SCHEDULING AND FREQUENCY
OF KNOWLEDGE OF RESULTS PRESENTATIONS:
AGE-RELATED EFFECTS ON MOTOR LEARNING

By

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ABSTRACT

Changes in motor control processes associated with advancing age have been the focus of considerable research interest. However, the effect of age on the processes involved in motor skill acquisition have received little attention. In this thesis, two experiments are reported that examine the differences in motor learning between young and older normal adults. The strategy was to evaluate the age-related effects on learning of knowledge of results (KR) variables. The learning task in both experiments was a multisegment task with spatial/temporal requirements. The KR variables evaluated were, 1) random and blocked KR schedules, and 2) different schedules of relative frequency of KR. In general, while the findings indicated large performance differences between age groups, there was no difference between age groups in how the KR variables were used to learn the task. The results suggest that despite declines in performance that accompany age, there seems to be no decline in the capabilities of older adults to use these KR variables to acquire and retain this motor skill.
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PREFACE

This dissertation is a combination of background papers, a published paper, and a paper that has been submitted for publication. The Effects of Aging and Schedules of Knowledge of Results on Motor Learning (Chapter 3) was published in Journal of Gerontology: Psychological Sciences, 1992, 47, 406-411. This article is reprinted with permission from the journal. The Effects of Aging and Reduced Relative Frequency of Knowledge of Results on Motor Learning (Chapter 4) was submitted for publication to Journals of Gerontology: Psychological Sciences.

In both of these articles, Dr. Timothy Lee is the second author. The student’s original contribution to both experiments was to be primarily responsible for the design, implementation, data collection and analyses, and write up of both experiments.
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Chapter 1: AGING AND MOTOR PERFORMANCE

INTRODUCTION

A combination of extended average life expectancy and an elevated post-World War II birth rate has resulted in a change in the demographics of society in North America over this century. There is an increasingly larger percentage of the population over 60 years of age, with the fastest growing segment of the population over 75 years old (Lovelace, 1990). With this rapid increase in the elderly population, knowledge about the effect of age on skills and behaviours is crucial for the maintenance and development of functional abilities of these older adults. The identification of age-related changes in performance of learned skills (which is the area of motor control) is different from the study of the acquisition of new skills (which is the motor learning domain). However, knowledge of their combined influence can be used to enable older adults to maximize their participation in a variety of recreational and work-related skills, as well as acquiring adaptive skills in response to physical limitations. An understanding of the effects of age on the ability to perform and learn motor skills will provide a basis for maximizing the physical functioning potential of aging adults.

The purpose of this chapter is to review what is known about the age-associated changes in motor performance, focusing on changes in healthy, older adults (60 years of age and older) compared to younger adults (between the ages of 18 and 30). Although
there is evidence that age affects a wide range of functions, this review will concentrate on the effect of age on motor performance. The coverage of this area will begin with a review of the findings of the effects of age on motor performance. After identifying the types of motor performance that are affected by age, I discuss the processes underlying motor performance that are affected by age. The research in this area has been based on an information processing model. The focus has been to identify the processes within the model that are age-sensitive. More specifically, through manipulation of different variables, an attempt has been made to determine the effects of age on both movement preparation and movement execution.

In the later sections of this chapter, evidence for changes in motor performance strategies will be considered. The manner in which older adults perform movement tasks, combined with whether or not they use different strategies, has implications for how older adults learn new motor skills. If there are changes in the processing of information and in movement strategies that affect movement execution, the expectation is that older adults may use different learning strategies in order to obtain new skills. An understanding of the motor performance changes that occur with aging is essential in order to adequately study the potential implications of age on motor learning which will be the focus for the remainder of the thesis.

**EVIDENCE OF CHANGE IN MOTOR PERFORMANCE WITH AGE**

A number of physiological changes occur with age that have been associated with decreased functioning of the visual, somatosensory and the neuromuscular systems, as
well as the peripheral and central nervous systems (see Mortimer, Pirozzolo, & Maletta, 1982; Williams, 1989, for review). The relation between the physiological changes and motor performance is not clear. However, a consistent finding is that with advancing age there is a general decline of speeded performance, as measured by reaction time and movement time (see Stelmach & Goggin, 1989, for review).

Reaction time is defined as the interval between stimulus onset and the initiation of a response. It is considered to be a measure of central processing duration for processes involved in stimulus identification and movement planning (e.g., Massaro, 1975). Movement time is the period from response initiation to the completion of the movement. It is thought to be influenced by central processes (such as error correction) and peripheral processes (such as neural transmission) (Goggin & Stelmach, 1990a). Although the changes in the various peripheral systems will influence both reaction and movement time, the age-related slowing of motor performance is thought to be largely determined by changes in central processes (Botwinick, 1984, chapter 13; Cerella, 1985; Salthouse, 1985a, 1985b; Welford, 1982, 1984). As a result, a major focus of psychological research has been to identify what aspects of the central processing are affected by aging (Goggin & Stelmach, 1990a; Light, 1990; Stelmach & Goggin, 1989).

INFORMATION PROCESSING MODEL OF MOTOR PERFORMANCE

Research paradigms that have been used are based on information processing models of motor performance. In order to produce purposeful movements in response to a changing environment, the central nervous system (CNS) needs to process and
interpret sensory input, decide on the best response, and then produce the appropriate action by executing the correct movement sequencing, timing and coordination. Collectively, these activities in the CNS are referred to as information processing. Although different information processing models of movement control are described in the literature, the Schmidt (1988) model includes the three essential stages. In the first stage, the stimulus is detected and identified (the stimulus identification stage). In the second stage, the appropriate response is selected (the response selection stage). In the final stage, the response is organized and initiated (the response programming stage). A basic premise of this model is that time is required to complete each of the stages of processing. The length of time to complete each stage can be considered a measure of the amount of processing (Donders, 1868/1969). By challenging the different stages with various manipulations, the relative time to complete a stage can be used as an indirect measure of how these manipulations affect information processing (Sternberg, 1969). The influence of age can be evaluated by comparing the differences in responses to various manipulations of task requirements by younger and older adults.

The intent of this review is to provide an overview of the age-related changes in motor performance rather than to identify what stage is most affected by age. For the purpose of this review, the literature will be discussed as it relates to processes involved in preparing for action. As such, the findings from these studies will be presented under the general headings of movement preparation and movement execution.
AGE-RELATED FACTORS THAT INFLUENCE MOVEMENT PREPARATION

Reaction time can be used as a measure of movement preparation. Suppose, in an emergency, someone asked you to dial a phone number as quickly as possible. If the number were written on paper then the translation of the input (the digits written on the paper), to the output (the digits that appear on the dials of the telephone) would be rather direct, and the time taken to prepare to begin dialling would have been relatively short. If however, the digits had been given orally, then a translation from the auditory code to a code that was appropriate for the action would have been required during the movement preparation period. This is an instance where the nature of the stimulus information affected movement preparation. However, other factors affect movement preparation as well. Suppose you had a long number to dial, such as first dialling a seven digit, long-distance access code, followed then by a ten digit destination number. A likely strategy would be to divide the actions into "chunks" of three or four digit sequences. The time prior to executing each chunk would also be a part of the preparation period. And lastly, consider that the phone you were using had a layout with which you were unfamiliar. This would also require some time to prepare for the route to be taken between keys (or holes on the dial). This simple example of dialing a phone number in a hurry illustrates some of the various movement preparation factors that have been examined in the aging research.

The tasks that have been used to study reaction time have focused on upper limb performance of short, rapid movements. Typically, subjects are asked to move to a designated target in response to a signal. The instructions often stress to subjects to
move as quickly and accurately as possible. Depending on the research question, various task parameters can be manipulated such as: the amount and timing of premovement information, the length of the preparation time, the validity of advanced information, the number and compatibility of response choices, and the response complexity.

**Amount of Premovement Information**

One of the variables that has been studied in relation to the effect of age on movement preparation is the amount of premovement information. The amount of premovement information refers to how much information is provided to the subject about the movement prior to the signal to respond (i.e., direction or extent of movement, or limb to move). The time required to prepare or program a movement can be assessed by varying the amount of information.

Findings from studies addressing the age-related effects of varying the amount of information available prior to movement indicate that older adults take longer to prepare movements where less information is provided. For example, Stelmach, Goggin, and Garcia-Colera (1987) varied the amount of advanced information. They used a precuing technique in which different amounts of information were given, ranging from no advanced information to full information about the details of the movement to be made. The task consisted of three movement parameters: extent, direction and arm. The amount of information varied from no information to cuing on all three parameters. Both younger and older adults were able to use advanced information, but older adults were increasingly slower than younger adults as less information was provided prior to
movement. These findings indicate that the processes that are associated with preparing movement parameters become less efficient with age.

