 20 cm movements were seen at any age. However, while grade 6 subjects showed no length effect at all, grade 3 subjects produced greater errors at 40 cm than at 10 cm and kindergarten subjects showed differences between 40 cm movements and both 10 and 20 cm ones.

If absolute error is taken as an indication of the accuracy of the criterion movement reproduction independent of the direction of the error, the results indicate that children of all ages tested reproduced shorter movements more accurately than longer ones in terms of absolute values. This result can be interpreted in one of two ways. First, from a developmental point of view, the results agree with a proximal-distal theory of movement control acquisition by children (Cratty, 1967). If children learn to perform skills proximal to the midline of the body more easily than those which are more distal, it would be expected that shorter movements which begin and end close to the midline would be reproduced more accurately than longer ones which take at least the movement endpoint farther away from the midline. The absolute error results show this to be so. Second, from an information processing point of view, it could be argued that a longer movement contains more information than a shorter one, in an analogy to Fitts Law (Fitts, 1954), and is more susceptible to "noise" (that is, error) during reproduction.

This approach is more useful in explaining the age difference which is apparent upon observation of the errors for each movement length for each age group. If, as the literature illustrates is so for visual and verbal tasks, the ability to process proprioceptive information increases with age, absolute error at each movement length should decrease as age increases. This occurs since the information content of a given movement length decreases as a fraction of the total capacity of the subject as children grow older. Again, the absolute error data show this to be the case.

FIGURE 4: THE EFFECT OF MOVEMENT LENGTH ON ERROR MEASURES

4A: ABSOLUTE ERROR VS. MOVEMENT LENGTH
4B: CONSTANT ERROR VS. MOVEMENT LENGTH
4C: VARIABLE ERROR VS. MOVEMENT LENGTH

Figure 4a

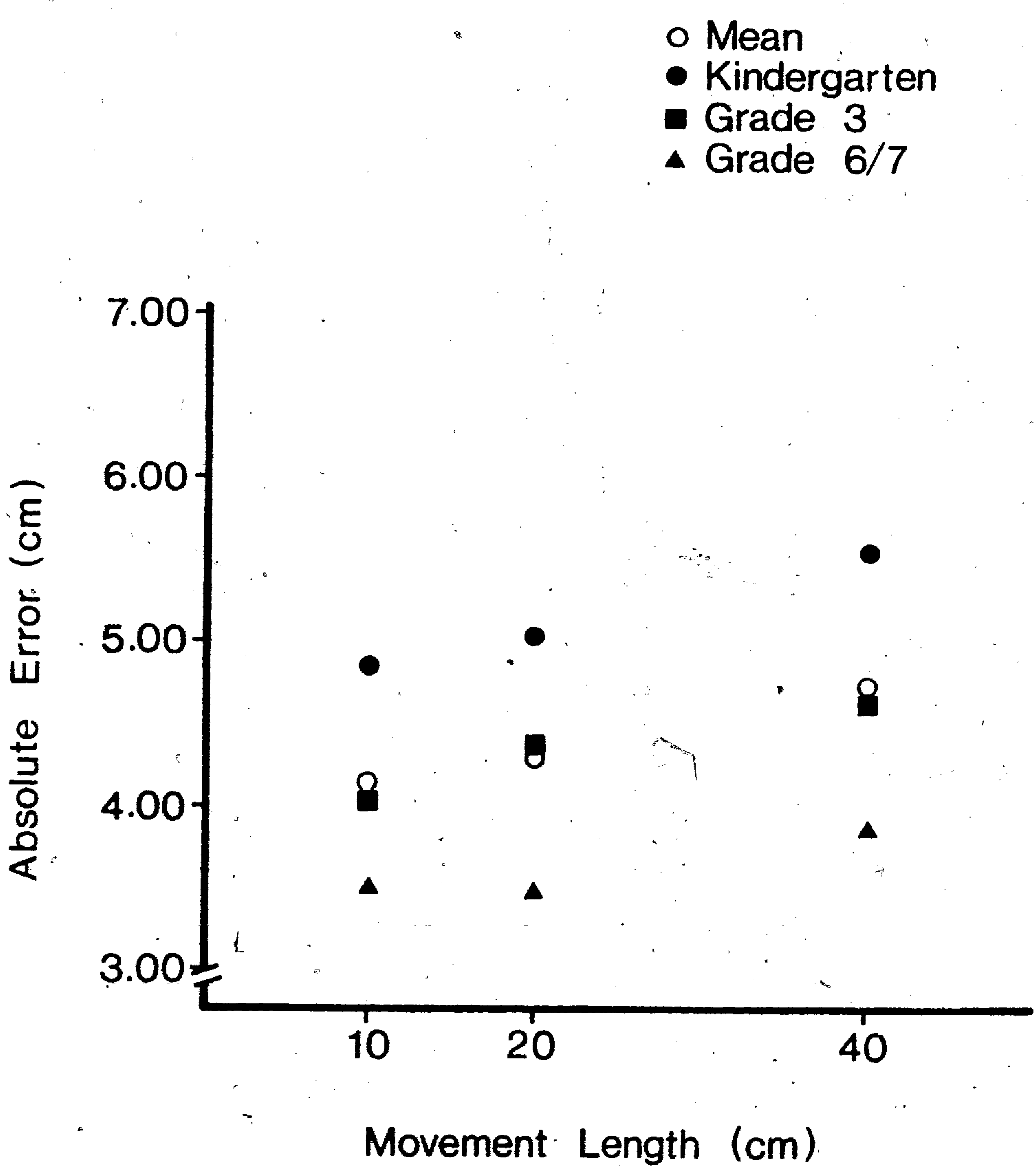

○ Mean
● Kindergarten
■ Grade 3
▲ Grade 6/7
7.00
6.00
5.00
4.00
3.00
Absolute Error (cm)
10
20
40
Movement Length (cm)

Figure 4b

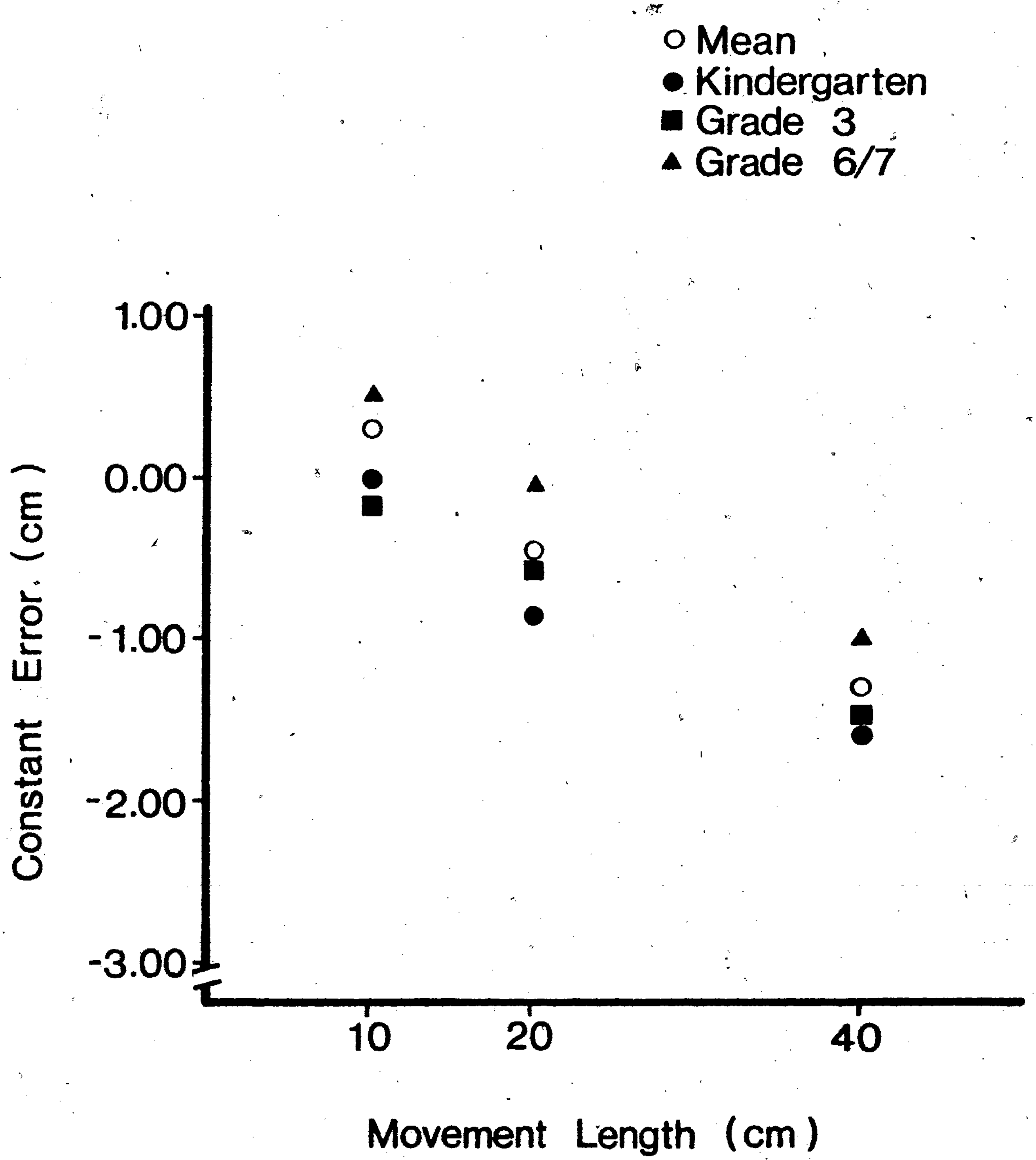
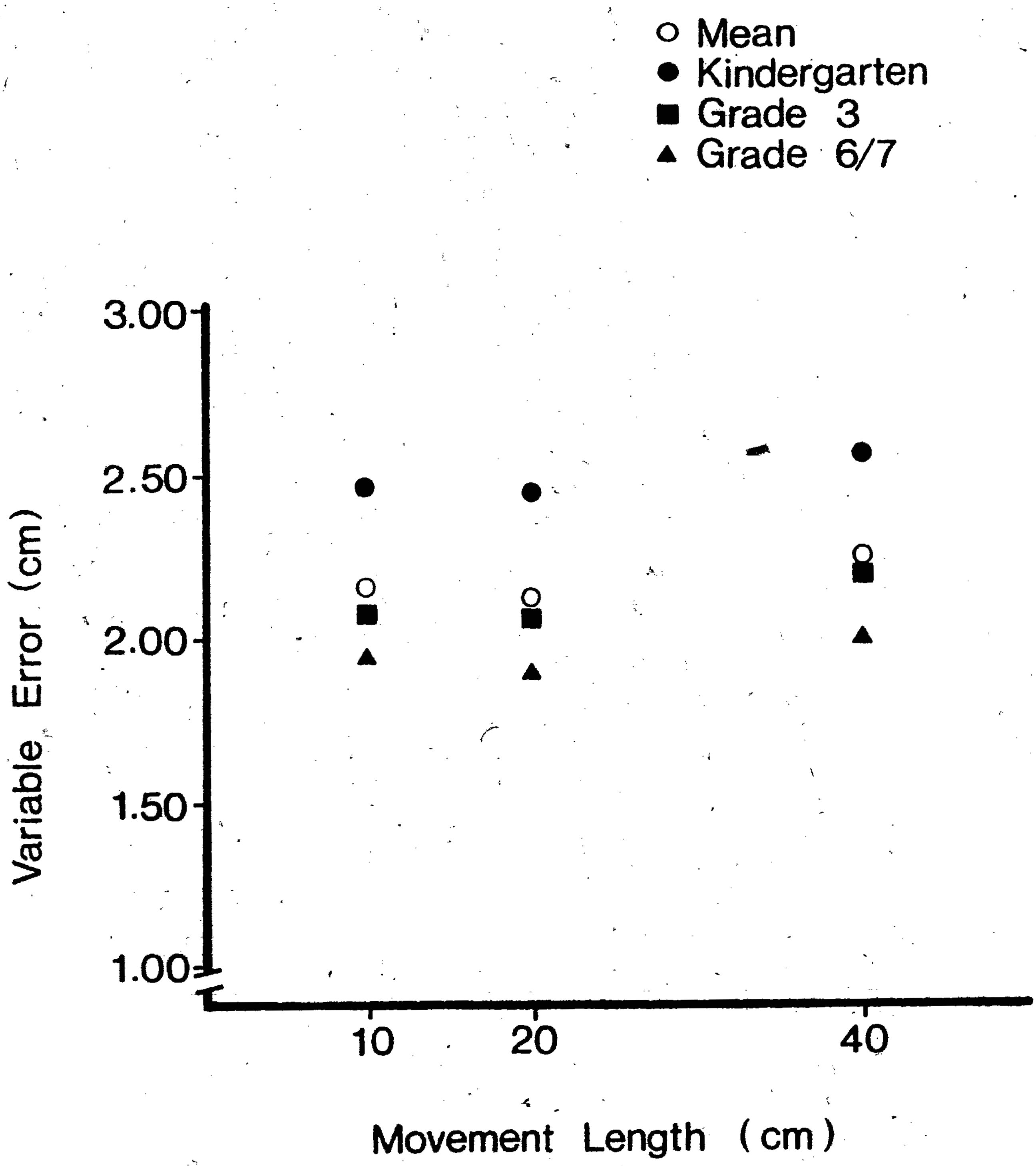

○ Mean
● Kindergarten
■ Grade 3
▲ Grade 6/7
1.00
0.00
-1.00
-2.00
-3.00
Constant Error (cm)
10
20
40
Movement Length (cm)

Figure 4c


Mean
Kindergarten
Grade 3
Grade 6/7
3.00
2.50
2.00
1.50
1.00
Variable Error (cm)
10
20
40
Movement Length (cm)

From a procedural standpoint, one anomaly can be introduced into the results if care is not taken by the experimenter to properly define the approximate endpoints of the longest movements. If the endpoint is located such that it is at the limit of the movement range of the subject (this is particularly important for younger, smaller subjects), the subject will reproduce the movement extremely accurately no matter what the length of the retention interval. Presumably this occurs since the subject must simply remember to move as far as is physically possible, a rehearsal strategy with an easily remembered verbal label. The performance is then quite independent of attending to proprioceptive cues which are supposedly being tested.