Length of Preparation Time

The ability to maintain the preparation can be assessed by altering the timing of the premovement information. For example, information can be provided well in advance or immediately before the subject is required to execute the designated movement. In this paradigm, the ability to gain or maintain the preparation of the movement is assessed. Gottsdanker (1980a) used a transit-signal method of measuring reaction time in which a target moved across a screen at a constant rate crossing 10 different, equally spaced, vertical lines. The subject’s task was to press a button with a forefinger in response to a signal. The signal (a tone) could occur only as the target crossed one of the lines. Using this transit-signal method, Gottsdanker (1980a) found no difference in reaction times with long preparation time (4.68 seconds) in both young and older adults who had been matched on simple reaction time. However, in a study that compared the ability to maintain preparation over different lengths of constant preparation intervals (1 and 4 seconds), Gottsdanker (1982) found that older adults’ reaction time was slower than younger adults with a longer constant preparation time (4 seconds) compared to the short preparation interval (1 second). Thus, it seems that older adults have difficulty with the control of preparation depending on the length of the preparatory interval and the preparation required by the task.
Strauss, Wagman, and Quaid (1983) compared constant and irregular preparation intervals ranging from 1 to 13 seconds by randomly placing sets of four trials of the same preparation interval in series of trials with random preparatory intervals. The reaction time for the fourth trial of the repeated set was used as a measure of the effect of the length of the constant preparation interval. The first trial in the repeated set was used as a measure of performance due to irregular preparation intervals. This method was thought to control for both fatigue and motivation effects. Strauss et. al. (1983) found that older adults had more difficulty maintaining preparation if the preparation interval was long and constant (13 s) when compared with shorter regular preparation intervals. At 13 seconds, performance on the irregular trials was better than the regular trials. Unfortunately, this experiment did not have a young adult group, which would have allowed for a direct comparison of age-related changes.

Goggin, Stelmach, and Amhrein (1989) also manipulated the length of preparation, using intervals from 200 ms to 2 s. In addition they varied the length of the precue stimulus viewing time. They found that a combination of short precue viewing time and short preparation time increased the reaction time in older adults compared to young adults. With the very short interval, older adults did not have enough time to complete the movement preparation.

The collective results of these studies suggest that older adults need more preparation time, but they tend to have difficulty maintaining the preparation if the time is too long.
Adjusting for Invalid Advanced Information

Another method of evaluating the effect of age on movement preparation is by changing the validity of the advanced information. In this paradigm, incorrect advanced information is provided to the subject on a small proportion of the trials. In the incorrect information trials, subjects who have already prepared one movement based on erroneous information are expected to reprogram the correct movement during the reaction time interval. The time requirement is longer to prepare a movement that needs to be reprogrammed compared to a movement that has already been prepared in response to a correct precue. Larish and Stelmach (1982) and Stelmach, Goggin, and Amhrein (1988) investigated the provision of either correct or incorrect advanced information to younger and older adults. These studies found that although older adults’ reaction times were slower than younger adults, they were not differentially affected by the incorrect precuing of arm and direction. However, Stelmach and his colleagues (1988) found that older adults were slower when they had to reprogram a short distance movement. These findings suggest a selective slowing on movement reprogramming: no age associated effect on arm and direction reprogramming, but slowing when a change in movement amplitude is required.

In the above studies, the precue stimulus display and the preparation interval were fixed at 1 s each. Given this length of time, it is difficult to determine if there was a masking of age-related differences in the movement preparation plan, maintenance, and/or reprogramming strategies. In recent experiments (Amhrein, Stelmach, & Goggin, 1991; Amhrein, Von Dras, & Anderson, 1993), the length of the preparation interval
(250, 500, 750, or 1000 ms) was manipulated together with incorrect precuing about arm and or direction on 25% of the trials. Interestingly, in the reprogramming trials with a preparation interval of 1000 ms, older subjects were faster than young adults at reprogramming direction of the movement, suggesting that they were less able to construct and maintain a movement plan for direction than young adults. Thus, when a restructuring of direction of the movement was required, older adults had either not planned for this parameter in response to the precue, or they were not able to maintain the plan. Indeed, they took less time to respond because they only had to plan the movement, as opposed to the longer process of altering the intact movement plan and then planning a new response.

Collectively, these studies suggest some differences between ages in adjusting to invalid information. However, further work is needed to clarify more precisely the movement parameters that are most affected by advanced age.

Number and Compatibility of Response Choices

Other variables that have been found to have an age-related influence on movement preparation are the number of response choices as well as the compatibility of the response with the stimulus. Several studies have shown that simple reaction time, such as pressing a key in response to a stimulus are tasks minimally affected by age (Welford, 1982). But older adults take longer to initiate a response when there is an increase in the number of choices (Welford, 1982). Furthermore, when the stimulus is not compatible with the response, (for example, when the left hand is to move in
response to a stimulus on the right side), older adults again are slower to react than younger adults (Rabbitt 1964, Welford, 1982).

**Response Complexity**

Another variable that has been used to address the effect of age on movement preparation is response complexity. Movement complexity is altered by increasing the number of movement components or by increasing the number of movements that are to be performed simultaneously. The guiding principle is that the more complex the movement the longer it takes to program it (Henry & Rogers, 1960).

Williams, Keith, Richter, Clancy, and Carter (1987) assessed the effects of age on planning movements involving increasing complex movements of the hand and arm. In response to a light stimulus the reaction time was measured to initiate a finger lift. Complexity was varied by following the finger lift either with a simple or a complex arm/hand movement. For the simple movement, preparation time increased with each age decade between 50 and 95 years. There was a more pronounced slowing of preparation of the complex movement with advanced age, suggesting that there is a greater effect of age on preparation of complex tasks.

Stelmach, Amhrein, and Goggin (1988) investigated age-related effects of task complexity by requiring single or dual limb responses. Eight possible combinations of upper limb movements (unimanual, symmetrical bimanual, and asymmetrical bimanual lateral movements) were created by manipulating which arm and how far to move. The complexity of the task increased as more movement parameters were incorporated. The
results indicated that reaction time for older adults was slower than young adults regardless of task complexity. As well, age had a differential effect on movement extent. Older adults were slower to prepare short movements compared to longer movements, whereas there was no difference in the reaction time of young adults for movement extent. However, both age groups demonstrated a similar increase in reaction time with more complex tasks. Another finding from this study indicated an additional difference related to aging changes in preparation of movement. When the initiation of bimanual movements was assessed, older adults were found to exhibit asynchrony, particularly in the asymmetric tasks. In other words, older adults prepared more complex movements in a similar manner to young adults, but there seemed to be some difficulty in bimanual movement initiation.

By using four different movements of the fingers (right index flexion, right pinch, bilateral flexion, and bilateral pinch), Light and Spirduso (1990) also investigated the age associated effects on preparation of tasks that varied in complexity. This choice of tasks represents an increase in difficulty from a one digit movement with one hand to a two digit movement with both hands. Each movement represented a different level of movement complexity. Overall, older adults were slower to initiate all the movements. In addition, older adults took significantly longer to program each of the greater complexities of movement. In contrast, younger adults were significantly slower only when programming the bilateral movements compared to the unilateral movements. This study suggests that there is a differential age response to increased movement complexity in tasks involving one or both hands. These findings differed from Stelmach et al.’s
(1988) results in which there was no age-related difference in response to task complexity. The difference in the findings between these studies may be due to the type of tasks, but both studies indicate there is some difficulty with preparation of bimanual tasks.

Summary of Age-related Changes in Movement Preparation

In summary, this work on movement preparation has identified several variables that differentially affect reaction time in older adults. These variables include the amount of premovement information, the length of preparation time, the validity of advanced information, the number and compatibility of response choices, and the complexity of the movement task. Generally, these manipulations of these variables increase the difficulty of the preparation and the result is slower reaction times in older adults compared to young adults.

From these studies, it appears that with aging, there is increased difficulty in preparing or programming movements. Movement preparation is adversely affected if there is either too long a time between the precue signal and the movement cue, or too short a time for precue viewing before the movement cue. As well, older adults appear to function differently in response to the need to reprogram a movement once they have attempted to prepare another movement. Furthermore, older adults have more difficulty programming movements when there is movement uncertainty due to more movement choices or incompatibility between stimulus and response. Finally, older adults have a tendency to take longer than younger adults to prepare more complex movements.
AGE-RELATED CHANGES IN MOVEMENT EXECUTION

Having reviewed the effects of age on the preparation of movement as measured by reaction time, the next question to consider is the effect of age on the control of movement execution. Movement execution can be characterized in a variety of ways. To extend the analogy given earlier, the time to dial the phone number provides a gross idea of the movement speed. A more detailed analysis of the movements however, such as the velocity and acceleration profiles between the individual keys, and the forces by which the keys are depressed, would provide a more fine-grained description of how the dialling action was executed.

Movement Time

Movement time is a measure of response duration that includes central control processes and the time for muscles to contract. Although there has not been the same interest in movement execution as there has been in movement preparation, as mentioned at the beginning of this chapter, many studies have indicated that there is a slowing of response duration with advanced age, particularly with more complex tasks (Salthouse, 1985b; Singleton, 1954; Welford, 1988).

Stelmach, Amrhein, and Goggin (1988) found that older adults were slower than younger adults when performing bimanual movements as opposed to movements with one hand. In this study not only was the movement time slower in older adults, but, interestingly, older adults demonstrated greater asynchrony in bilateral movement termination. Although subjects were not asked explicitly to finish bimanual movements
simultaneously, both age groups demonstrated this tendency which is considered a measure of limb compensation. However, older adults were less able to compensate or yoke interlimb activity. These findings suggest that older adults have less ability to control movement execution, and particularly, more complex interlimb movements.