Interestingly, when subjects were informally asked, "Do you think it is easier to remember the short ones or the long ones?", 58 of 90 subjects said that longer movements were more easily remembered while 26 said that shorter ones were easier to reproduce. The remaining 6 expressed no preference. Clearly, the subjects' perceptions of their performances were contrary to their actual performances.

The data for constant error, which can be interpreted as an indication of the direction of the error around the criterion, shows that as movement length increases, constant error becomes more negative. This is, at least in part, in agreement with the central tendency effect described by Stelmach (1970) among others. The relatively long 40 cm. movements were substantially undershot upon reproduction, a finding which is in keeping with the central tendency concept. The 20 cm. movements were also undershot by all age groups, however, a finding not expected in view of the fact that 20 cm. movements are closer in length to the short 10 cm. movements which for the mean of all ages were overshot as predicted by central tendency theory. Nevertheless, the 20 cm. movements did occupy an intermediate position between 10cm. and 40 cm. While, with adults, one might not expect a movement as short as 20 cm. to be undershot, for children, a 20 cm. movement may well be a long one and, therefore, subject to overshooting.

A further mitigating factor is that even the 10 cm. movements were undershot by the kindergarten and grade 3 subjects. There appears then, to be a tendency to toward underestimating all movement lengths at the younger ages, a tendency which gradually disappears as children take on the more adult-like strategies presumably evident in the grade 6/7 subjects.

Variable error can be thought of as the variability around a criterion which is subject defined rather than around the imposed criterion defined during the learning trial. It was the experimenter's impression as testing proceeded that the four attempts supposedly being made at reproducing the learned criterion movement were not being made by the subjects with that idea in mind. It was felt that the first movement was a legitimate attempt to reproduce the criterion: however, the remaining three were not attempts to reproduce the criterion but rather were attempts to recreate the first reproduction trial.

The changes in variable error with movement length are relatively small although the overall effect is statistically significant. This suggests that subjects may be quite capable of reducing their error around a criterion length or location regardless of the length involved provided they are allowed to choose their own criterion. There is evidence gathered with adult subjects that when subjects are allowed to preselect their own criterion movement length, absolute error is less than that of movements which are of a constrained length (Kelso and Stelmach, 1976). This was attributed to the ability afforded the higher processing centres to prepare for incoming proprioceptive feedback during preselected movements , a capacity not available during uncertain, constrained movements (Jones, 1974). The subsequently acquired motor trace in the preselected condition is, therefore, better learned and better reproduced. The data in this study indirectly suggest that preselection may also be beneficial to children as an error reducing strategy since the increase in variable error with length is relatively small when compared with the increase in absolute error with length.

ii. Retention Interval Length

Collapsed over all conditions of age, movement length, and available movement cues, there is a statistically significant difference due to retention interval length for all three dependent error measures. These results are portrayed graphically in Figures 5a (absolute error), 5b (constant error), and 5c (variable error) in which the mean dependent error measures for all ages together are plotted against retention interval length. In addition, the dependent error measures for each individual age group are simultaneously plotted.

The overall effect of the amount of time intervening between learning and reproduction of the criterion was to increase absolute error for all age groups. This finding is consistent with the trace hypothesis of forgetting, that is, that the memory trace acquired during learning is lost spontaneously during the retention interval even when no interpolated activity occurs.

FIGURE 5: THE EFFECT OF RETENTION INTERVAL LENGTH ON ERROR MEASURES

5A: ABSOLUTE ERROR VS. RETENTION INTERVAL LENGTH
5B: CONSTANT ERROR VS. RETENTION INTERVAL LENGTH
5C: VARIABLE ERROR VS. RETENTION INTERVAL LENGTH

Figure 5a

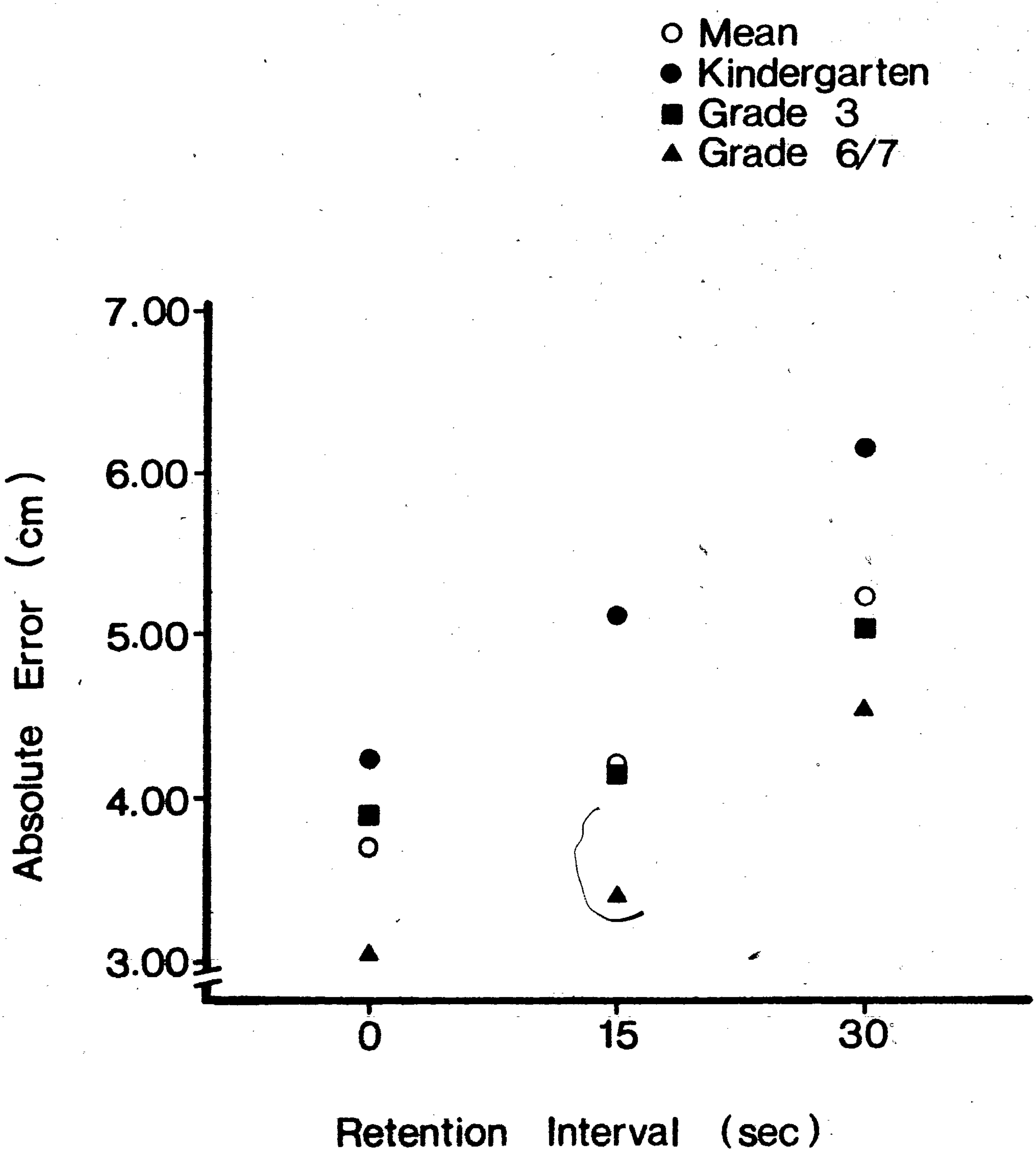
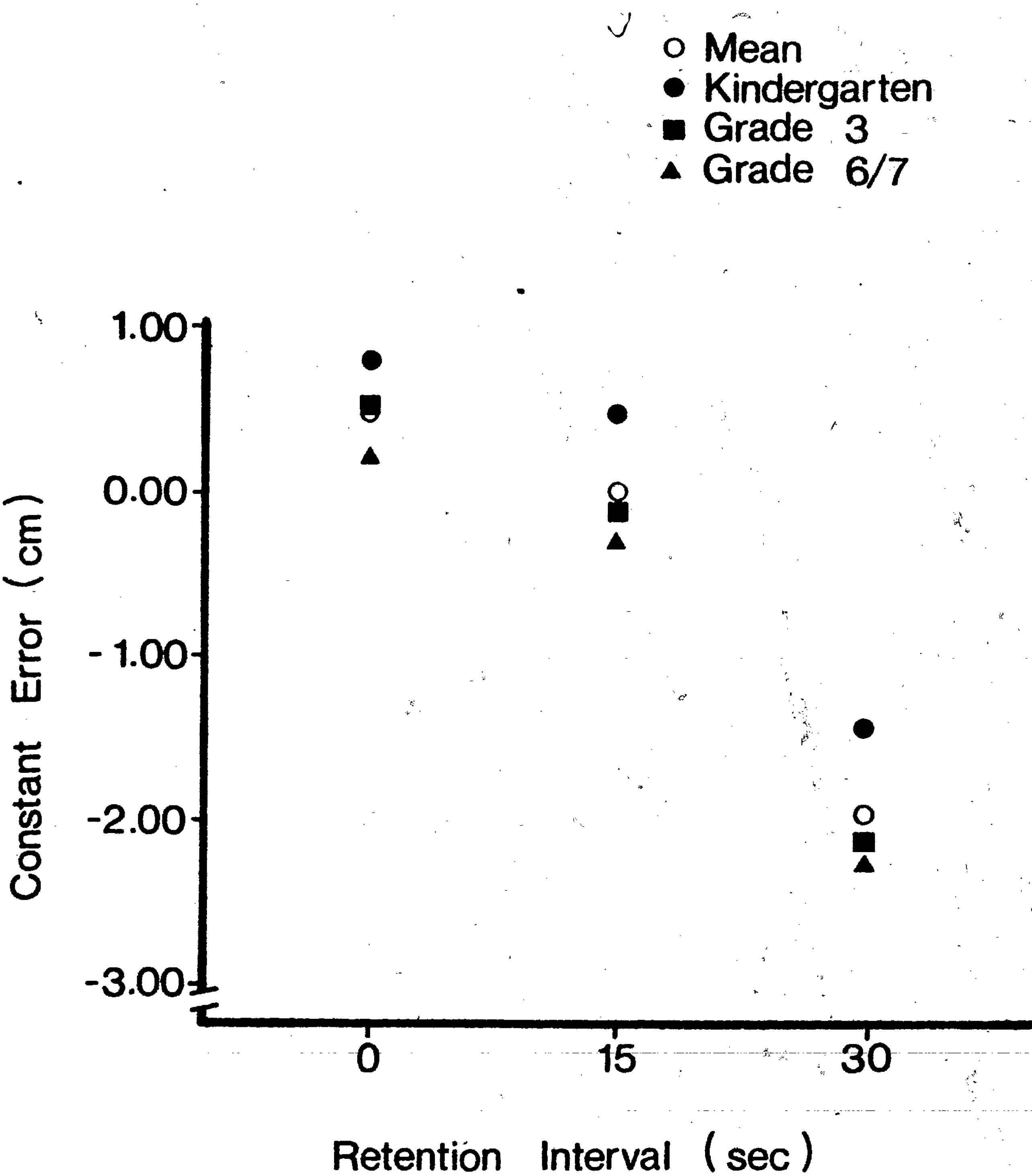
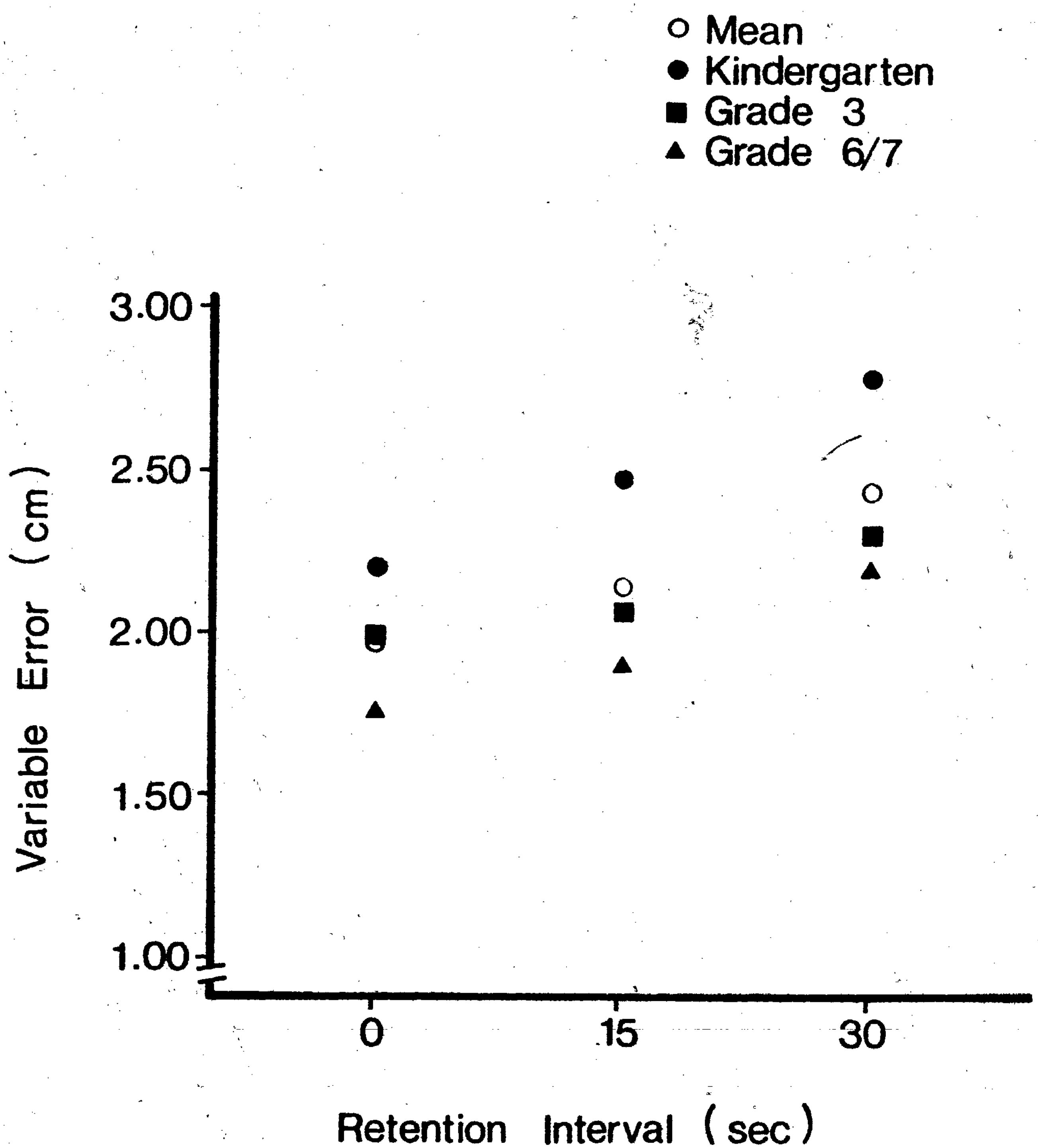

○ Mean
● Kindergarten
■ Grade 3
▲ Grade 6/7
7.00
6.00
5.00
4.00
3.00
Absolute Error (cm)
0
15
30
Retention Interval (sec)

Figure 5b



○ Mean
● Kindergarten
■ Grade 3
▲ Grade 6/7
1.00
0.00
- 1.00
-2.00
-3.00
Constant Error (cm)
0
15
30
Retention Interval (sec)

Figure 5c



○ Mean
● Kindergarten
■ Grade 3
▲ Grade 6/7
3.00
2.50
2.00
1.50
1.00
Variable Error (cm)
0
15
30
Retention Interval (sec)

Figure 5a resembles closely the pattern of trace decay seen with adults recalling verbal material in a short term memory paradigm (Peterson and Peterson, 1959). Unfortunately, the trace decay theory has never been fully tested with children as subjects. Nevertheless, Smothergill (1973) and Haith (1971) among others have provided some evidence that visual information decays during short term memory tasks performed by children.