Movement Kinematics

Evidence also suggests that in addition to movement time changes with advancing age, older adults use different movement patterns or kinematics. Murrell and Entwisle (1960) evaluated the pattern of movement produced by young and older adults in a choice reaction time paradigm where the task was to move the hand in response to a four-choice stimulus. They found that older adults were slower to accelerate and had a shorter deceleration phase than younger adults.

In a more recent study, Goggin and Stelmach (1990b) compared the movement patterns of young and older adults in different precuing conditions. The precuing conditions were similar to an earlier study by Stelmach, Goggin and Garcia-Colera (1987) in which precue information about arm, extent and direction of movement was manipulated. In all precuing conditions, older adults were slower to reach peak velocity and had a prolonged deceleration phase than young adults. In addition, older adults showed no difference in peak velocity between long and short movements (5 or 10 cm), while young adults scaled the peak velocity according to the length of the movement. According to Goggin and Stelmach (1989), the difference between the findings of the length of the deceleration phase, compared to the Murrell and Entwistle (1960) results,
may have been due to the increased accuracy requirement of the Goggin and Stelmach (1989) task.

Cooke, Brown, and Cunningham (1989) also studied kinematic characteristics of arm movements in younger and older adults. Using a visually guided step tracking task, they found that both age groups produced similar movement times and maximum velocities, but that in older adults the deceleration phase was longer than young adults. Older adults exhibited more variability in all movements, but particularly so in smaller amplitude movements (less than 40 degrees) and in the deceleration phase of all movements. The increased variability and time requirements exhibited by older adults during the deceleration phase of targeted movement suggest that older adults have difficulty controlling the precision components of movement.

Kinematic differences have been found between younger and older adults using aiming tasks of different amplitudes and different sizes of targets (Goggin & Meeuwsen, 1992). Older adults’ movements were slower to accelerate, achieved smaller peak velocities and acceleration, and had longer deceleration phases (see also Warabi, Noda, & Kato, 1986; Winchester & Roy, 1991). As well, older adults produced more movement adjustments when moving longer distances to the large targets. In contrast, younger adults increased the number of adjustments in response to smaller targets. Goggin and Meeuwsen (1992) hypothesized that more corrective type adjustments are made by older adults because they move more slowly, and thus have more time to adjust their movements. Interestingly, in this study, older adults made fewer errors than young
adults, perhaps due to a cognitive strategy to sacrifice speed for accuracy. The influence of age-associated changes in cognitive strategies will be addressed in a later section.

Although the tasks differ among these studies, the results generally indicate that there are some differences in kinematic characteristics in movement execution by older adults compared to younger adults.

**Movement Kinetics**

Although there is a paucity of work evaluating the effect of aging on the kinetic or force characteristics of movement, there is some evidence that suggests that older adults have more difficulty controlling force output. Vrtunski, Patterson, and Hill (1984) found that older adults had more difficulty in controlling a braking action in order to release a button. Further evidence regarding the effects of age on force production was found in a study by Stelmach, Teasdale, Phillips, and Worthingham (1989). Using an isometric contraction of the wrist and forearm subjects were asked to produce a variety of forces (15, 30, 45, and 60% of their maximum force output). There were no differences in the ability to produce the force requirements, but older adults increased the time-to-peak force in response to an increase in the required force. Young adults maintained a time-to-peak force regardless of the required force outputs. This finding suggests as the force requirements increase, older adults take longer to produce the force than younger adults.

Cole (1991) compared grasp force during a grasp and vertical lift of a small object in younger and older adults. He found older adults produced greater forces and
more variability in force production. Some of the increased force was explained by increased slipperiness and loss of tactile discrimination in the older adults' fingers.

Although much more work needs to be done in this area, the limited evidence suggests that there are changes in force production associated with age.

Summary of Age-Related Changes in Movement Execution

Collectively, these findings indicate that older adults execute movements, particularly more complex movements, more slowly than young adults. Furthermore, there are indications that both the kinematic and the kinetic aspects of movements are altered with age. As well, there seems to be age-related differences in the ability to coordinate bimanual movements.

COGNITIVE CAUSES OF AGE-RELATED CHANGES IN MOTOR PERFORMANCE

The studies presented above have identified several variables that differentially affect motor preparation with age as well as changes in how movements are executed. It is not clear whether these changes in movement preparation and execution are due only to the age-related differences in the information processing systems that control motor performance. There may be other factors associated with aging that influence changes in motor performance. One possibility is that older adults use different cognitive strategies when performing motor skills.
There is some evidence in the literature that there is an age-related difference in cognitive strategies. In some situations these changes in cognitive strategies enhance motor performance while in other situations the cognitive strategies are detrimental to performance. On the positive side, certain highly practised skills are maintained with age. For example, Murrell, Powesland, and Forsaith (1962) compared young and older men who were experienced pillar drillers and found no difference in speed and accuracy of the drilling. From this study, it is not clear whether the underlying control mechanisms were maintained or if cognitive strategies were used in order to maintain performance.

In a more recent study, Salthouse (1984) found that the typing speed and accuracy of older expert typists were the same as young expert typists. Evaluation of the strategies revealed that older typists who were slower on tests of choice reaction time compensated for this slowness by processing more characters in advance of the concurrently typed characters. Thus the skill is maintained with age due to adaptive changes in performance strategies.

However, other cognitive strategies that have been associated with aging tend to slow motor performance. One of the strategies that seems to be affected by age is the relation between speed and accuracy (Salthouse, 1988). Generally, when executing movements there is a tendency to become less accurate as the speed of movement increases. Several studies have suggested that compared to younger adults, older adults tend to move slower in order to maximize accuracy (Salthouse, 1979; Smith & Brewer,
1985; Welford 1984b). Older adults seem to place more value on accuracy and as a result, are more cautious in their movements.

There is also evidence that older adults do not make use of information that could help movement planning and execution. For example, compared to younger adults, older adults do not seem to use relative probabilities (Rabbitt, 1979; Rabbitt & Vyas, 1980; Sanford & Maule, 1971) to enhance motor performance. Although there is some evidence to the contrary (Gottsdanker, 1980b), this finding suggests that older adults may not make use of cognitive strategies than could enhance performance.

Overall, although the reasons are not well understood, the evidence indicates that in a variety of situations, older adults use cognitive strategies that are different than young adults. Some strategies seem to be used in order to counteract the declines in motor performance associate with movement preparation and execution.

CONCLUSION

The evidence presented in this chapter indicates that there are differences between younger and older adults in preparation and execution of movements. Generally, older adults are slower in both preparing and executing movements. As well, they respond differently to variables that influence movement preparation, and they tend to show differences in the kinematics of movement when compared to younger adults. These findings have practical implications for how older people function in their environment. For example, this literature has ramifications for the effect of aging on driving (Stelmach
& Nahom, 1992) and the types of interventions that can be devised to assist the older driver.

In addition, these findings have both practical and theoretical implications for how older adults learn motor skills. Given the differences in motor performance with age and the associated differences in performance strategies, older adults may adopt different learning strategies than younger adults. More specifically, older adults may utilize learning variables differently than young adults.
Chapter 2: AGING AND MOTOR LEARNING

INTRODUCTION

Whether in activities of daily living, recreational or work related pursuits, the ability to learn motor skills is an essential element to maximizing function throughout life. Although the effect of aging on motor control has been a focus of many investigations, the relationship between aging and motor learning has received very little attention. Given the age-related changes in the control of movement discussed in Chapter 1, the possibility arises that the process involved in learning motor skills in older adults may be different than in young adults.

There are at least two distinct stages of the motor learning process (Adams, 1971; Fitts & Posner, 1967; Gentile, 1972; Snoddy, 1926). The early stage of motor learning is thought to be highly cognitive, involving the active, problem solving processes of the learner. With the influence of cognition in early motor learning, the question of whether or not older adults learn motor skills differently than young adults becomes more intriguing in light of findings that changes in cognition are associated with aging. Perhaps with the age related cognitive changes (which will be discussed in this chapter), there are associated changes in the way older adults learn motor skills. With a
combination of age related changes in cognition and motor control, ultimately older adults may adopt different learning strategies.

One of the ways of assessing the possible changes in motor learning associated with aging is to manipulate a variable that is known to influence the early stages of motor learning in young adults. There are many variables that affect the early stages of motor learning, however, knowledge of results (KR) is the factor that probably has received the most attention. Knowledge of results is defined as "extrinsic, usually verbal (or verbalizable) information about the success of an action with respect to the environmental goal" (Schmidt, 1991c, p.231). Although studied extensively using young adults, there has been very limited research on the effect of KR on motor learning in older adults.

The overall purpose of this chapter is to review the literature on the role of KR in motor learning by both younger and older adults. This chapter will begin with an overview of the stages of learning and a review of the literature evaluating the role of KR in motor learning in young adults. The research on the effects of aging on motor learning will be presented including the evidence for the effectiveness of practice in older adults and the limited work on the role of KR in learning motor skills by older adults.

**STAGES OF MOTOR LEARNING**

Understanding how young adults learn motor skills has been a focus of study for many years. The learning process has been described as having different qualitative stages (Adams, 1971; Fitts & Posner, 1967; Gentile, 1972). The stages have been defined in relation to the amount and nature of cognition utilized throughout practice
(repetitions of the skill). Although there are differences in defining these stages, there is agreement that the earlier stages of learning involve cognitive activity including selective attention, error detection, and problem solving. Fitts and Posner (1967) identified three stages of motor learning: cognitive, associative and autonomous. In the cognitive stage, the learner attempts to gain an understanding of the task through practice and discussion about the task requirements. Performance tends to be highly variable with many errors, and the learner has little understanding of how to detect or correct errors. In the associative stage, the learner’s cognitive efforts are concentrated on refinement of the skill by applying error detection and correction strategies. Performance becomes more accurate and variability decreases. By the final autonomous stage, the skill has been practiced extensively and the cognitive requirements are reduced. The performer executes the skill almost automatically, focusing on adjustments of the skill in response to environmental and task related information in order to maximize performance.

Adams (1971) proposed a slightly different model of the stages of learning that has two stages: verbal-motor and motor. In the verbal-motor stage, which is similar to Fitts’ and Posner’s cognitive and associative phases, the learner attempts, through practice, to gain an overall concept of the skill. The cognitive skills include the learner’s verbalizing both subvocally and with others about the task. The motor stage is similar to Fitts’ and Posner’s autonomous stage in that execution of the skill is almost automatic and the role of cognition is to refine the skill to optimize performance.

Gentile (1972) developed a model of motor learning that was similar to the other models. She also identified an early stage in which the task of the learner was to "get
the idea of the task" by deciding what input information was important and identifying the best method of executing the movement. In the second stage, the learner perfected the task in response to the environmental requirements relating to the type of task.

With this agreement between models that cognitive activity is an integral part of early motor learning, generally, research in motor learning has focused on the early stages and the influence of variables on cognitive processes that mediate learning. Regardless of the motor learning model, extrinsic information about the outcome of the movement (KR) is considered an essential ingredient in these cognitive processes.

ROLE OF KNOWLEDGE OF RESULTS IN MOTOR LEARNING IN YOUNG ADULTS

Results from the work on motor learning in young adults identify information feedback, in combination with practice, as the most important variable in the early stage of motor learning (Adams, 1987; Newell, 1976; Salmoni, Schmidt, & Walter, 1984; Schmidt, 1988). Information feedback is a broad term referring to information provided to the learner about the achievement of the movement goal (Bilodeau, 1966). This type of feedback is considered extrinsic as it is provided by an external source and is supplemental to the intrinsic information. Intrinsic feedback is inherent to the action and is derived from sources such as proprioceptive, touch, and visual receptors (Winstein & Schmidt, 1989). The term "information feedback", or "augmented feedback", has been further differentiated into knowledge of performance (or KP) and KR (Gentile, 1972). Knowledge of performance refers to information about the pattern of the movement,
while KR refers to the outcome of the movement. Of the two types of feedback, KR has been studied more extensively (Adams 1987; Salmoni, Schmidt, & Walter, 1984).

The theoretical role of KR in learning has changed over time. According to behavioural theorists (Thorndike, 1927; Hull, 1943), the role of KR was to strengthen the associative bonds between the stimulus and response. Learning was thought to be an automatic formation of these connections due to repetition of the stimulus-response connection, and the learner was seen as relatively passive. Knowledge of results was the reinforcement that encouraged repetition of the most appropriate stimulus-response bond.

By the 1960s, under the influence of information processing models of motor control, KR was thought to be a powerful source of error information that the learner could use to actively change performance. Based on the information processing framework, theories of motor learning (Adams, 1971; Schmidt, 1975) were developed according to the premise that both learning and control of movements involved a series of processes or manipulations of intrinsic and environmental information. In Adams’ closed-loop theory of motor learning (1971), KR was considered essential for establishing perceptual traces in memory that became the basis for evaluating kinesthetic feedback from future movements. With each repetition, KR would be used to perfect the performance, and ultimately, the repetition of the correct performance would lead to a strong perceptual trace. Thus, the acquisition of the performance was dependent on KR. But, once the perceptual trace was strong, the correct movement could be generated without extrinsic feedback, relying instead on the perceptual trace.
Schmidt (1975), in response to some limitations of Adams' theory (Schmidt, 1988), developed a motor schema theory which proposed that a generalized motor program (an internal representation of a class of movements) was acquired with practice. The idea of a generalized motor program was in direct contrast to Adam's concept of a separate motor memory for each movement. The motor program is characterized by invariant features that are apparent regardless of the specific requirements of a task. An example used by Schmidt (1988) is handwriting, in which there are predictable patterns regardless of the size of writing or how it is executed (e.g., right or left hand). When a specific movement is required, the generalized motor program would be implemented by changing the parameters such as speed or force in response to the specific task requirements. This theory does not indicate how the generalized motor program is developed. However, KR is considered essential for development of the schema, which is the memory representation that produces and evaluates the specific movement. The schema is responsible for the parameterization (establishing the specific characteristics of the movement).

A common principle in both Adams' and Schmidt's theories of motor learning as well as in the behavioural theories, was that KR would enhance learning when provided as frequently, immediately, and precisely as possible. Knowledge of results presented in this manner provided a "crutch" to support errorless performance. In general, these theories endorsed any presentation of KR that would facilitate the use of KR to eliminate errors in subsequent performance. This view was supported by studies showing that skill was facilitated when KR was allowed to serve this role.
However, according to a more recent view (Salmoni, Schmidt, & Walter, 1984), if a distinction was made between performance and learning, the function of KR needed to be reconsidered. The identification of the role of KR in the theories of motor learning to date was based on studies that evaluated the effect of KR during the practice or the performance period. But, the problem with measuring outcome at the end of the performance period is that it is difficult to differentiate between temporary changes due to the energizing effects of KR, and the relatively permanent effects ascribed to learning. A more recent study design has evolved that includes a retention phase which occurs after the practice period and following a rest interval. This interval is thought to allow the temporary performance changes to dissipate. In the retention phase, performance is measured under equivalent conditions (such as no KR). In this design, changes in retention are thought to represent a relatively permanent change in behaviour or learning.

Using the performance-learning design modifications, several different aspects of KR have been manipulated to determine their effects on motor skill learning. Based on the findings of these studies, Salmoni et al. (1984) proposed the guidance hypothesis for KR. According to this hypothesis, KR has both positive and negative influences. On the positive side, KR provides information that can be used to improve performance of motor skills. However, the negative side is that the way in which KR is provided can also create a dependence which leads to poor performance when KR is no longer available. The positive effects of KR are both motivational, in that the learner is more likely to repeat the skill, and informational, in that the learner can implement corrections based on the KR. Thus, performance is enhanced with more frequent, immediate and
precise KR during acquisition of a skill. This positive guidance role of KR corroborates early views on the role of KR. But, when learning is assessed during a retention phase, the negative effects of using KR as a crutch become apparent. Generally, if KR is provided excessively during practice, a dependence on KR develops and subsequent performance without KR deteriorates.

There have been several possibilities proposed to explain the negative effects of too much dependence on KR (Schmidt, 1991a). One postulate is that KR becomes an intrinsic part of the task. As a result, the performance deteriorates when the learner attempts to perform without KR. Another possibility is that KR interferes with the processes that normally occur during motor learning including using the intrinsic feedback such as proprioception (Winston & Schmidt, 1990). As a result, the learner does not develop the intrinsic error detection and correction capabilities that are necessary for successful performance in situations where KR is no longer available. In addition to interfering with the error detection mechanism, it is possible that KR interferes with the problem solving associated with motor learning. The provision of KR eliminates the need to reconstruct the movement commands in response to intrinsic error information (Schmidt, 1991a). A third hypothesis is that in response to KR, the learner is continually adjusting the performance resulting in retention of less consistent information. These adjustments can be considered maladaptive in that the corrections can be in response to very small errors, even ones that are due to random neural noise and are physiologically impossible to correct. The instability created by continued adjustments ultimately has a detrimental effect on long term retention.
These negative effects of KR occur under practice conditions where KR is provided frequently, immediately, and precisely; in other words, when KR becomes too much of a crutch. Several manipulations of KR will be discussed that illustrate these negative effects.

**Bandwidth KR**

Bandwidth KR is the provision of error information when performance falls outside a predetermined range of acceptance. If performance is within the acceptable range, no feedback is provided and the learner understands that performance is correct. A wide bandwidth allows for a wider range of performance errors to occur before KR is provided. No bandwidth means that error information is provided after every repetition. Bandwidth KR allows for a margin of error, and as such, could be considered a manipulation of the precision of KR. According to traditional theories of KR, the narrowest bandwidth (KR after every repetition) would enhance learning because it would provide more precise, and more frequent information.