The absolute error results of the present study suggest that children in the motor domain demonstrate forgetting during an unfilled retention interval. It is tempting to view this as decay of an hypothesized memory trace: however, the findings of Sroufe (1971) that children maintain a less stable state of attention during short term memory tasks complicates matters. The poorer reproductions of criterion movements at 30 seconds relative to 0 and 15 seconds may be , at least in part, attributable to a loss of attention to the task which occurs over time, particularly with the youngest children. Since no measure of attention was made during this study, (a point which can be made about virtually all short term memory studies), the results are supportive but not proof of trace decay. This point could be circumvented by treating attention and trace decay as two sides of the same coin rather than as two different components of motor performance.

An unexpected finding concerning retention interval length is seen in the constant error data which show that as the retention interval lengthened, the direction of the error became more negative. This means that when subjects at all ages wait for longer periods of time before reproducing the criterion movement, their recall of that criterion is shorter than its actual length, resulting in undershooting. This result has not been reported with adults and there is no readily available explanation for this time effect on constant error.

Variable error, like both absolute error and constant error, increases for all age groups as the length of the retention interval increases. In the preceding discussion of variable error and movement length, the theory was advanced that, while the first reproduction trial was a legitimate attempt to recreate the criterion, the subsequent three trials were attempts to recreate the first reproduction trial. This being the case, variable error would not be expected to increase over time since the time between the first reproduction trial and the subsequent ones is constant, independent of the time between the learning and first reproduction trials.

The data show that this is not the case, thus mitigating against the experimenter's empirically-based hypothesis. The variable error data can most easily be interpreted as an increase in the uncertainty of the subjects in reproducing movements following longer retention intervals. Still, the increase in variable error with retention interval could also be interpreted as being the result of decreased attention being paid to the task after longer retention intervals. If this was so, the hypothesis regarding the subjects' strategy during the repeated measures would not necessarily be discounted.

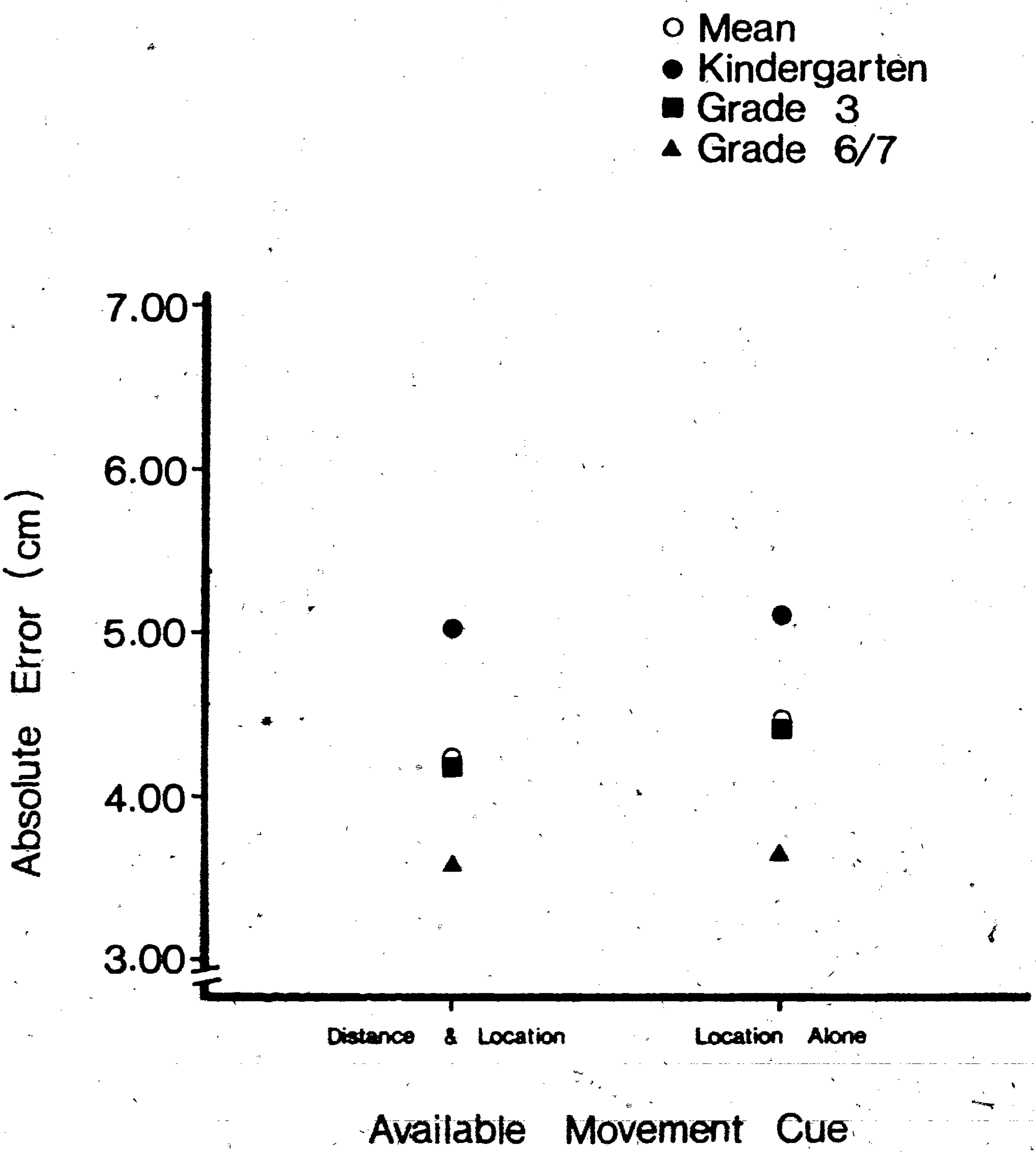
iii. Available Movement Cues

Subjects were afforded the opportunity to reproduce learned movements with either movement extent and endpoint information available, or with endpoint information alone. The literature suggests that location is a rehearsable cue not as subject to trace decay as the non-rehearsable extent information, though the true characteristics of these two cues are not fully understood. The data in this study show that, collapsed over all conditions of age, movement length, and retention interval length, there is a statistically significant difference between the two movement cue situations for all the dependent error measures. The results are portrayed graphically in Figures 6a (absolute error), 6b (constant error), and 6c (variable error).

FIGURE 6: THE EFFECT OF MOVEMENT CUES ON ERROR MEASURES

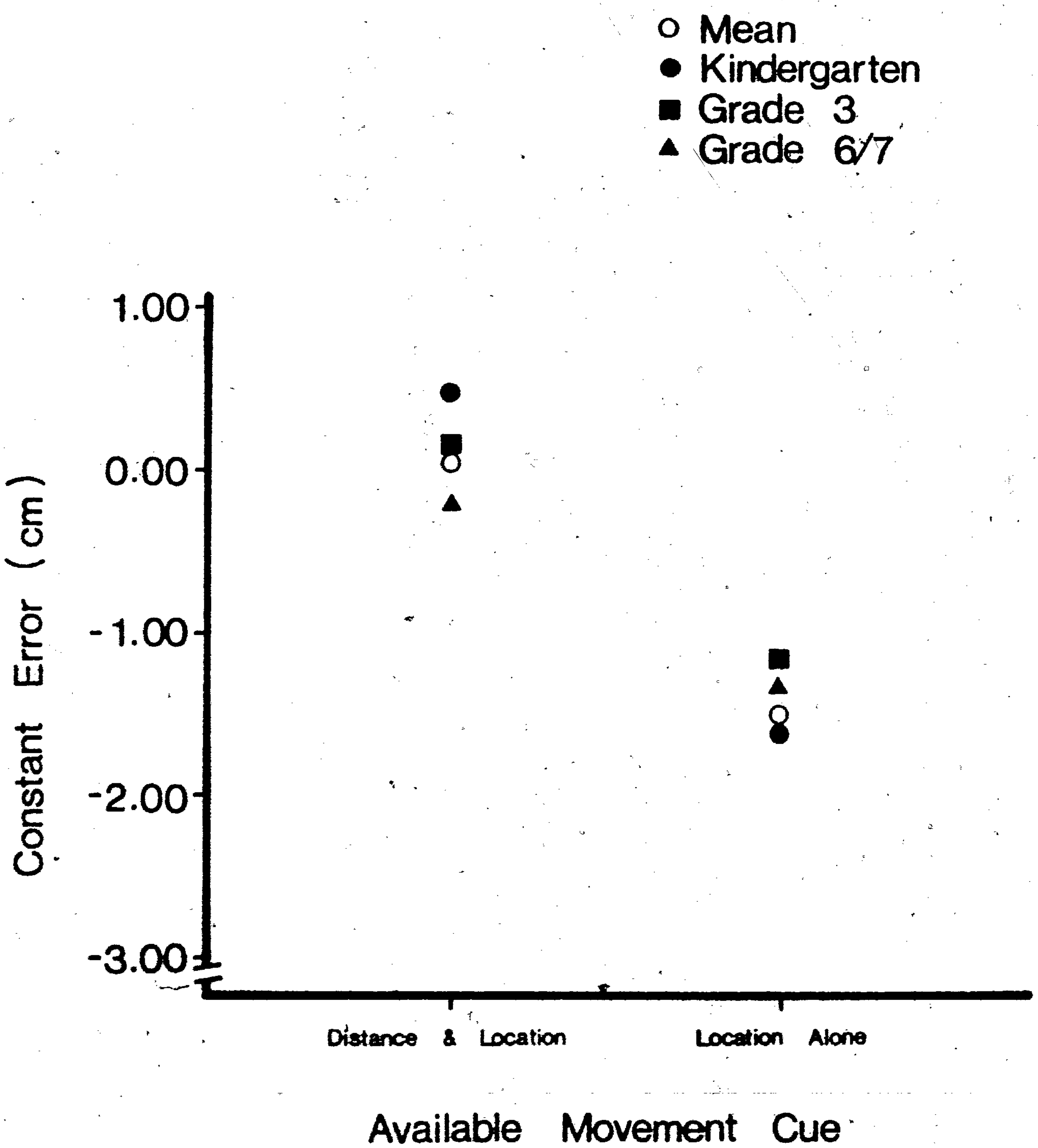
6A: ABSOLUTE ERROR VS. MOVEMENT CUES
6B: CONSTANT ERROR VS. MOVEMENT CUES
6C: VARIABLE ERROR VS. MOVEMENT CUES

Figure 6a



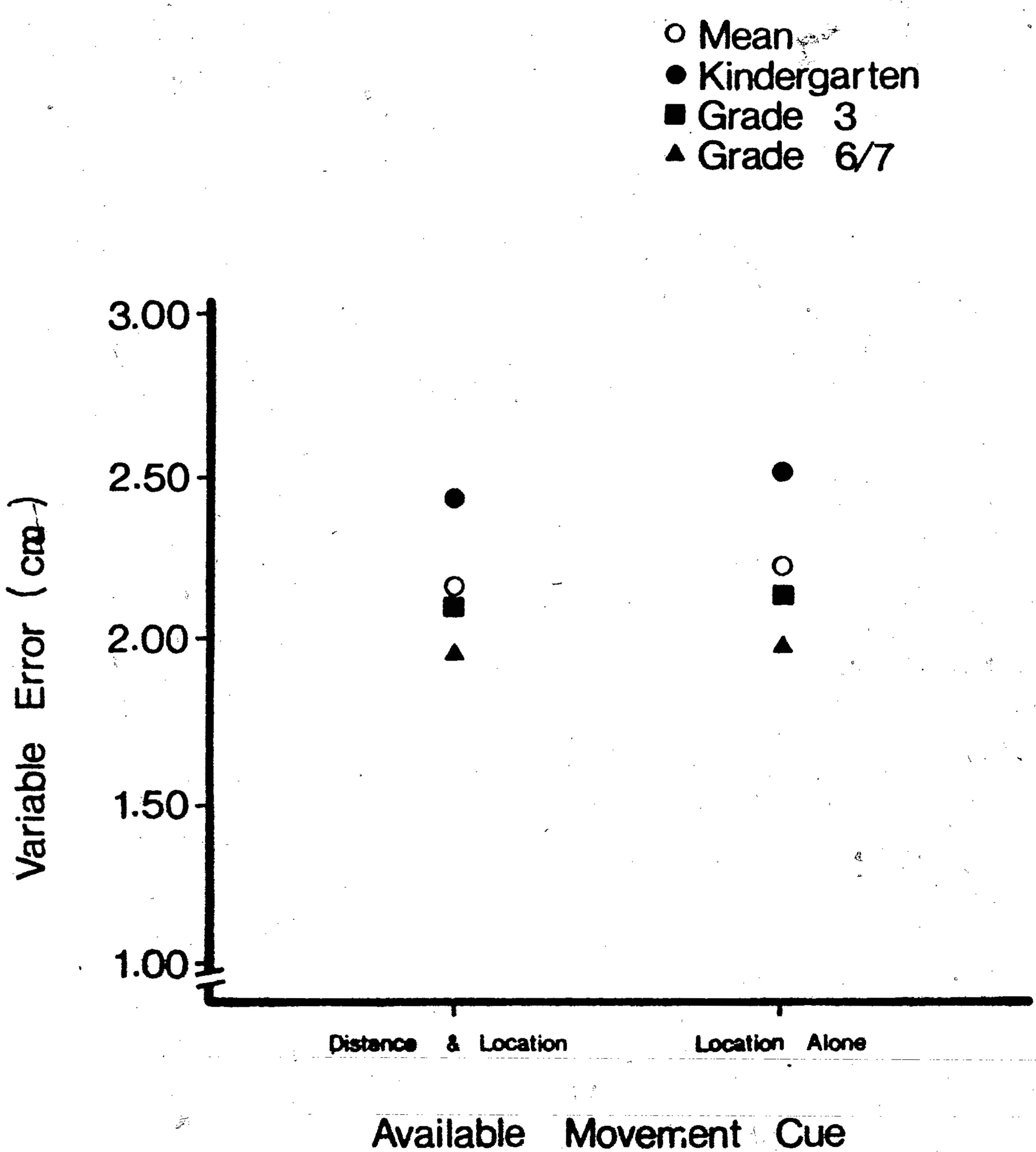
○ Mean
● Kindergarten
■ Grade 3
▲ Grade 6/7
7.00
6.00
5.00
4.00
3.00
Absolute Error (cm)
Distance & Location
Location Alone
Available Movement Cue