Using a research design that incorporated a no KR retention phase, Sherwood (1988) evaluated the effect of three different sizes of KR bandwidths (0%, 5%, 10%) on the acquisition and learning of a 200 ms arm movement. There was no difference between groups during acquisition except that the 10% KR group was more stable over the early repetitions. Compared to KR after every repetition (the 0% bandwidth condition), the 10% bandwidth group was more stable during retention, with the 5% bandwidth condition performing at an intermediate level. These findings, replicated by
Lee and Carnahan (1990a), suggest that the provision of KR in a way that allows some error in performance and less frequent KR actually enhances learning.

**Timing of KR**

In traditional motor learning theory, KR was thought to be most effective if provided as soon after the completion of the attempt as possible. However, recent evidence indicates that a delay period between the attempt and KR is actually better for learning than no delay. Swinnen, Schmidt, Nicholson, and Shapiro (1990) examined the effect of delaying the provision of KR on learning a coincident timing task which had similar characteristics to hitting a baseball. The task was practiced for two days with the two groups receiving either instantaneous KR or KR that was delayed by 3.2 s. By the second day of practice an advantage in favour of the delayed KR period became apparent and was maintained in the 10 minute and 2 day no KR retention tests.

Another experiment (Swinnen, Schmidt, Nicholson, & Shapiro, 1990) supported these findings and also showed that learning was further enhanced if the learner was asked to estimate the movement time during the KR delay interval (8 s). The task in this study was to learn an arm movement pattern with specified timing requirements. These findings suggest that the activities during the KR delay period have an important effect on learning. It seems that the learner uses this time to evaluate performance and this activity can be enhanced if the learner is directed to self-evaluate. Again, this research supports the guidance hypothesis in that instantaneous KR seems to be detrimental to
learning. The active involvement of the learner in the problem solving process associated with learning a task is facilitated by delaying KR.

Summary KR

Another area of KR research that brought into question the traditional role of KR is summary KR. Rather than providing KR after every trial, the learner executes a series of repetitions following which a summary of the KR from the series of trials is provided. The evidence from several studies suggests that the summary of KR may be detrimental to acquisition performance but beneficial to learning. Following an early study by Lavery (1962), Schmidt, Young, Swinnen, and Shapiro (1989) evaluated the effect of different summary lengths of KR (1, 5, 10, 15 trial summaries) on learning an arm movement which had specific movement and timing characteristics. The longest summary lengths (10, 15) were detrimental to performance over the acquisition phase of the study, compared to the 1 and 5 trial groups. No differences between groups were found in the 10 minute, no KR retention test. However, in the 2 day test, the 15 trial summary group was best at retaining the task, while performance was the worst in the group that received KR after every trial.

These findings seem to depend on the complexity of the task. Using a coincident timing task with complex spatial/ temporal characteristics, Schmidt, Lange, and Young (1990) found that a 5 trial summary length was optimal for learning compared to summary lengths of 1,10 and 15 trials. The task in this study was more complex than the one used by Schmidt, Young, Swinnen, and Shapiro (1989), and as a result, a shorter
KR summary length was optimal for learning. These studies suggest that too short a summary length creates a dependency on the KR, but too long a summary length does not provide enough information to guide the learner. As well, the summary length seems to be dependent on the complexity of the task.

Another recent KR summary study (Wright, Snowden, & Willoughby, 1990) evaluated the effect of the amount of information provided in the KR summary. They compared providing KR for only the last trial of the summary block with giving a summary of KR for each of the trials in a 5 trial summary block. Both the KR summary conditions had the expected effect, in that the acquisition was impeded, but no KR retention was enhanced when compared to a condition in which KR was provided after every trial. These results suggest that the variable that affects learning more is the format of summary KR, rather than the amount of KR provided in the summary. In other words, this summary scheduling of KR creates no KR trials in which the learner evaluates intrinsic information.

Scheduling of KR

There are many potential sources of feedback in learning complex skills. For instance, in learning a forehand tennis swing, an instructor can provide information about a variety of movement characteristics such as timing, joint angles, and body position. One question of interest, given such a multitude of potential sources for information feedback, is to determine the schedule of providing KR that will most effectively facilitate learning.
One recent experiment on this issue examined the influence of blocked versus random KR schedules on the acquisition and retention of a multi-segment movement timing task by young adults. Lee and Carnahan (1990b) compared practice in a blocked KR schedule with a random KR schedule for a movement task consisting of three different timing characteristics. KR in the form of actual movement time was provided in a blocked or a random schedules. In a blocked schedule, KR was provided for one of the three segments for a block of 20 acquisition trials. For the next 20 trials, another segment received KR, and for the last 20 trials, the remaining segment received KR. There were two random order schedules in which KR was provided in a quasi-random fashion in that each of the segments received KR on 20 trials. The difference between the random schedule groups was that one group (cued random) was told which segment would receive KR while the uncued random group did not know which segment would receive KR. The results indicated that when KR was provided randomly, performance was less accurate in early acquisition, but more accurate in later acquisition and retention than when the KR was provided in a blocked schedule. There was no difference between the random schedule groups in retention, even though the intent of the cuing was to focus the learner on the one segment to the detriment of the other segments. This finding suggests that regardless of the cuing, the random schedule was more effective for learning. Generally, these results seem rather counterintuitive. Receiving feedback repeatedly for one aspect of the movement could be presumed to allow mastery of this segment before learning another part of the movement. However, the results of this study indicated that learning was enhanced if feedback was provided in a random
schedule, suggesting that although KR can be used to guide the learning, an overdependence on KR was created in blocked practice, resulting in impaired learning of the entire task (Salmoni, Schmidt, & Walter, 1984).

Relative Frequency of KR

Another variable of KR that influences learning of motor skills is the amount and timing of KR trials over practice. Absolute frequency of KR refers to the actual number of practice trials of the task that are followed by KR. In contrast, relative frequency of KR refers to the number of trials of the task that receive KR, expressed as a percentage of the total number of trials performed. Early work on the comparison of relative versus absolute frequency indicated that the absolute number of trials followed by KR was the more important factor in maximizing learning. The practice trials without KR were thought to be "blank trials", contributing nothing to the learning process (Bilodeau & Bilodeau, 1958; Bilodeau, 1966). This finding, based on acquisition data only, is consistent with the early view of KR that the more frequent the KR, the better the learning (e.g., Adams, 1971; Bilodeau & Bilodeau, 1961; Schmidt, 1975).

Recent evidence from studies designed with common retention tests have indicated that lower relative frequencies of KR can be as effective during performance as 100% relative frequency, and that minimally, this effect is maintained in no KR retention tests (Ho & Shea, 1978; Lee, White, & Carnahan, 1990, Experiment 2; Sparrow & Summers, 1992, Experiment 1; Weinstein & Schmidt, 1990, Experiment 1). Moreover, the findings from other studies suggest that lower relative frequencies of KR actually facilitated
learning, compared to 100% KR conditions (Lee, White, & Carnahan, 1990, Experiment 3; VanderLinden, Caurough, & Greene, 1993; Winstein & Schmidt, 1990, Experiments 2 & 3; Wulf & Schmidt, 1989). As yet, it is not clear why some studies show no differential effects while some show positive learning effects of reduced relative frequency. Regardless, all studies have been consistent in finding support for the conclusion that 100% KR is not necessarily better, and can, indeed, be worse than less frequent KR. Collectively, these studies present a strong argument against earlier views that more KR was better for motor learning.

A recent study (VanderLinden, Caurough, & Greene, 1993) is an example of a study that found benefits for learning as a result of practice with reduced relative frequency. Subjects learned an isometric elbow extension task and KR, in the form of the learner’s force and temporal performance superimposed over the criterion, was provided either after every attempt (100% relative frequency) or after every second attempt (50% relative frequency). There was no difference in performance between KR conditions during acquisition. However, the 50% relative frequency group was more accurate in both immediate and delayed (48 hours) retention tests. Lee, White, and Carnahan (1990), using a timing task, and Sparrow and Sumners (1992, Experiment 2), using a positioning task, found similar beneficial effects of reduced relative frequency of KR on learning.

Winstein and Schmidt (1990, Experiment 2) attempted to maximize the effects of reduced relative frequency of KR by using a "faded" schedule. In this paradigm, young adults received 100% KR during early practice, but KR was gradually reduced over trials
so that, overall, there was a 50% relative frequency of KR. The rationale behind the "faded" schedule was that frequent KR at the beginning of practice would provide the learner with enough information to acquire the idea of the movement (Gentile, 1972), and that fading the KR over practice would prevent the detrimental effects of over-dependence on KR (Schmidt, 1991). Winstein and Schmidt (1990) found no difference between the two KR frequency groups in the performance of a complex spatial arm movement over the two day practice period. However, in the delayed no KR retention test, subjects who trained in the faded 50% relative frequency KR schedule performed with less error than those in the 100% KR group.

These results were replicated and extended by Wulf and Schmidt (1989, Experiment 1) and Young and Schmidt (1992, Experiment 2). Wulf and Schmidt asked subjects to learn three different versions of a sequential timing task in which all versions consisted of the same relative timing. The question addressed was whether reduced relative frequency KR would enhance learning a class of movements with one generalized motor program (a consistent or invariant ratio between components of the movement). Practice was performed under one of two conditions- 100% KR relative frequency, in which KR was provided for each of the three segments of the movement after every trial; and a 67% KR group in which KR was faded over the acquisition trials in a similar fashion used by Winstein and Schmidt (1990). Learning of a generalized motor program was assessed in a no KR transfer test in which all subjects performed a movement with the same relative timing but a different absolute timing as the movement performed
during acquisition. The results suggested that reduced relative frequency in a faded schedule was beneficial to learning the generalized motor program.