Figure 6b



Mean
Kindergarten
Grade 3
Grade 6/7
1.00
0.00
-1.00
-2.00
-3.00
Constant Error (cm)
Distance & Location
Location Alone
Available Movement Cue

Figure 6c



Mean
Kindergarten
Grade 3
Grade 6/7
3.00
2.50
2.00
1.50
1.00
Variable Error (cm)
Distance & Location
Location Alone
Available Movement Cue

While the results for the dependent measures may be statistically significant, examination of the means reveals very little difference between the two conditions. A posteriori analysis reveals no significant difference. Nevertheless, the difference for absolute error is consistent though small for all age groups with the distance plus location group producing slightly less unsigned error than the group having only location information. This implies that, while the contribution to recall made by distance information is small, it does enhance the accuracy of the reproduction somewhat.

This finding is interesting in view of the subjects' perceptions of their task performance. When asked about what cues were attended to during the retention interval, only 6 of 90 subjects made any reference to distance (for example, "I remembered how far I moved") even when distance was a reliable cue. Most subjects were location oriented in their approach, perceiving their strategies in such ways as "I just remembered where it (the stop) was".

Constant error again showed a surprising result, indicating that movements made with location information alone tended to be undershot relative to movements made with both distance and location information together. This result has not been reported with adults and there appears to be no theoretical base to explain it.

The difference in variable error is shown to be statistically significant. However, examination of the means reveals very little difference between the two conditions although the difference is consistent for all age groups. If there is more useful movement information available when subjects are given both distance and location, then it might be expected that their responses would be less variable about their own self-defined criterion movement. While statistically this appears to be the case, in practical terms there is little to choose in variable error between the two conditions.

iv. Interaction Effects

There are numerous interaction effects which can be considered given the data in Tables 1f, g, and h. Most important points of discussion can be made by referring to the two way interactions seen with absolute error as the dependent measure. The other dependent error measures show a similar pattern to that of absolute error and provide little additional information to that discussed in the main effects sections of this chapter or that to follow concerning two-way interactions for absolute error. The significant three-way interactions for absolute error will also be briefly discussed.

Perhaps more interesting than those two-way interactions which are statistically significant are the two which are not, although null results should be cautiously considered. First, interaction of available movement cues with age is not significant. This result, which is best seen in the parallel nature of the lines for the three age groups in Figure 6a, shows that the effect described in section iii of this chapter is the same at all ages. No age effect in the apparent superiority of distance plus location over location alone is seen. Children at all ages tested demonstrate slightly less error with both cues present suggesting that the way in which proprioceptive cues are used is fixed by the age of five and is not altered by the age of twelve. It is interesting to note, however, that for adults, the superiority of distance plus location over location alone is difficult to demonstrate.

Second, the interaction of movement length with movement cue is also not significant, meaning that proprioceptive perception of available cues is the same independent of the movement being performed. This is not surprising given that the different movements tested in this study were of the same class, differing only in length and not in the method of performance.

Although the interaction of movement cues with age was not significant, the interactions of movement length and retention interval length with age are both statistically significant. The former can be seen in Figure 4a, the latter in Figure 5a. In both cases, the lines for the three age groups depart from parallel, graphically showing the interaction. In the case of the movement length by age interaction, the two younger groups show a similar response to movement length. It is the oldest group which diverges from the pattern of the other two, displaying no effect of movement length on absolute error between 10 cm. and 20 cm. movements. The increase in absolute error at 40 cm. seen in the two youngest groups is evident in the oldest group as well, however. This indicates that at the longer movement lengths, the effect which was in some way buffered by the oldest group at shorter lengths occurs.

In the case of the retention interval by age interaction, it is the youngest group which departs from the pattern of the other two. The absolute error for the youngest subjects increases markedly for the 30 second retention interval while the increase for the two oldest groups is approximately linear with the increase seen between 0 and 15 seconds. Younger children are clearly more affected by long retention intervals than older children. In fact, this disparity might be expressed by saying that a short retention interval for an older child might well be a long one for a younger child.

Two other two-way interactions are statistically significant. These are the length by retention interval and the retention interval by available movement cues interactions portrayed graphically in Figures 7a and 7b respectively. The former effect is the result of the deviation of the 30 second group of movements showing a greater increase in error with movement length than the rate of increase seen between the two shorter retention intervals. This implies that the longer the retention interval, the more difficult it becomes to reproduce those movements which are most difficult to perform. Relatively speaking, the movements made at the shorter retention intervals are less susceptible to the movement length effect.

The remaining significant two-way interaction to be discussed here is that of retention interval by available movement cues. This results from two basically different shaped curves, one for distance plus location, the other for location alone (Figure 7b). The curve for distance plus location appears to plateau as the retention interval increases while the location alone curve appears to accelerate as retention interval increases. This suggests that the greater amount of proprioceptive information available in the distance plus location condition is of particular value at the longer retention intervals. It might be speculated that if even longer retention

FIGURE 7: INTERACTION EFFECTS FROM ANALYSIS OF VARIANCE IN EXPERIMENT 1

7A: MOVEMENT LENGTH BY RETENTION INTERVAL INTERACTION
7B: RETENTION INTERVAL BY MOVEMENT CUE INTERACTION

Figure 7a

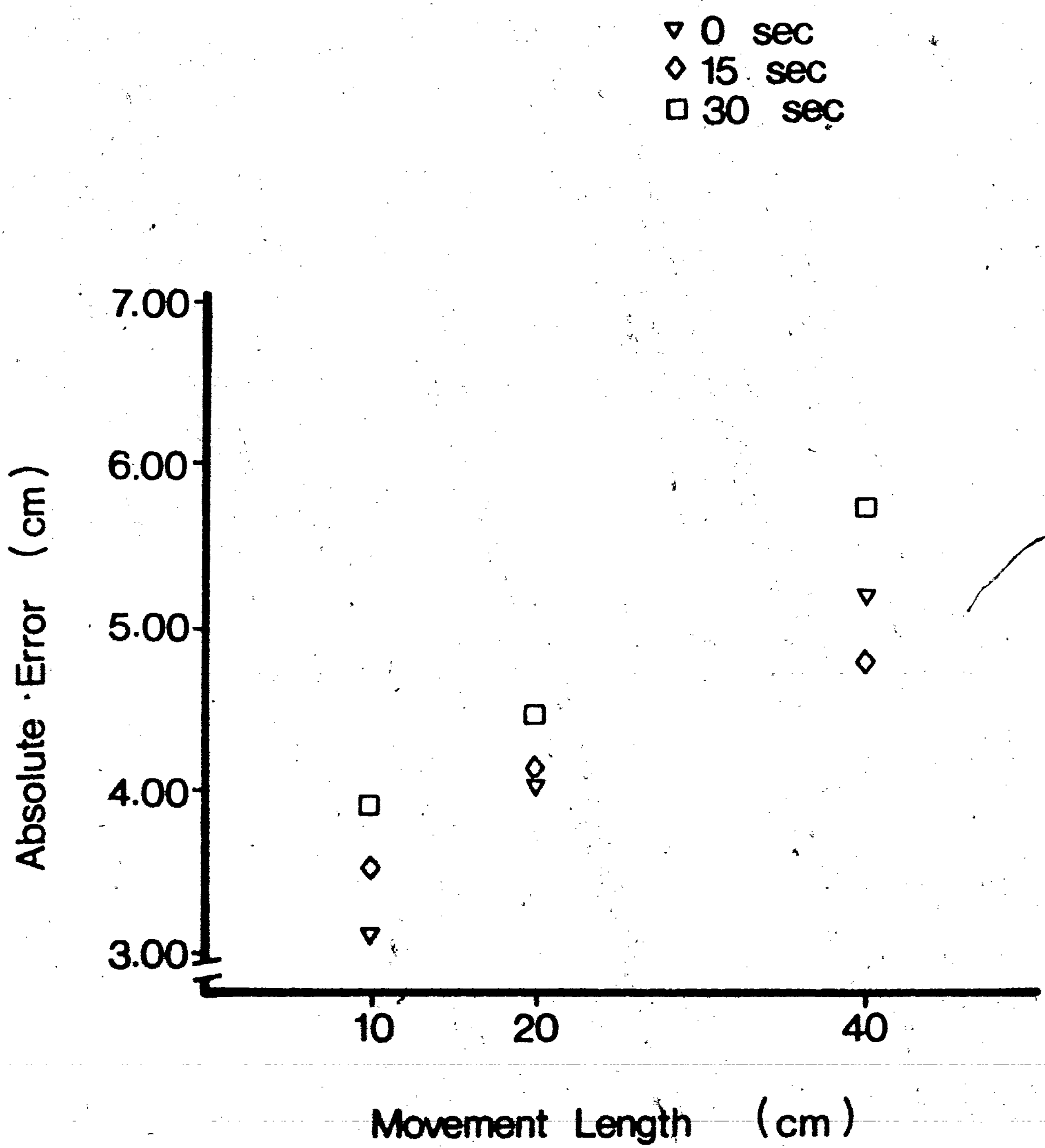
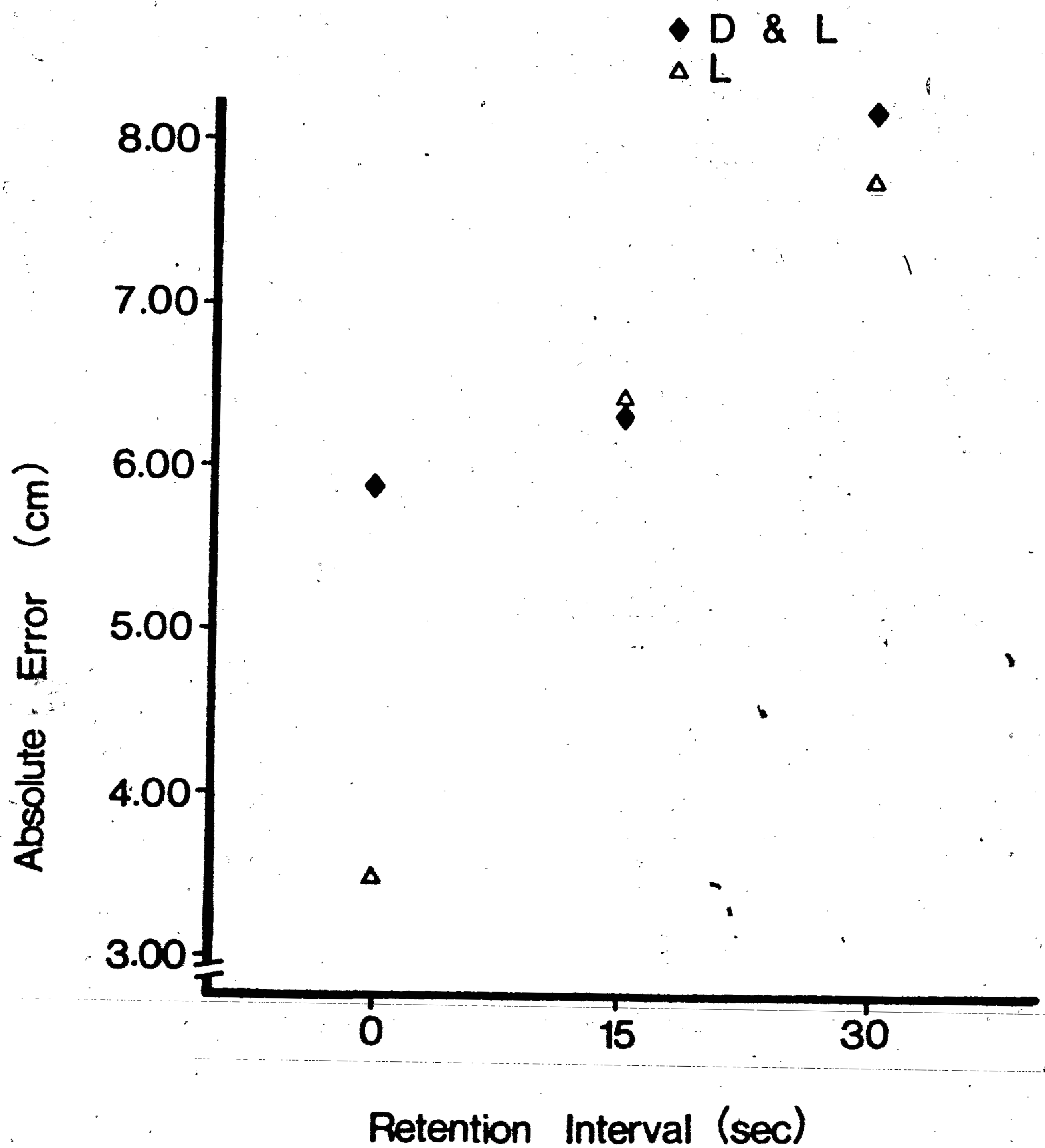

▽ 0 sec
◇ 15 sec
□ 30 sec
Absolute · Error (cm)
7.00
6.00
5.00
4.00
3.00
10
20
40
Movement Length (cm)

Figure 7b


◆ D & L
△ L
8.00
7.00
6.00
5.00
4.00
3.00
Absolute Error (cm)
0
15
30
Retention Interval (sec)

intervals were used, location alone might become inadequate more quickly than the distance plus location condition, indicating a "buffering" effect of some kind of increased sensory information on task difficulty.

Two significant three-way interactions with absolute error and one four-way interaction involving age occurred (Table 1g). These were the movement length by retention interval by age, retention interval by movement cue by age, and the movement length by retention interval by movement cue by age interactions. Both of the three-way interactions were examined graphically and the nature of the interactions subjectively interpreted. These complex interaction effects were deemed not to contribute substantially to the discussion of developmental trends and their analysis is not included here.

It should be noted that the results of Experiment 1 relating to motor learning theory must be viewed with caution. For practical reasons, all subjects performed 18 movements. While in statistical terms this was handled by the use of repeated measures statistical techniques, in human terms, the buildup of proactive interference (discussed in Chapter 3) may have had some effect which is incalculable. However, it is not unreasonable to suggest that this effect mitigated against finding significance and to propose caution is not to suggest a lack of confidence in the findings.

CHAPTER 3

Experiment 2

A. Introduction

Proactive interference can be regarded as a buildup of activity prior to learning a specific task which inhibits recall by creating a background of prior experience against which it is difficult to pick out the desired response during recall. Much attention has been given to interference effects and motor short term memory in an attempt to evaluate the relative contributions of trace decay and interference to forgetting.

Relatively more research in motor skills has been devoted to proactive interference effects than retroactive interference ones, (an interesting state of affairs when one considers that, in verbal learning, proactive interference effects on retention are of lesser magnitude than those of retroactive interference (Postman, 1961). Since proactive interference was easily generated in verbal learning studies, it was strange to discover during early attempts to transfer proactive interference studies from the verbal to the motor domain that there was no demonstrable effect in single trial designs. Such a failure was no doubt frustrating from the aspect of parsimony in that it argued against the existence of a common behavioural law which encompassed both verbal and motor learning. Among the studies reporting negative results for proactive interference in motor short term memory were Montague and Hillix (1968) and Hicks and Cohn (1975). However, some evidence for proactive interference in motor tasks was reported by Ascoli and Schmidt (1969) and Williams (1971) who reported that criterion movement recall was indirectly a function of the number of previous movements. In 1974, Burwitz discussed these inconsistent results of motor proactive interference experiments in terms of the cognitive control of motor behaviour, referring specifically to the idea of directed forgetting.

While in single trials designs in the motor domain proactive interference is not produced, it can be demonstrated in a reverse order or multiple trial design (Ascoli and Schmidt, 1969). In such a design, subjects learn a series of movements, the last of which is the criterion movement, then recall them in reverse order. This prevents the first movements of the series from being discarded (directed forgetting) since, unlike the subjects in a single trials design, subjects must recall all movements in the series. Burwitz showed that, in a multiple trials design, proactive interference could be eliminated by instructing subjects to ignore the first four movements of a five movement series. Thus it was illustrated that success or failure to generate proactive interference in motor short term memory experiments was dependent upon procedural differences, specifically whether or not subjects could purposefully forget material deemed to be task-irrelevant. Such experimental results are consistent with those theoretically summarized by Burwitz (1974 who emphasized the importance of directed forgetting as a basic process in avoiding a potentially debilatating buildup of proactive interference in everyday situations. However, it is worthwhile to note that, like verbal learning, the amount of proactive interference generated in motor learning studies is still less than the amount of retroactive interference (Pepper and Herman, 1971).

Another aspect of proactive interference is worthy of discussion here, that being an inconsistency between the verbal and motor domains. Even taking into account directed forgetting, it is still impossible to generate proactive interference in a single trial design for movements, but possible in single trial verbal designs. Burwitz attributed this not to different mechanisms of learning and performance but to procedural differences between experiments. In the motor domain, responses are measured on a continuous scale while in verbal studies responses are binary, that is, either right or wrong, remembered or forgotten, with no way of knowing the degree to which the nonsense syllables are remembered. Accepting this explanation, we can view the memory mechanisms in verbal and motor skills to be basically the same. In fact, in verbal learning, it is possible to show responses on a continuous scale if CCC syllables are used in place of the more common CVC syllables. By measuring the number of letters remembered correctly, results can be brought into line with those reported in motor learning (Jung, 1972).

B. Experimental Design And Methods

i. Hypotheses

1. All error measures are not significantly different for the directed forgetting proactive interference design relative to controls: however, all error measures increase relative to the other two groups for the no directed forgetting paradigm. Such findings would be taken as support for the idea that, within each age group, cognitive control of motor behaviour exists in the form of directed forgetting. In addition, an increasing effect of directed forgetting with increasing age is hypothesized as the result of increased cognitive control.

ii. Subjects

The same subjects who performed tasks in Experiment 1 were tested in Experiment 2 after Experiment 1 was completed.

iii. Apparatus

The apparatus was the same as that used in Experiment 1.

iv.Design and Analysis

Experiment #2 was designed to investigate proactive interference. Thirty subjects from each age group performed under 3 conditions, the order of which was randomly assigned. The first condition was a control, in which a movement of length 20 cm. was repeated following a 30 second unfilled retention interval. In the other two designs, three interfering movements of lengths 15, 25, and 35 cm. were used to generate proactive interference. In the first of the two, subjects performed, then recalled 30 seconds later each of the 3 interfering movements and the criterion movement. The criterion movement was always last in the sequence; the interfering movements were presented in random order. This design may be represented in the following way:

M1-------30 seconds-------R1

M2-------30 seconds-------R2

M3-------30 seconds-------R3

M4-------30 seconds-------R4

where M represents a learning trial and R a reproduction trial. M4 was the 20 cm criterion movement.

In the second of the two interference designs, the subject performed all four movements one after another, with the criterion movement being fourth in the sequence and the interfering movements preceding it in random order. All four movements were reproduced in reverse order beginning 30 seconds after the learning trial of the criterion movement. The design may be represented in the following way:

M1,M2,M3,M4 ----30 seconds---- R4, R3, R2, R1

Four attempts at each criterion movement recall were given. The design tested by statistical analysis was a 3(ages) x 3(conditions of proactive interference) design with repeated measures on the second factor.

V. Procedure

Subjects had already completed Experiment 1 and were acquainted with the apparatus. After a three minute rest period, the following additional instructions specific to Experiment 2 were given:

The control condition and the directed forgetting paradigm in which learned movements were each reproduced after 30 seconds required no additional instructions from those recieved by the subjects during Experiment 1. The no directed forgetting paradigm required the administration of these additional instructions:

In this series of movements, you will move four times in a row to a stop that I will place in a different location each time. Then I will ask you to repeat the four movements one after another but in reverse order, starting with the last one first. You will do movement 1 to the stop, then movement 2 to the stop, then movement 3 to the stop, then movement 4 to the stop. Then we will wait for a few seconds and you will repeat movement 4 four times without the stop in place to help you, then movement 3, then movement 2, then movement 1. Do you understand or would you like to go over the instructions again? (If so, repeat the instructions).

When the experimenter was satisfied that the subject fully comprehended what was required, the experiment proceeded as outlined in the instructions.

C. Results

Basic descriptive statistics for each of the three conditions at each age group are given in Tables 2a (absolute error), 2b (constant error), and 2c (variable error). The main effect of the proactive interference paradigm was statistically significant for absolute error and constant error, but not for variable error. In addition, the interaction effect between the paradigms and age was statistically significant for absolute error and constant error but not for variable error (Table 2d).

TABLES 2A,B,C,D.

DESCRIPTIVE STATISTICS AND ANALYSIS OF VARIANCE DATA
FOR EXPERIMENT 2

Table 2a: Descriptive statistics of absolute error (Expt 2)

EXPERIMENTAL CONDITION	KINDER		GRADE 3		GRADE 6	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
CONTROL	3.57	1.55	3.00	1.47	2.60	2.26
DIRECTED FORGETTING	5.38	2.29	3.12	1.71	2.87	1.86
NO DIRECTED FORGETTING	7.58	2.61	4.20	1.93	4.74	2.70

Table 2b: Descriptive statistics of constant error (Expt 2)

EXPERIMENTAL CONDITION	KINDER		GRADE 3		GRADE 6	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
CONTROL	-0.84	3.83	-1.47	3.03	-1.67	3.05
DIRECTED FORGETTING	-3.54	4.72	-2.25	2.80	-2.16	2.67
NO DIRECTED FORGETTING	0.66	8.10	-3.44	3.11	-3.44	4.28

Table 2c: Descriptive statistics of variable error (Expt 2)

EXPERIMENTAL CONDITION	KINDER		GRADE 3		GRADE 6	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
CONTROL	1.22	1.01	0.98	0.79	1.07	1.13
DIRECTED FORGETTING	1.18	1.02	1.05	0.82	0.95	0.88
NO DIRECTED FORGETTING	1.34	1.06	1.11	0.86	0.90	0.97

Table 2d: Analysis of variance table (Expt 2)

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	p
Absolute Error					
MEAN	18252.7	1	18252.7	1737.09	<0.01
AGE	1044.2	2	522.1	49.71	<0.01
PI DESIGN	1134.6	2	567.3	54.06	<0.01
A x DES'N	260.4	4	65.1	6.20	<0.01
ERROR	2732.2	260	10.5		
Constant Error					
MEAN	4375.7	1	4375.7	67.70	<0.01
AGE	324.7	2	162.3	2.51	0.08
PI DESIGN	316.7	2	158.3	2.45	0.09
A x DES'N	1202.9	4	300.7	4.65	<0.01
ERROR	16809.4	260	64.7		
Variable Error					
MEAN	1277.5	1	1277.5	123.7	<0.01
AGE	14.5	2	7.2	4.10	0.02
PI DESIGN	0.6	2	0.3	0.16	0.85
A x DES'N	3.97	4	1.0	0.56	0.69
ERROR	459.0	260	1.77		

D. Discussion

As children age, their ability to disregard task-irrelevant information increases (Hagen, 1967; Druker and Hagen, 1969). The three proactive interference designs essentially represent three different conditions of task-relevant/task-irrelevant information. The control condition represents a situation in which only relevant information is present, in particular, the specific movement being tested. The directed forgetting paradigm, on the other hand, represents a situation in which the specific task-relevant information is preceded by irrelevant information in the form of three interfering movements. The subject is provided with the opportunity to ignore that information by the process of directed forgetting, however. In the no directed forgetting paradigm, the specific performance task is again preceded by other information. In this case, all the information is perceived by the subject as being relevant and not subject to directed forgetting. Performance on the directed forgetting task relative to the control is thus a test of the subject's ablity to disregard task-irrelevant information. Performance in the no directed forgetting paradigm relative to the control is indicative of the central processing capacity of the subject, lower reproduction errors implying a greater ability to retain information in a proper temporal order without allowing preceding information to interfere with that which follows.

Using absolute error as a yardstick, it is seen in Figure 8a that all age groups were affected by the increase in perceived relevant information. This demonstrates with children, as it is known to be with adults (Ascoli and Schmidt, 1969), a multiple trials design is capable of producing proactive interference in the motor domain. For kindergartens, the single trials design with directed forgetting also produces proactive interference although less than that generated when no directed forgetting is possible. This indicates that the strategy of directed forgetting is not firmly established in children of kindergarten age. This strategy was present in grade 3 and grade 6 subjects: both groups performed the single trials design as well as the control condition. This suggests that grade 3 and grade 6 children were capable of perceiving the nature of the information in the single trials design, a capability not possessed by the youngest subjects in the study. Such a conclusion is in line with literature reviewed in Chapter 1 for visual and verbal tasks.