Rather than fading KR, Young and Schmidt (1992, Experiment 2) examined the effect of fading kinematic feedback on a laboratory version of hitting a moving ball. Kinematic feedback in the form of information about movement patterning was provided under three conditions during the 200 acquisition trials: following every trial; following every 5th trial (absolute frequency of KR - 40 trials); and faded across trials (absolute frequency of KR - 20 trials). An average of the kinematic feedback from the previous no feedback trials was provided in the reduced feedback conditions. Both the no kinematic feedback retention tests at one day and one week later, indicated that learning in the two reduced kinematic conditions was better than the condition in which KR was provided after every trial. Both reduced kinematic feedback conditions enhanced learning even though the faded schedule provided only half the absolute frequency of KR. Thus, there was no difference in learning between the condition with the further reduction in absolute frequency of kinematic feedback combined with the faded schedule and in the reduced relative frequency condition.

Nicholson and Schmidt (1991) further investigated the role of the faded schedule of KR by using an experimental design that controlled the relative frequency of KR. Various 50% relative frequency schedules were used including uniform (equal distribution) and faded schedules. Although, there was a benefit on learning for the reduced relative frequency, there was no additional benefit of fading. In a subsequent experiment, the effect of withholding KR early in practice (reversed faded KR schedule)
was compared to uniform KR and withholding KR late in practice (faded KR schedule). In all conditions the relative frequency of KR was 50%. Compared to the reversed faded schedule, the faded and uniform conditions enhanced performance on retention. These findings suggest that decreased frequency of KR in late practice is beneficial to learning.

In summary, these studies of the various manipulations of KR including bandwidth, timing, summary, scheduling, and frequency have provided considerable support for the guidance hypothesis for KR. Although the underlying mechanisms remains to be clarified, the findings suggest that motor learning is enhanced when KR is provided during acquisition of a skill in a way that prevents dependence for the production of the skill. The subjects in these studies have been young, healthy adults. It remains to be seen whether older adults utilize KR to learn motor skills in a similar way to young adults.

AGING AND MOTOR LEARNING

There has been little work in the area of the age-related effects on motor learning, particularly in the early stages where cognitive functioning is considered to be very important. This is somewhat surprising as a common finding is that aging is associated with a decline in cognitive functioning (Salthouse, 1985a, 1991). Although, there is substantial evidence that documents the decline in cognitive functioning, there is very little agreement about the underlying causes. Rabbitt (1982) summarizes the research by describing it as "a very large, though fragmentary and disconnected literature shows that as people grow old their cognitive efficiency declines" (p.79). However, some of
the cognitive mechanisms found to be affected by aging include receiving external stimuli, encoding input, selectively attending to appropriate stimuli, searching and retrieving from long term memory, and using working memory to integrate information and formulate a response (Toole & Abourezk, 1989). In particular, Salthouse (1990) has reviewed several studies of the effect of advancing age on working memory and concluded that some of the age related changes in cognitive functioning can be attributed to reductions of the capabilities of the working memory. These capabilities include simultaneous storage and processing of information such as KR. Changes in the various mechanisms involved in cognitive skills ultimately can affect the abilities to learn, remember, and problem solve.

As discussed earlier, during the early stage of motor learning, there is considerable cognitive effort directed at establishing appropriate movement strategies (Fitts & Posner, 1967), and it is during this cognitive stage that KR has a very powerful role (Adams, 1971). But, given the changes in cognitive functioning with age, it is unclear whether these changes will affect the way the older adult uses information feedback. One way of investigating the effects of cognitive change is to evaluate the differences between younger and older adults in how they use KR for learning. Whether or not KR has a similar effect on older learners has never been investigated.

**KR, Motor Learning, and Aging**

Although there is a lack of studies that evaluate age-related differences in the use of variables that enhance motor learning, there has been research directed at the effects
of aging on practice of motor skills. These studies indicate that older adults benefit from practice, but generally, their performance does not reach the same level as young adults (Light, 1990; Spirduso & MacRae, 1990; Williams, 1989). Some of these studies have used rather simple tasks such as limb positioning (Anshel, 1978; Meeuwsen, Sawicki, & Stelmach, 1993). However, the vast majority of studies measure performance in relation to reaction time, and as a result, the focus is on the changes in the information processing that translate sensory input into action rather than on the execution of a motor skill (e.g., Baron, Menich, & Perone, 1983; Hetzog, Williams, & Walsh, 1976; Salthouse & Somberg, 1982). Nevertheless, these studies provide valuable insight into the ability of the older adult to improve some cognitive operations with practice. However, they provide little insight into the effects of age on learning new motor skills.

The lack of studies that directly address the influence of age on the use of variables that are thought to enhance motor learning is striking (Kausler, 1991). An exception to this paucity is a study that evaluated the effect of mental practice in conjunction with physical practice (Surburg, 1976). Mental practice consisted of mental rehearsal of a motor task without movement. There is ample evidence that this activity enhances motor learning in young adults (Feltz & Landers, 1983; Feltz, Landers, & Becker, 1988). Using a pursuit rotor task, subjects performed in a variety of conditions that manipulated the amount of physical and mental practice. The results of an eight week retention test indicated that, generally, the young-old group (65-79) was better than the old group (80-100). However, both age groups made equal gains from a half physical- half mental practice schedule compared to a variety of physical practice
schedules. This study did not include a young adult group and as a result a direct comparison between young and old was not possible.

This study's positive findings suggest that older adults do benefit from a variable that influences motor learning. Yet, there is a lack of studies that evaluate other important learning variables such as KR. To my knowledge, no studies exist that acknowledge the performance/learning distinction. For example, a study by Szafran (1953, as reported in Kausler, 1990) evaluated the effect of age and KR on a line drawing task. There were two conditions, a no KR condition and a KR condition that provided information about the amount of error from the required length of the line. In the no-KR condition, there was no difference among the three age groups (18-29, 30-49, and 50-69). However, compared to the younger groups, the oldest group's performance during practice did not benefit from KR. Unfortunately, the influence on learning is difficult to interpret because there was no retention test.

A study by Wiegand and Ramella (1983) suffered from a similar methodological flaw. This study evaluated the age-related effect of the temporal location of KR between practice trials on a coincident timing task. This study found that both age groups improved with practice. However, there were age-related differences in performance with the younger adults performing more accurately than the older adults. In addition, there were differential effects of the timing of KR. The older adults benefitted from a long post-KR interval (15 sec.) compared to shorter post-KR intervals (.5, 1, 3 sec.) The post-KR interval is the period of time between the presentation of KR and the next practice trial. Although young adults were less accurate in the short post-KR intervals
(.5, 1 sec.), there was equal benefit for conditions with longer post-KR intervals (3, 15 sec.). These findings suggest that older adults require a longer time to process the information provided by KR. Unfortunately, because this study did not take into consideration the performance/learning differences, it remains unclear how these age-related differences in performance affected learning.

CONCLUSION

Having reviewed the literature on aging and motor learning, it is amazing that there is so little, given the evidence in young adults that KR is an important variable for motor learning. Overall, there is a general lack of literature in the area of motor learning and aging, and more specifically in relation to the effect of KR on motor learning. It seems that this lack of research is based on the assumption that either older adults do not learn new skills, or that the theory that has been developed based on young adults can be directly applied to older adults. Yet, it is clear that older adults need to learn new skills— in daily living, work and recreational activities as well as in rehabilitation situations that are designed to optimize function in response to impairments. An understanding of the role of KR in motor learning in older adults is essential for facilitating all the different motor learning situations that older adults will encounter. Furthermore, the idea that motor learning theory can be applied directly across the lifespan is questionable. As indicated in the first chapter, there are age-related changes in how movements are controlled. In addition, based on evidence provided earlier in this
chapter, there are changes in the cognitive functioning of older adults that may influence how variables such as KR are utilized in the learning process.

Given the lack of work in this area, it was difficult to decide where to start. The question was whether to "start at the beginning" and replicate the early KR findings from studies on younger adults in the older populations, or to build on the most recent KR findings from the work on young adults. The latter approach was chosen and the studies were designed to address the issues of the effect of aging and the use of multiple sources of KR for motor learning.

Generally, the experiments were designed to address the following question: is there an age related difference in performing and learning a sequential motor timing task using different schedules and frequencies of KR? Specifically, the first experiment will evaluate the effects of two different schedules of KR for the segments of a multisegment movement. The second experiment manipulated scheduling of KR in a different way. In this experiment, using the same task, the effect of age in combination with the frequency and the fading schedule of KR, within and between practice trials, was examined.

Given the possibilities of KR manipulations that could have been chosen, the scheduling of KR for a multisegment movement task was thought to be most relevant in relation to practical and theoretical application. From a practical view, older adults learn or relearn complex tasks (e.g., recreational pursuits such as golf, or rehabilitation activities such as gait training) which require KR about various aspects of the tasks. Although there are limitations when comparing a laboratory task to the complexities of
many practical tasks, using a more complex laboratory task will make the application of the findings more generalizable to the training of real world skills.