There is a statistically significant effect of the proactive interference paradigms on constant error (Figure 8b). For the two oldest groups, the pattern is similar. Relative to the control condition, the single trials design yields reproduction responses

FIGURE 8: THE EFFECT OF PROACTIVE INTERFERENCE ON ERROR MEASURES

8A: ABSOLUTE ERROR VS. PI DESIGN
8B: CONSTANT ERROR VS. PI DESIGN

Figure 8a

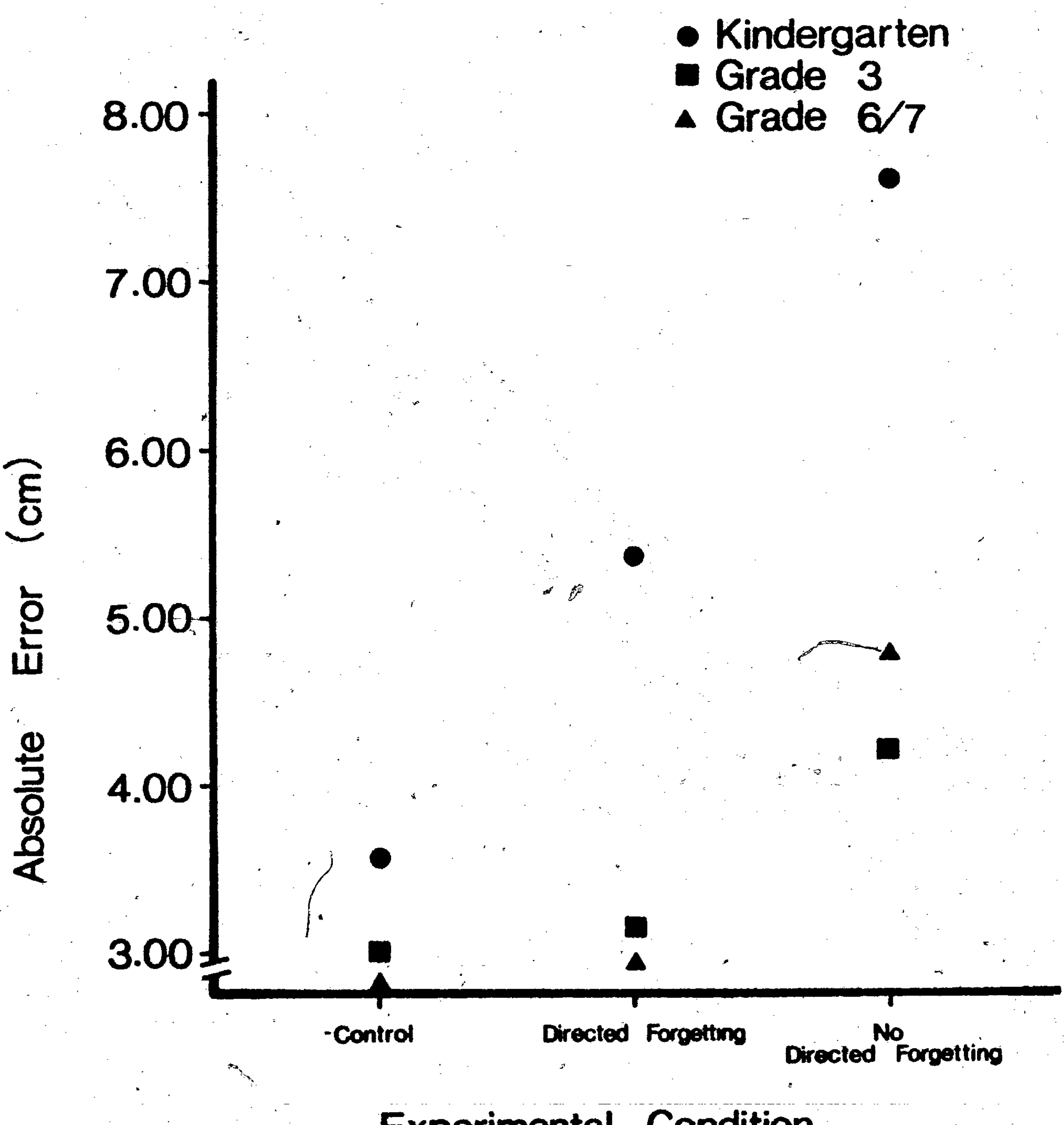
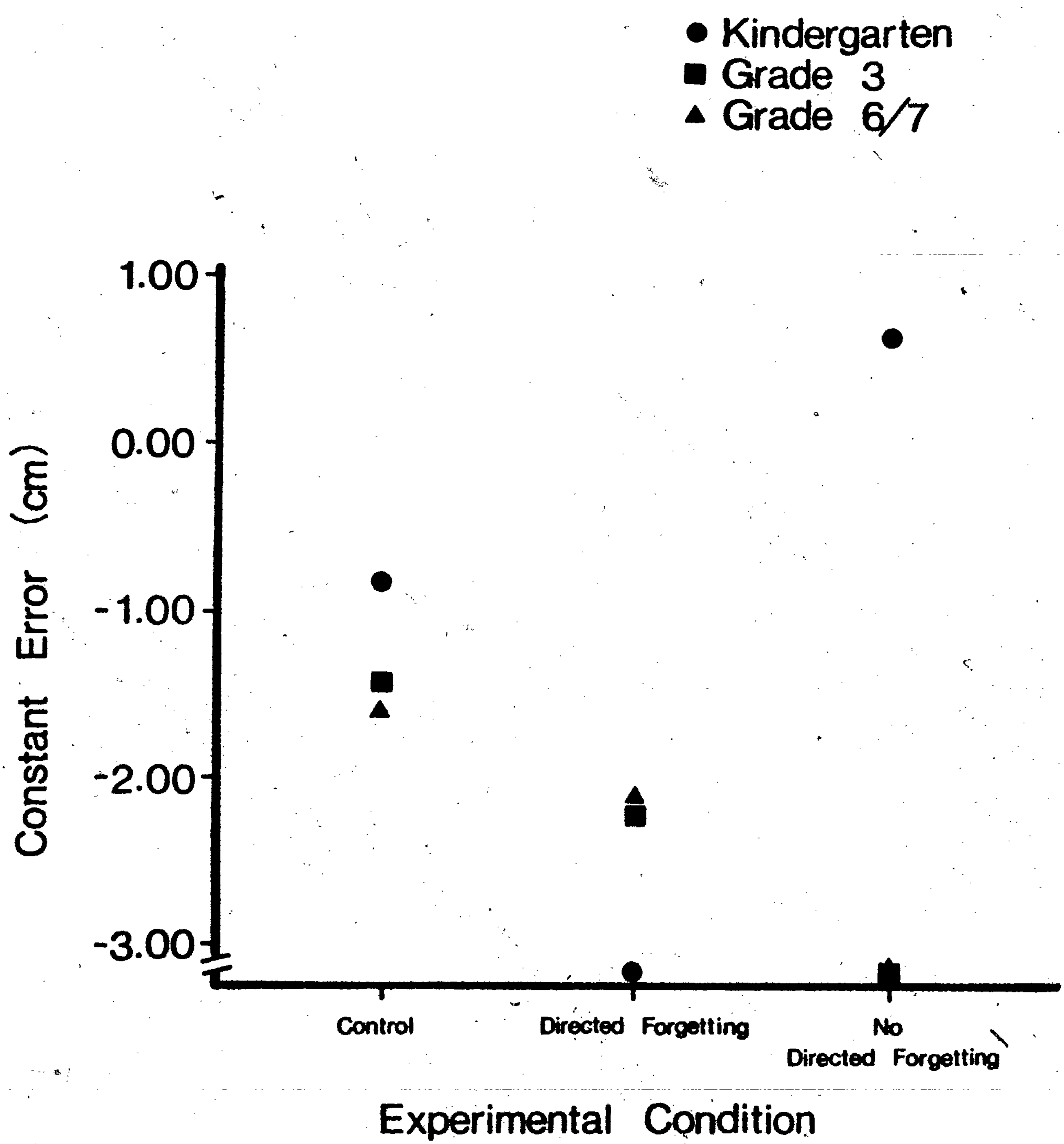

● Kindergarten
■ Grade 3
▲ Grade 6/7
8.00
7.00
6.00
5.00
4.00
3.00
Absolute Error (cm)
Control
Directed Forgetting
No Directed Forgetting
Experimental Condition

Figure 8b



● Kindergarten
■ Grade 3
▲ Grade 6/7
1.00
0.00
-1.00
-2.00
-3.00
Constant Error (cm)
Control
Directed Forgetting
No Directed Forgetting
Experimental Condition

which are undershot while the multiple trials design produces an even greater undershooting of the criterion. The youngest subjects depart from the pattern on the two older groups, in that movements made in the multiple trials design were overshot relative to both the control and the criterion itself. These responses are unexpected since two of the three interfering movements were longer than the criterion and might reasonably be expected to elicit an adaptation response in the direction of the overall interference. Such a response would produce positive, not negative, constant error. It could be speculated that subjects responded to relatively long interfering movements by overcompensating and, therefore, undershooting. This suggestion gives subjects credit for a higher degree of cognitive control of motor behaviour than the absolute error data on directed forgetting indicate, however. At the present time, this finding is inexplicable given present theories of adaptation level responses (Helson, 1964).

No statistically significant effect of the proactive interference paradigms on variable error was demonstrated although the age effect, as previously discussed, was significant. Older children showed consistently less variable error in all conditions than younger ones. The paradigms by age interaction effect was not significant showing that proactive interference affects children in the same way at all ages tested.

CHAPTER 4

Experiment 3

A. Introduction

Jenkins and Dallenbach (1924) found that subjects showed different amounts of retention of verbal material following sleep than following waking activity. Subjects displayed decreases in retention during the first two hours after learning under both conditions though the sleeping subjects showed marginally less forgetting. However, between two and eight hours post learning the waking group, unlike the sleeping group, continued the loss of material even though the activities in which they were involved were unrelated to the test nonsense syllables. These results led to the suggestion that general activity speeds the loss of newly acquired skills. This interference concept, among others, was a break with traditional thought which held forgetting to be a function of the decay of the memory trace acquired during learning. It was included in a summary of the basic principles of retroactive interference (or reactive inhibition in Hullian terms) published by McGeoch and Irion (1952).

Among the factors thought to affect the interfering qualities of interpolated activities were:

1. The degree of similarity between original and interpolated activities as elaborated in the Skaggs-Robinson hypothesis (Robinson, 1927) and the Osgood transfer surface and its modifications (Osgood, 1946; Martin, 1965). Interpolated tasks of slight similarity to the original have the greatest interfering effect.

2. The level of original learning, that is, interfering effects are reduced under conditions of high original learning (Kreuger, 1929).

3. The amount of interpolated material and the degree to which it is learned, that is, the greater the amount and learning of interpolated material, the greater the loss of original material (Underwood, 1954).

Even before Adams and Dijkstra (1966) suggested that more attention be paid to the results of interference on motor skills retention, Boswell and Bilodeau (1964) had done exactly that. Their subjects were pre-trained by guidance in a lever positioning task and then instructed to move unguided to the test target. During a 28 second retention interval, one of two interpolated tasks was introduced: subjects either re-zeroed the lever or picked a pencil up from the floor. Re-zeroing induced no retroactive interference while picking up the pencil did have a significant interfering effect. Additional demonstrations of retroactive interference in motor tasks have been reported by Herman and Bailey (1970) and Pepper and Herman (1970). Taken together, their results indicate that, for force responses, retroactive interference is an important cause of forgetting: in fact, the latter paper failed to produce any evidence for the trace decay hypothesis for recall intervals between 4 and 60 seconds though the authors do express their support for a dual process theory of forgetting in motor short term memory. Interpolated force responses greater than the criterion were uniformly successful in producing retroactive interference, while interpolated forces less than the criterion generated less interference. The direction of the induced error increase was in the direction of the interpolated movement, supporting an adaptation level response as discussed by Helson (1964) and Dickinson (1976).

Recent studies of interference have concentrated not simply on observing the effect of interfering movements on the reproduction of a criterion but rather have attempted to use interference as a tool to gain insight into the characteristics of the codes which subserve movement information. Kerr (1973) proposed that interference is of two kinds. Capacity interference occurs when tasks demand more of the limited central processing capacity than is available; structural interference occurs when tasks compete for the same perceptive and memory processes. Both Diewert (1976) and Laabs (1974) have reported that different kinds of movement information (for example, direction vs. amplitude or distance vs. location) are interfered with differently. At the present time, however, such studies are preliminary and little is known of the ways in which movement information is coded.

B. Experimental Design and Methods

i. Hypotheses

1. All error measures increase in subjects performing under conditions of retroactive interference relative to control subjects. Such a finding would be taken as support for a role of retroactive interference in short term motor forgetting.

2. All error measures are less under both conditions of interference and control when a higher level of original learning is given. Such a finding would be taken as support for the resistance to retroactive interference afforded by increased original learning.

ii. Subjects

Subjects who had performed tasks in both Experiments 1 and 2 were tested in Experiment 3 following completion of the other experiments.

iii. Apparatus

The apparatus used in Experiment 3 was the same as that used for Experiments 1 and 2.

iv. Design and Analysis

Experiment #3 was designed to investigate retroactive interference. Each of 30 subjects in each age group performed under one of two conditions of initial learning, either 1 or 10 learning trials of the 20 cm. criterion movement. Following the final trial of the criterion movement, a 30 second retention interval preceded the reproduction trial. During the retention interval, subjects performed either 0 (i.e. an unfilled retention interval, or control condition) or 3 interfering movements of 15, 25, and 35 cm., the order of which was randomly assigned. Four recall attempts of the criterion movement were tested. Separate analyses were performed on the retroactive interference conditions and on the original learning conditions. The design tested by statistical analysis of interference effects was a 3(ages) by 2(interference vs. control) design with repeated measures on the second factor. The design tested for original learning effects was also a 3(ages) x 2(conditions of original learning) design with repeated measures on the second factor.

For the retroactive interference and original learning experiments, 10 subjects in each age group performed under one or two of four conditions. Ten subjects performed both interference and control paradigms with one original learning trial. The remaining 20 subjects in each age group performed under one of two conditions (10 in each), either control or interference, but with ten original learning trials.

v. Procedure

Subjects had previously completed Experiments 1 and 2 and were acquainted with the apparatus. The following additional instructions specific to Experiment 3 were given:

The instructions specific to Experiment 1 were repeated to the subjects at this time. The only change was that those subjects who were to be given ten original learning trials were told that they would receive ten, not one, learning trials. Subjects performing the retroactive interference paradigm required these additional instructions:

After you have done your learning trial(s), there will be a waiting period before I ask you to repeat your learned movement. During that time I will ask you to make three different movements to the stop, one right after another. When you have done these three, I will ask you to repeat the movement you learned before the waiting period."

When the experimenter was satisfied that the subject fully comprehended what was required, the experiment proceeded as outlined in the instructions.

C. Results

Basic descriptive statistics for the control and the interference conditions at each age group are given in Table 3a. Basic descriptive statistics for the conditions of high and low original learning are also given in Table 3a. The main effect of retroactive interference was statistically significant for absolute error, but not for constant error or variable error (Table 3b). The interaction effect of retroactive interference and age was not statistically significant for any of the three dependent error measures (Table 3b). For both control and interference groups, the effect of original learning was statistically significant for all of the dependent error measures (Table 3c).

TABLES 3A,B,C,D.

DESCRIPTIVE STATISTICS AND ANALYSIS OF VARIANCE DATA FOR EXPERIMENT 3.

Table 3a: Descriptive Statistics Of Retroactive Interference Experiment (Expt. 3)

	KINDERGARTEN		GRADE 3		GRADE 6/7	
	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
CONTROL						
AE	3.60	2.24	2.55	1.16	2.67	1.83
CE	-0.34	4.25	-1.36	2.51	-1.13	3.08
VE	0.70	0.83	0.60	0.72	0.44	0.57
INTER-FERENCE						
AE	6.50	3.33	4.87	8.23	5.14	2.21
CE	-2.52	7.03	0.18	9.62	-4.52	3.30
VE	0.73	1.04	0.60	1.26	0.69	1.02

Table 3b: Descriptive Statistics For Original Learning Experiment (Expt 3)

	HIGH ORIGINAL LEARNING		LOW ORIGINAL LEARNING	
	$\bar{X}$	SD	$\bar{X}$	SD
CONTROL				
AE	1.69	1.79	2.24	2.60
CE	-0.59	2.41	-0.72	3.06
VE	0.54	2.41	0.62	0.95
INTER-FERENCE				
AE	3.96	6.47	2.88	3.47
CE	-1.40	7.49	-1.37	4.30
VE	0.63	0.93	0.81	1.20

Table 3c: Analysis of Variance Table For Retroactive Interference Experiment (Expt. 3)

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F	p
Absolute Error					
MEAN	8194.9	1	8194.9	137.41	<0.01
AGE	148.6	2	74.3	1.25	0.29
RI DESIGN	744.86	1	744.8	12.49	<0.01
A x DES'N	7.4	2	3.7	0.06	0.94
ERROR	6560.4	110	59.6		
Constant Error					
MEAN	1198.2	1	1198.2	10.38	<0.01
AGE	411.3	2	205.7	1.78	0.17
RI DESIGN	205.0	1	205.0	1.78	0.19
A x DES'N	534.5	2	267.3	2.32	0.10
ERROR	12698.9	110	115.4		
Variable Error					
MEAN	308.2	1	308.2	139.86	<0.01
AGE	3.0	2	1.5	0.69	0.50
RI DESIGN	3.9	1	3.9	1.78	0.18
A x DES'N	1.5	2	0.8	0.35	0.70
ERROR	381.2	110	1.9		

Table 3d: Analysis of Variance Table For Original Learning Experiment (Expt. 3)

SOURCE		SUM OF SQUARES	DF	MEAN SQUARE	F	p
CONTROL						
AE	MEAN	1358.6	1	1358.6	96.99	<0.01
	ERROR	1218.7	88	14.0		
CE	MEAN	140.1	1	140.1	5.07	0.03
	ERROR	2406.0	88	27.7		
VE	MEAN	117.2	1	117.2	95.80	<0.01
	ERROR	106.4	88	1.2		
INTERFERENCE						
AE	MEAN	4164.5	1	4165.5	1.04	0.38
	ERROR	8516.9	88	96.8		
CE	MEAN	680.4	1	140.1	5.10	0.03
	ERROR	11739.3	88	133.4		
VE	MEAN	184.5	1	184.5	58.8	<0.01
	ERROR	276.0	88	3.1		

D. Discussion

i. Retroactive Interference

The ability to produce decrements in recall of learned material by introducing interpolated activity into the retention interval has a long history in both the verbal and motor domains. Given that children do not attend to short term memory tasks as well as adults (Sroufe, 1971), children would be expected to readily demonstrate retroactive interference effects. The absolute error data show that, collapsed over all ages, this is the case. Only the grade 3 subjects show no statistically significant different effect of the retroactive interference paradigm, possibly due to the extremely large variance about the mean demonstrated by the grade 3 subjects during the interference task. The results, taken with the previously reported trace decay results, offer support for a dual process forgetting mechanism in the age groups tested in the motor domain. While the interaction effect between interference and age was not significant, thus setting it apart from the trace decay data, similar results (that is, younger children showing greater trace decay than older ones as the retention interval lengthened) might have been obtained if different levels of retroactive interference had been produced by different amounts of interpolated activity. Younger children, with less central processing capacity, would demonstrate increasingly greater interference effects as the retention interval is increasingly filled.

The data for constant and variable errors show no statistically significant effect of retroactive interference. Nevertheless, while the results are not statistically significant, the means for constant error show the same unexpected adaptation level response for two of the age groups as was described for the proactive interference data. The interpolated activity, though generally of greater magnitude than the criterion movement, produced reproduction efforts which were markedly undershot relative to controls. As stated before, there is no readily available explanation for this phenomenon.

ii. Original Learning

Adams and Dijkstra (1966) tested, with adults, the hypothesis that a more firmly established memory trace is more resistant to the interfering effects of interpolated activity than a less well established one. Subjects were provided with either small, medium, or large amount of original learning prior to the filled retention interval. Subjects who had had the most learning trials were less affected by retroactive interference.

The data in this study indicates that the same effect apparently does not occur with children. For control groups, that is, no interpolated activity, the group having more original learning trials had a reduction in absolute error upon reproduction of the criterion. The interference group, on the other hand, showed exactly the opposite effect to the controls and to the expected result. These subjects who had supposedly learned the task to a higher degree were actually more susceptible to the effects of retroactive interference as indicated by their significantly increased absolute error. In addition, increased original learning had little effect between control and interference groups as shown by the means in Table 3a. For constant error, the overall effect of increased original learning was to shift reproduction responses inexplicably in the negative direction. Only for variable error was a predictable effect of increased original learning seen. Subjects in both control and interference groups showed a decrease in variable error when more learning trials were given. This indicates that the increased learning did generate a more well established memory trace. Nevertheless, in the face of interpolated activity, only the confidence in the memory trace remained since what the subjects remembered as being the criterion was not it at all, hence the interference effect.

Original learning appears to have an unusual and unpredictable effect on children in the context of the short term memory paradigm. The cause of these results is not understood at this time. It is possible that, by imbedding the experiment on original learning within a large number of other experimental demands upon the subject, the effect of proactive interference inherent in the design confounded the original learning results producing the unexpected findings. The difference between one and ten original learning trials may well have been trivial by the time Experiment 3 was performed.

CHAPTER 5

General Discussion

The results presented in this study have implications in both teaching of motor and motor learning and performance theory. For the latter, the points to be made stand on firm ground since, generally speaking, theoretical approaches to motor learning have been formulated from the simple kinds of movements such as those used here. For the former on the other hand, care must be taken not to generalize to movement classes far removed from the experimental ones. Complicated physical education skills are very different from linear positioning and generalizations should be made only with caution. Still, the findings here can be used as guidelines for instructing children in motor skills provided that they are recognized as having come from simple skills and may require modification in order to be applied in the "classroom" setting.

Considering first the findings of Experiment 1, several points of interest arise. The trace decay of motor information seen with children duplicates that seen in other short term memory work in both the verbal and motor domains with adults. For retention interval length effects, children conform to theoretical expectations and do not require special consideration within the theoretical framework. From a practical standpoint, it is worthwhile noting that younger children are less successful at retaining proprioceptive information in short term memory and presumably at transferring it to long term memory. This suggests that in a situation in which guidance is being provided during skill learning (a situation analogous to the constrained learning trials), children, particularly young ones, should be allowed to attempt to repeat the movement on their own as quickly as possible after the guided learning trial. In this way, the reproduction trial will approximate the learning trial as closely as possible. If all learning and reproduction trial combinations are performed in this manner, a model of the skill - a perceptual trace - (Adams, 1971) will be acquired with a minimun of variance or noise associated with it. Such a trace stored in long term memory could conceivably facilitate future performance of that particular skill due to the small amount of uncertainty associated with it.

When discussing trace decay results from Experiment 1, it is worth noting that an inconsistency arises when the findings are compared with control findings in Experiment 2. For all age groups, the 30 second unfilled retention interval in Experiment 1 should match with the 30 second unfilled retention interval in Experiment 2. They do not match, however. There is considerably more memory loss under conditions in Experiment 1 than in Experiment 2. The difference may be explained by the fact that, in Experiment 1, subjects performed in a situation of accumulating proactive interference. Therefore, the data in Experiment 1 can at best be only suggestive of trace decay. The results may be equally well explained by the alternative mechanism of proactive interference.

Despite the controversy about the relative usefulness of distance and location information, evidence here shows two points clearly. First, children use location information as their primary proprioceptive input, a result in keeping with what is known about adults. This is not to say that distance information is not of value. Subjects at all ages benefitted slightly from the presence of the extra distance information, suggesting that, whenever possible, it is useful to advise children to attend to all available movement cues and, if necessary, to help them develop strategies by which they might better use them.

Children in this study, when informally questioned ablut their performance strategies, implied that they were unaware of using distance information in any way. Yet the data show that, although unaware of it, they were. Also, children stated that longer movements were easier to remember than short ones although the data show the opposite to be true. These results, taken together, indicate that children's perceptions are not the best source of information regarding their progress at a given motor task.

Delving into the effect of movement length, the data in this study shows within a behavioural framework what has been recently demonstrated by at least some authors in neurophysiological studies. There is evidence (Millar, 1975; Tracey, 1979) that, during extensor movements, joint receptors providing location information fire differentially at different positions. As extension continues, the location of the limb is less reliably monitored in the joints resulting (from a behavioural standpoint) in the subject having less reliable location information for movements requiring greater extension than for movements requiring lesser extension. While the absolute error data for movement length bear this out in this particular study (both for absolute and percent values, that is, error expressed as a percent of the total length), the proposition is still tentative. The arm positioning task conducted on subjects here is primarily a shoulder and elbow task and the receptor information comes from studies of the knee, wrist, and elbow. The transferability of characteristics of receptors from one joint to another is uncertain (P. Bawa, personal communication) and the knowledge in this aspect of motor control awaits a combined behavioural/neurophysiological study.

Another study of future interest arising indirectly from Experiment 1 would investigate whether or not children perform better under conditions of preselection than under constrained conditions. Such is the case with adults: however, this matter has has not been pursued with children. Such a study performed over age groups of normal children would provide insight into the development of central processing events.

Schmidt (1975) presented a schema theory of motor learning whose underlying principle was that a wide variety of practice movement experiences results in better performance under transfer to a movement of the same class. This theory seemingly flies in the face of the theory of proactive interference which states that preceding movements are debilitating to movements of the same class. This apparent difference can perhaps be reconciled by assuming that schema theory is best suited to well learned skills in long term memory and proactive interference is best suited to short term memory paradigms. Even so, the rough ride which has been given schema theory in the literature (for example, Zelaznick, 1976) may be the result of proactive interference effects subverting schema effects.

This points to the fine line which must be adhered to by motor skills instructors who must insure that, for positive transfer to occur, original skills are learned very well.

Children are easily affected by proactive interference and younger ones have poorly developed cognitive skills like directed forgetting. To minimize these effects, the goal of teaching a progressive series of skills should be fully explained so that the child fully comprehends that all the skills are related and that the easy ones at the beginning of the series are task-relevant.

With reference to retroactive interference, it is clear that children are dramatically affected by interpolated activities. This can be minimized in the practical setting by reducing as much as possible the length of the retention interval so as to reduce the opportunity for interference to occur. While this makes both theoretical and practical sense, the data on level of original learning produced in this study creates the untenable pedagogical position of having to advise against practice for fear of having performance degenerate altogether. These results may be best interpreted in the context of proactive interference confounding this part of Experiment 3.

The basic premises of motor skills research developed with adults have been related to child growth and development. Children adhere closely to the performance characteristics of adults suggesting that the laws of motor behaviour are parsimonious over the three age levels, extending probably to adulthood. Differences do occur between age groups in those tasks which require a high degree of cognitive control over motor behaviour indicating that some motor performances may require more cognitive ability than very young children possess. Nevertheless, the basic principles of motor learning and performance hold true for children as they do for adults.

BIBLIOGRAPHY

Adams, J.A. "A closed loop theory of motor learning." J. Motor Behavior 3(2):111-150. 1971.

Adams, J.A. and S. Dijkstra. " Short term memory for motor responses." J. Expt. Psych. 71:314-318. 1966.

Alton, M.W. and J. Weil. "Young children's use of temporal and spatial order information in short term memory." J. Expt. Child Psych. 24:147-163. 1977.

Anooshian, L.J. and K.L. Witson. "Distance distortions in memory for spatial locations." Child Dev. 48:1704-1707. 1977.

Ascoli, K.M. and R.A. Schmidt. "Proactive interference in short term memory." J. Mot. Behav. 1:29-36. 1969.

Babich, F.R., A.L. Jacobson, and S. Bubash. "Cross-species transfer of learning: effect of RNA from hamsters on rat behaviour." Proc. Nat. Acad. Sci. 54:1299-1302. 1965.

Boswell, J. and E.A. Bilodeau. "Short term retention of a simple motor task as a function of interpolated activity." Perc. and Motor Skills 18:227-230. 1964.

Brown, J.B. "Some tests of decay theory of immediate memory." J. Expt. Psych. 10:12-21. 1958.

Brown, R.M. "An examination of visual and verbal coding processes in preshcool children." Child Dev. 48:38-45. 1977.

Bruner, J. "Organization of early skilled action." Child Development 44:1-11. 1973.

Burwitz, L. "Proactive interference and directed forgetting in short term memory." J. Expt. Psych. 102:799-805. 1974.

Chorover, S.L. and P.H. Schiller. "Short-term retrograde amnesia in rats." J. Comp. Physiol. Psych. 59:73-78. 1965.

Cohen, R.L. and T. Sandburg. "Relation between intelligence and short term memory." Cog. Psych. 9:534-554. 1977.

Conrad, R. "The chronology of the development of covert speech in children." Developmental Psych. 5:398-405. 1971.

Corkin, S. "Acquisition of motor skill after bilateral medial temporal lobe excision." Neuropsychol. 6:255-265. 1968.

Corlett, J.T. "A systems model of physical training and performance." Unpublished M.Sc. thesis, Simon Fraser University. 1977.

Corlett, J.T., T. Calvert, and E.W. Banister. "The cybernetics of human performance." In "Current Topics In Cybernetics And Systems". Springer-Verlag Pub. Co. Berlin. 1978. Ed. J. Rose.

Cratty, B.J. "Movement Behaviour And Motor Learning". H. Kimpton Pub. Co. London. 1967.

Dickinson, J. "Directed forgetting in motor short term memory." J. Hum. Move. Studies 1:49-50. 1975.

Dickinson, J. "Adaptation level and retroactive interference in motor short term memory." Perc. and Motor Skills 44:691-694. 1977.

Diewert, G.L. "Retention and coding in short term memory: a comparison of storage codes for distance and location information." J. Motor Behaviour 7(3):183-190. 1975.

Diewert, G.L. "The role of vision and kinesthesis in coding of two dimensional movement information." J. Hum. Movement Stud. 3:191-198. 1976.

Diewert, G.L. and E.A. Roy. "Coding strategy for memory extent information." J. Expt. Psych. 4(6):666-675. 1978.