From a theoretical perspective, the choice of these experiments has two different potential contributions. In relation to KR theory, the experimental task and the KR manipulation were designed to extend the application of the guidance hypothesis. Historically, the theory has been developed based primarily on relatively simple tasks and, as a result, there is limited understanding of the application of KR principles to more complex movements. In relation to the theoretical contribution of these experiments to aging and motor learning, the use of the combination of the more complex movement task and the more complex manipulation of KR was designed to maximize the possibility of identifying differences in how older adults would use KR to learn motor skills. Conceivably, differences in the use of KR may become more evident when the older adult is learning a more complex motor task. This process requires active manipulation of both intrinsic and extrinsic infoe Wing-Kristofferson Model. Research Quarterly for Exercise and Sport, 64, 32-38.


Swanson, L.R., & Lee, T.D. (1992). The effects of aging and schedules of knowledge of results on motor-learning combined with modification of the previously executed motor program, and finally execution of the new movement. Perhaps the role of KR may be modified in older adults, given the changes with age in programming more complex movements combined with the changes in cognitive functions. Rather than creating a dependency that interferes with motor learning,
the immediate and frequent presentation of KR may be necessary to advance learning.
Chapter 3: **THE EFFECTS OF AGING AND SCHEDULES OF KNOWLEDGE OF RESULTS ON MOTOR LEARNING**

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ABSTRACT

Little research has been conducted on aging and the learning of motor skills. In the present study, we examined the effects of different schedules of knowledge of results (KR) on the acquisition and retention of a movement timing task by young adults (20-23 years), and older adults (60-82 years). The results indicated that there were differences between young and older adults in the accuracy and consistency of motor performance when KR was provided. Accuracy effects persisted during a retention interval when KR was no longer provided, although there were no differences in variability. There were no interactions of age with any of the KR related variables. These findings suggest that the ability to process KR, and the effects of KR on motor learning, are similar in young and older adults. These findings are discussed in terms of age related issues in movement control and learning processes.
INTRODUCTION

Research on aging and motor behavior has a long history (e.g., Miles, 1931; Ruch, 1934; Snoddy, 1926; Welford, 1951). Most of this work has focused on the processes that affect the control of movement. Research on aging and the learning of motor skills has not received much attention (Anshel, 1989; Williams, 1989). However, there is a practical need for concentrated study in this area. Older adults do learn new motor skills — as part of new job training, recreational pursuits, and rehabilitation therapy. A better understanding of how the elderly acquire, retain and transfer motor skills is needed to be able to facilitate the performance of these activities.

One general conclusion from research using young adults is that motor learning is a problem-solving process that requires cognitive intervention between perception and action, particularly so in the early stages of skill acquisition (Adams, 1971; Fitts, 1964). However, given the decline in cognitive processes that accompany aging (Salthouse, 1990), there is reason to suspect that factors which affect the learning of motor skills in young adults might operate differently in older adults. The factor addressed in the present experiment is the role of knowledge of results (KR), and how the processing of KR in a motor learning situation might change with age.

The study of KR effects in the learning of motor skills by young adults has received considerable interest (see Adams, 1987; Salmoni, Schmidt, & Walter, 1984, for reviews). In general, KR has been defined as "extrinsic, usually verbal (or verbalizable) information about the success of an action with respect to the environmental goal" (Schmidt, 1991, p. 231). The role of KR in motor learning by older adults is a
potentially fruitful area of investigation for several reasons. The verbal nature of KR insures that the information must undergo cognitive processing for a subject to learn the task. The verbalness of the task provides for a theoretical link regarding the acquisition of motor tasks with the literature on the effects of aging in the acquisition of non-motor tasks (e.g., Salthouse & Somberg, 1982). Perhaps most importantly however, there appears to be considerable generalizability regarding the processes involved in motor learning that are implicated by certain effects of KR (Schmidt & Bjork, in press).

Research on KR factors in motor learning as a function of aging has not been a focus of investigation. However, evidence about how aging affects movement preparation and control are relevant. For instance, although older subjects are generally slower than young subjects in movement preparation, the preparation process is similar (Amrhein, Stelmach, & Goggin, 1991; Gottsdanker, 1980; Larish & Stelmach, 1982; Stelmach, Goggin, & Amrhein, 1988; but also see Light & Spirduso, 1990). However, studies on movement control suggest the error correction portion of rapid aiming movements is performed differently by older than by young adults (Warabi, Noda, & Kato, 1986; Winchester & Roy, 1991). This could be due to either a reduced ability to process visual feedback (Jordan, 1978) or to a general strategy used by older adults to sacrifice movement speed to improve accuracy (Salthouse, 1979; Welford, 1951, Expts. 1 and 4). These findings suggest that there may be some dissociations in the ability to process movement related information with increases in age.

In the present study we compared young and older subjects on their ability to use extrinsic, verbal information feedback (KR) to learn a movement timing task. Since the
task did not require subjects to move as rapidly as possible, the importance of error reduction for performance and learning was stressed. Thus we were able to make several key comparisons. First, we examined whether movement accuracy and consistency, in general, was different between young and older adults. The specific effects of using KR during motor learning were examined by comparing the impact of the two schedules within each age group. If young and munity. All subjects scored 5 (the maximum) on the scale. Personal interviews indicated that one-half of the subjects in each of the older groups exercised for at least 30 minutes, three times per week.

Apparatus

The apparatus was similar to that used by Lee and Carnahan (1990b). It consisted of a start button and three small (12 cm x 8 cm), padded wooden barriers attached to a wooden base, mounted on a standard table. The subject was situated so that the start button was directly in front of the midline. The task required subjects to make a continuous movement from the start button to knock over a barrier, followed by a reversal in movement direction to a second barrier, then another reversal to a third barrier. These three movements were, specifically, 1) a 45 degree, 25 cm movement forward and to the left, 2) a 27 degree, 40 cm movement forward and to the right, and 3) a 27 degree, 40 cm movement forward and to the left. The barriers were hinged to fall in the direction of the movement. The direction of the movement for each segment was clearly marked on the apparatus. In addition, the movement time goal for each
segment was displayed on cards and attached to the apparatus at the midpoint of each respective segment.

A microswitch was attached to the start button and each of the barriers. A Lafayette Performance pack was connected to the apparatus in such a way that the three movement segments could be timed to the nearest ms. As well, the timing system was set up to provide a tone during the segment that was to receive KR. The timing data were recorded manually during the intertrial period.

Procedure

The goal of the movement task was not to finish the movement as rapidly as possible, but rather, to learn to complete each of the movement segments as close to goal movement times as possible. The goal of the first segment was a movement from the start button to the first barrier in 360 ms. The segment 2 goal was a movement from the first to the second barrier in 680 ms. The goal of the final segment was a movement from the second to the third barrier in 450 ms. The corresponding average movement velocities required to accurately perform the task were 0.69, 0.59, and 0.89 m/s for each of the successive segments. These movement speeds were well within the capabilities of each age group, thereby placing the emphasis of the task goal on timing. The experiment consisted of two phases: an acquisition phase and a retention phase.

a) Acquisition
The acquisition phase of the experiment consisted of 90 trials. One trial consisted
of a three-segment movement together with KR about the movement time for one of the
segments. Trials were separated by at least 10 sec following the KR. However, the
subjects could choose when to initiate the movement after the experimenter’s signal.

The critical manipulation in the experiment was the schedule by which subjects
received KR for each of the segments during the acquisition period. Subjects in the
blocked schedule groups received KR about the same segment for trials 1-30. For the
next 30 trials KR was provided about another segment, and the remaining segment
received KR for the last 30 trials. A Williams’ square design was used for assignment
of segmental KR orders to subjects (thereby controlling for the potential of order and
carry-over effects). Subjects in the random schedule groups also received KR about one
segment after each trial. The schedule determined that KR be presented about segments
in a quasi-random order, such that KR had been presented twice for each segment after
every six trials. Thus, the blocked and random KR schedules were different only in the
order by which segmental KR was provided over the acquisition trials; the number of
trials for which each segment was provided with KR was the same.

The goal of the movement task was explained to each of the subjects, and all
questions that required further explanation of the task goal were resolved before
beginning the acquisition phase. During each trial a tone was emitted for the duration
of the movement segment that was to receive the KR. This tone was intended to focus
the subject on the segment that would receive KR. The KR was verbal feedback from
the experimenter in terms of the actual movement time for that movement segment.
A retention interval of 10 minutes followed the last acquisition trial. All subjects played a computer game during this interval to prevent mental practice of the movement task, and to further dissipate any temporary effects of the KR schedules (Salmoni et al., 1984).

b) Retention

Learning was assessed by means of a common retention test. Subjects in each of the groups performed 18 trials of the task without any KR. A full explanation of the research project was explained to each subject after completion of the experiment (which lasted approximately one hour).