Dixon, W.J. and M.B. Brown. "Biomedical Computer Programs P-Series" Univ. Of Cal. Press. 1977.

Druker, J. and J. Hagen. "Developmental trends in the processing of task-relevant and task-irrelevant information." Child Development 40:371-382. 1969.

Dusenberry, L. "A study of the effects of training in ball throwing by children ages three to seven." Research Quarterly 23:9-14. 1952.

Ebbinghaus, H.I. Cited in "Memory: A Contribution To Experimental Psychology". Dover Press, N.Y. H. Roger and C. Buisenhuis, Eds.

Eckert, H.M. and D.H. Eichorn. "Developmental variability in reaction time." Child Dev. 48:452-458. 1977.

Emmerich, H.J. and B.P. Ackerman. "Developmental differences in recall: encoding or retrieval?." J. Expt. Child Psych. 25:514-525. 1978.

Ferguson, G.A. Statistical Analysis In Psychology And Education. McGraw-Hill Book Co. New York, N.Y. 1976.

Fishbein, H.D., J. Decker, and P. Wilcox. "Cross modality transfer of spatial information." Brit. J. Psych. 68:503-508. 1977.

Fitzgerald, J.M. "Verbalization effects in young children: classification abilities and the use of verbal labels." Child Dev. 48:604-611. 1977.

Flexner, L.B., J.B. Flexner, and R.B. Roberts. "Stages of memory in mice treated with acetoxycycloheximide before or immediately after learning." 56:730-735. 1967.

Gaito, J. "Molecular Psychobiology". C.C. Thomas Pub. Co. Springfie Illinois. 1966.

Gerson, R.F. and J.R. Thomas. "Schema theory and practice variability within a now-Piagetian framework." J. Motor Behavior 9(2):127-134. 1977.

Hagen, J.W. "The effect of distraction on selective attention." Child Development 38:685-694. 1967.

Haith, M., F. Morrisson, K. Sheingold and P. Mindes. "Short term memory for visual information in children and adults." J. Expt. Child Psych. 9:454-469. 1970.

Haith, M. "Developmental changes in visual information processing and short term visual memory." Human Development 14:249-261. 1971.

Helson, H. "Adaptation Level Theory". Harper and Row Pub. Co. N.Y. 1964.

Henry, F.M. "Absolute error vs. E in target accuracy." J. Motor Behavior 7:227-228. 1975.

Herman, L.M. and D.R. Bailey. "Comparative effects of retroactive and proactive interference in motor short term memory." J. Expt. Psych. 36(3):407-415. 1970.

Hicks, J. "The acquisition of motor skills in young children." Child Development 2:156-158. 1931.

Hicks, P. and I. Cohn. "Lack of proactive interference in a psychomotor task at two retention intervals." J. Mot. Behav. 7:101-104. 1975.

Hill, W.F. "Learning: A Survey Of Psychological Interpretations". Chandler Pub. Co. 1963.

Hodgkins, J. "Reaction time and speed of movement in males and females at various ages." Research Quarterly 34:335-343. 1963.

Hull, C.L. "Principles Of Behaviour". Appleton-Century-Crofts Pub. Co. N.Y. 1943.

Hyden, H. and E. Egyhazi. "Nuclear RNA changes of nerve cells during a learning experiment in rats." Proc. Nat. Acad. Sci. 48:1366-1373. 1962.

Jenkins, J.G. and K.M. Dallenbach. "Oblivescence during sleep and waking." Amer. J. PSych. 35:605-612. 1924.

Jones, B. "Role of central monitoring of efference in short term memory for movements." J. Expt. Psych. 102:37-43. 1974.

Jung, J. "Verbal Learning". Holt, Rinehart, and Winston Pub. Co. N.Y. 1972.

Kay, H. "Information theory in the understanding of skills." Occupational Psych 31:218-224. 1957.

Keele, S.W. "Attention and Human Performance". Goodyear Pub. Co. Pacific Palisades, Ca. 1973.

Keeney, T., S. Canizzo, amd J. Flavell. "Spontaneous and induced verbal rehearsal in a recall task." Child Development 38:953-966. 1967.

Kelso, J. and G. Stelmach. "Central and peripheral mechanisms in motor control." In "Motor Control Issues and Trends". Academic Press, New York. 1976. Ed. G.E. Stelmach.

Kerr, B. "Processing demands during mental operations." Memory and Cogn. 1:401-412. 1973.

Kolers, P.A. "Interlingual facilitation of short term memory. J. Verb. Learn. and Verb. Behav. 5:314-319. 1966.

Kreuger, W. "The effect of overlearning on retention." J. Expt. Psych. 12:71-78. 1934.

Krupski, A. and P.R. Boyle. "An observational analysis of children's behaviour during simple reaction time task: the role of attention." Child Dev. 49:340-347. 1978.

Keppel, G. and B.J. Underwood. "Proactive inhibition in short term retention of single items." J. Verb. Learn. and Verb. Behav. 1:153-161. 1962.

Laabs, G.J. "Retention characteristics of different reproduction cues in motor short term memory." J. Expt. Psych 100:168-177. 1973.

Laabs, G.J. Unpublished Doctoral Dissertation. Univ. of Oregon. 1971.

Laabs, G.J. "The effect of interpolated motor activity on the short term retention of movement distance and end location." J. Mot. Behav. 6:279-288. 1974.

Leuba, J.H. "The influence of duration and rate of our movements upon judgement of their length." Amer. J. Psych. 20:374-385. 1909.

Longstreth, L.E. and V. Zoltan. "Developmental changes in retention: independent of age?" J. Expt. Child Psych. 26:115-121. 1978.

Marteniuk, R.G. "Retention characteristics of motor short term memory." J. Mot. Behav. 5:249-259. 1973.

Marteniuk, R.G., K. Shields, and S. Campbell. "Amplitude, position, timing, and velocity as cues in reproduction of movement." Perc. and Mot. Skills 35:51-58. 1972.

Martin, E. "Transfer of verbal paired associates". Psych. Rev. 72:327-343. 1965.

McConnell, J.V. "Memory transfer through cannibalism in planarians." J. Neuropsychiat. 3:42-48. 1962.

McGeoch, J.A. and A.L. Irion. "The PSychology Of Human Learning". McKay Pub. Co. N.Y 1952.

Melton, A.W. and J.M. Irwin." The influence of degree of interpolated learning on retroactive inhibition and the overt transfer of specific responses." Amer. J. Psych. 53:173-203. 1940.

Millar, J. "Flexion-extension sensitivity of elbow joint afferents in cat." Exp. Brain Res. 24:209-214. 1975.

Milner, B., S. Corkin, and H.L. Teuber. "Further analysis of the hippocampal amnesic syndrome: 14 year followup of H.". N. Neuropsychol. 6:215-234. 1968.

Montagu, W.E. and W.A. Hillix. "Intertrial interval and proactive interference in short term memory." Can. J. Psych. 22:73-78. 1968.

Niemark,E., N. Slotnick, and T. Ulrich. "Development of memorization strategies." Developmental Psych. 5:427-432. 1971.

Osgood, C.E. "The similarity paradox in human learning: a resolution." Psych. Rev. 56:132-143. 1949.

Pavlov, I. Cited in "Learning: Processes". MacMillan Pub. Co. N.Y. 1964.

Pepper, R.L. and L.M. Herman. "Decay and interference effects in short term retention of a discrete motor task." J. Expt. Psych. Mono. Supp. 83:1-18. 1970.

Peterson, L. and M. Peterson. "Short term retention of individual items." J. Expt. Psych. 58:193-198. 1959.

Peterson, L.R., K. Hilner, and M. Saltzman. "Time between pairings and short term memory." J. Expt. Psych. 58:193-198. 1962.

Posner, M.I. "Characteristics of visual and kinesthetic memory codes." J. Expt. Psych. 74:103-107. 1967.

Postman, L. "The present status of interference theory." In "Verbal Language And Verbal Behaviour". McGraw-Hill Pub. Co. N.Y. Ed. C.N. Cofer.

Rarick, G.L. "Concepts of motor learning: implications for skill development in children." In "Child In Sport and Physical Activity". Univ. Park Press, Baltimore, Md. 1978. Eds. J. Albinson and G. Andrew.

Reiber, M. "Mediational aids and motor skill learning in children." Child Development 39:559-567. 1968.

Robinson, E.S. "The similarity factor in retroaction." Amer. J. Psych. 39:297-312. 1927.

Roy, E.A. "Measuring change in motor memory." J. Motor Behaviour 8:283-287. 1976.

Schmidt, R.A. "The schema as a solution to some persistent problems in motor learning theory." Psych. Rev. 82:225-260. 1975.

Schutz, R. and E.A. Roy. " Absolute error: the devil in disguise." J. Motor Behavior 5:141-153. 1973.

Sheingold, K. "Developmental differences in intake and storage of visual material." J. Expt. Child Psych. 16:1-11. 1973.

Singer, R.N. "Physical characteristics, perceptual-motor, and intelligence differences between third and sixth graders." Research Quarterly 40:803-811. 1969.

Singer, R.N. "Motor Learning And Human Performance". MacMillan Pub.Co. N.Y. 1975.

Skinner, B.F. "Science And Human Behaviour". MacMillan Pub. Co. N.Y. 1953.

Skinner, B.F. "Reinforcement today." American Psychol. 13:94-99.

Smothergill, D.W. "Accuracy and variability in localization of spatial targets at three age levels." Develcpmental Psych. 8:62-66. 1973.

Sperling, G. "The information available in brief visual presentations." Psych. Monographs, 74. 1960.

Sroufe, L.A. "Age changes in cardiac deceleration within a fixed foreperiod reaction time task: an index of attention." Developmental Psych. 5:338-343. 1971.

Stelmach, G.E. and M. Wilson. "Kinesthetic retention, movement extent, and information processing." J. Expt. Psych. 85:425-430. 1970.

Stelmach, G.E. "Kinesthetic recall and information reduction activity." J. Mot. Behav. 2:183-194. 1970.

Stelmach, G.E. "Retention of motor skills." In "Exercise and Sport Sciences Reviews". Vol.2. Academic Press, N.Y. Ed. J. Wilmore. 1974.

Stelmach, G.E., S.A. Wallace, and H. McCracken. "Location duration in distance reproduction." In "Psychology Cf Motor Behaviour and Sport". Vol. 1. Human Kin. Pub. Champaign, Ill. Eds. D.M. Landers and R.W. Christina. 1976.

Tanner, J.M. "Growth At Adolescence". 2nd Ed. Oxford: Blackwell Scientific Publications. 1962.

Tanner, J.M. "From Fetus To Man". Harvard Univ. Press. Cambridge, Mass. 1978.

Thompson, D. "Growth And Form". Rev. Ed. London. 1942.

Thorndike, E.L. Cited in "Learning: Processes". MacMillan Pub.Co. New York. Ed. M.H. Marx. 1964.

Tolman, E.C. "Theories Of Learning". In "Comparative Psychology". Prentice-Hall Pub. Cc. Englewood Cliffs, N.J. 1934.

Tolman, E.C. "There is more than one kind of learning". Psych. Rev. 56:144-155.

Tracey, D.J. "Characteristics of wrist joint receptors in the cat." Exp. Brain Res. 34:165-176. 1979.

Tulving, E. "Subjective organization in free recall of unrelated words." Psych. Rev. 69:344-354. 1962.

Underwood, B.J. "False recognition produced by implicit verbal responses." J. Expt. Psych. 70:122-129. 1965.

Underwood, B.J. "Speed of learning and amount retained: a consideration of methodology." Psych. Bull. 51:276-282. 1954.

Watson, J.B. "Behaviourism". W.F. Norton and Co. N.Y. 1930.

Welford, A.T. "Fundamenatals Of Skill". Methuen and Co. London. 1968.

Weist, R.M. and J. Crawford. "The development of organized rehearsal." J. Expt. Child Psych. 24:164-179. 1977.

Wickelgren, W.A. "Sparing of short term memory in an amnesic patient: implications for strength theory of memory." Neuropsychol. 6:235-244. 1968.

Wild, M.R. "The behaviour pattern of throwing and some observations concerning its course on the development in children." Research Quarterly 9:20-24. 1938.

Williams, I.D. "The effects of practice trials and prior learning on motor memory." J. Motor Behaviour 3:205-211. 1971.

Zelaznik, H.N. "Transfer in rapid timing tasks: an examination of the role of variability in practice." In "Psychology Of Motor Behaviour And Sport". Human Kin. Press. Champaign, Ill. Eds. D.M. Landers and R.W Christina. 1976.

APPENDIX 1: A POSTERIORI ANALYSIS OF SIGNIFICANT MAIN EFFECTS OF EXPERIMENTS 1, 2, AND 3

Appendix 1 presents the results of a posteriori analysis of significant main effects described in the text in Tables 1 and 2. Only absolute error main effects are considered here since they are the only ones around which the discussion of development has revolved. Calculations were done using the method of Scheffe as described by Ferguson (1976). Critical F values were chosen to test statistical significance at the 0.05 level.

The following abbreviations are used in this appendix:

KIN = KINDERGARTEN

GR3 = GRADE 3

GR6 = GRADE 6

10CM = 10 CENTIMETER MOVEMENTS

20CM = 20 CENTIMETER MOVEMENTS

40CM = 40 CENTIMETER MOVEMENTS

0SEC = 0 SECOND RETENTION INTERVAL

15SEC = 15 SECOND RETENTION INTERVAL

30SEC = 30 SECOND RETENTION INTERVAL

CON = CONTROL GROUP, EXPERIMENT 2

DF = DIRECTED FORGETTING, EXPERIMENT 2

NDF = NO DIRECTED FORGETTING, EXPERIMENT 2

COMPARISON	CALCULATED F	CRITICAL F
GR3 - GR6	5.27	6.22
GR3 - KIN	6.84	6.22
GR6 - KIN	24.19	6.22
10CM - 20CM	5.63	6.22
20CM - 40CM	38.03	6.22
10CM - 40CM	72.90	6.22
0SEC - 15SEC	38.62	6.22
15SEC - 30SEC	110.62	6.22
0SEC - 30SEC	280.00	6.22
CON - DP	13.32	6.22
DP - NDP	22.56	6.22
CON - NDP	70.56	6.22