Data Analysis

Both the dependent variables and the statistical analyses were similar to those used by Lee and Carnahan (1990b).

a) Dependent Variables

Absolute constant error |CE| was used as the measure of timing accuracy. Variable error (VE) provided a measure of movement consistency. For a given segment, a trial’s error score was calculated as the signed difference between the segment goal time and the actual performance time. A mean and standard deviation of these error scores was calculated over blocks of 6 trials. The mean’s sign was removed in order to
eliminate the potential of negative values cancelling positive values when averaged over segments or subjects.

For the random KR schedule groups, the blocks were established chronologically such that Block 1 consisted of Trials 1-6, Block 2 consisted of Trials 7-12, etc. However, for the blocked KR schedule group, if blocks were constructed chronologically, the amount of feedback would not be balanced across segments. To equate the amount of KR on each segment over trials, a block was formed based on trials that had an equivalent number of KR presentations for each segment. Thus, Block 1 consisted of Trials 1, 2, 31, 32, 61, and 62, while Block 2 was composed of Trials 3, 4, 33, 34, 63, and 64, and so on.

A separate analysis evaluated the effect on performance of KR on the different segments of the blocked groups. In this analysis, the 90 acquisition trials were organized chronologically. There were 15 blocks of 6 consecutive trials each. By this method, the segments that were receiving KR at that time were compared with the segments that had either received KR or had not yet received KR. By this analysis, Blocks 1-5 represented the performance of the segment that received KR over the first 30 trials, as compared with the other two segments, which had not yet received KR. Blocks 6-10 consisted of the next segment to receive KR for trials 31-60 compared to the segments that had received KR on the first 30 trials and the segment that had not yet received KR. The last five blocks reflected the performance of the last segment to receive KR, compared to the segments that were no longer receiving KR.
VE was used as the measure of within-subject consistency. For each subject, the standard deviation about a subject's CE for a given segment was computed across blocks of six trials. Blocks were defined in the same way as when calculating |CE|. These measures of VE were averaged across the three segments to obtain a measure of average consistency within a trial.

The calculation of error scores was similar for all groups' retention data since these trials were performed under common, no KR conditions. The 18 retention trials were grouped into three blocks of six trials each. Both |CE| and VE were determined as before.

b) Statistical Analyses

Each dependent measure of the acquisition data was analysed in a 2 (Age) X 2 (KR schedule) X 15 (Block) ANOVA, with repeated measures on the last factor. The chronological assessment of the blocked data was analysed in a 2 (Age) X 3 (KR segment) X 3 (KR availability) X 5 (Block) ANOVA, with repeated measures on the last three factors. The retention data were analysed using 2 (Age) X 2 (KR schedule) X 3 (Block) ANOVAs, with repeated measures on the last factor. Post-hoc tests, to determine differences between means following significant ANOVA effects, were performed using the Newman-Keuls method.

RESULTS

Acquisition
Figure 1 (CE) and Figure 2 (VE) illustrate the group means for each trial block. Overall, the young groups were more accurate than the older groups, as revealed by a \(|CE|\) main effect for age, \(F(1, 44) = 12.43, p < .001\). As well, all groups improved in accuracy over the 15 blocks, as revealed by a main effect for block, \(F(14, 616) = 5.90, p < .001\). An interaction between KR schedule and block was also significant, \(F(14, 616) = 3.19, p < .001\). For the first few trial blocks, the blocked KR groups were more accurate than the random KR groups. However, this pattern of results was reversed, and by block 7 the random groups were more accurate than the blocked groups. There were no interactions of any of the experimental factors with age.

The young adults were also less variable during acquisition than the older adults \(F(1, 44) = 5.46, p < .02\). As well, the random schedule KR groups had less VE than the blocked KR schedule groups, as revealed by a main effect for KR schedule, \(F(1, 44) = 24.51, p < .001\). All groups became more consistent over blocks of trials \(F(14, 616) = 12.58, p < .001\). However, once again, there were no interactions of age with any of the experimental variables.

Retention

The results of the retention analyses indicated that the young adults were more accurate than the older adults \(F(1, 44) = 22.58, p < .001\), and that the random schedule KR groups were more accurate compared to the blocked schedule KR groups, \(F(1, 44) = 12.55, p < .001\). Young adults also were more consistent than older adults, \(F(1, 44) = 4.78, p = .032\). However, in the last block of retention, the
random KR schedule groups became less consistent, as revealed by a KR schedule X block interaction [F(2, 88) = 4.78, p = .002]. Once again, there were no interactions with age for either |CE| or VE.

Further Analyses of the Blocked Groups

Figure 3 (young adults) and Figure 4 (older adults) show the |CE| of subjects in the blocked KR schedule groups, all of whom received KR about 1 segment for 30 trials, then KR about another segment for the next 30 trials, and so on. Similar to the analysis by Lee and Carnahan (1990b), these figures illustrate the difference in the accuracy of performance for segments receiving KR compared to segments not receiving KR. In this analysis, the actual sequence of the movement segments is not considered. For example, the circles in Figures 3 and 4 refer to the average |CE| for the segments that were provided KR in blocks 1-5 (trials 1-30), regardless of whether that segment was the first, middle, or last segment of the movement.

Similar to the findings of Lee and Carnahan (1990b), a clear pattern of results emerged over blocks. Over blocks 1-5, |CE| decreased for segments that received KR, while those segments that did not receive KR did not improve in accuracy. Over blocks 6-10, the segment now receiving KR improved, the segment that had received KR in blocks 1-5 deteriorated, and the segment that had not yet received KR remained the same as before. During the final five blocks, the last segment to receive KR improve rapidly, while the segments that were no longer receiving KR deteriorated. In general however, the segments that had received KR early, then withdrawn later in acquisition, were
performed at a level of accuracy better than at the start of practice, which indicated a general retention over trials. These observations were supported by a main effect for time of delivery of KR \( F(2, 44) = 10.28, p < .001 \), a two way interaction of segment and time \( F(2, 44) = 10.28, p < .001 \), and a three way interaction between segment, block, and time \( F(16, 352) = 2.22, p < .01 \). Of more interest here though was the finding that despite better performance accuracy by the young adults \( F(1, 22) = 4.89, p = .035 \), there was no interaction of any of these practice effects with age.

**DISCUSSION**

The present experiment was an initial attempt to compare the abilities of young and older adults to use KR to learn a movement timing task. In general, young subjects profited more by the KR than did the older subjects. Regardless of the KR schedule, the young subjects performed more accurately both during the acquisition trials (when KR was provided), and during the retention trials (when KR was withheld). At least two reasons could account for the accuracy differences. One explanation is that the young subjects were better, or more efficient, at processing KR, and this accounted for the accuracy differences during practice. Further, these processing differences resulted in better learning of the task. When KR was later withheld, the effect of having learned the task better during practice resulted in the age differences that persisted across retention trials.

An alternative interpretation of these findings however, is that young subjects were just generally better at timing accuracy than the older subjects, and that both age
groups were similar in their ability to process KR. The absence of an age group by block interaction for |CE| would support this explanation. As illustrated in Figure 1, both young groups performed better than the two older groups, beginning on first block of trials, and this difference remained at generally the same amount throughout the practice period. A KR processing account of these data would require that the age differences be magnified as a function of practice in the presence of KR. The chronological analysis of the blocked groups’ data also does not support a KR processing account. Recall that there were no interactions of age with any of the other variables in the analysis. If differences in the processing of KR were to account for these aging effects, then the differences between groups should have been largest for the segments that were currently receiving KR, and smallest for the segments that had not yet received KR. The analysis of these data, and the means illustrated by comparing Figures 3 and 4, do not support a KR processing account of the age differences in movement accuracy.

A KR processing account of the differences between the age groups can also be discounted when considering the effects of the practice schedules. Regardless of age, the random practice schedule resulted in better learning of the task than the blocked KR schedule. This finding replicates a previous finding that had used only young adults as subjects (Lee & Carnahan, 1990b). However, the absence of an age group by practice schedule interaction, during either the acquisition trials or the retention trials, suggests similarities in the way that the available information was processed.

The effects of age and the KR manipulations on movement variability (VE) also provide some insights into movement control and learning factors. As is typically found
in these movement tasks, KR is used to reduce timing errors. But, in so doing, KR tends to elevate trial to trial variability, since the subject is attempting to reduce error through a change in motor behavior (Lee & Carnahan, 1990a). A main effect difference between the age groups was found for VE during acquisition, and age did not interact with any other variables. We interpret this finding to suggest that subjects of both age groups were using KR to correct for movement errors, but that the adjustments made by the older adults were larger because their timing was less accurate. Consistent with this view is that VE differences between ages were eliminated when KR was withdrawn. A general strategy for subjects during trials after the withdrawal of KR is to lock into a particular movement pattern (or motor program), and repeat it consistently (Lee & Carnahan, 1990a; Rubin, 1978). This was done equally well by both age groups.

To summarize, we found no evidence that aging resulted in differences in the manner by which KR is processed to learn a motor skill. This conclusion is in general agreement with the findings of Salthouse and Somberg (1982) for the acquisition of non-motor tasks. One other observation is also worth noting. We asked our subjects, after the experiment was complete, whether or not they had devised a particular strategy to learn the task. All of the younger adults identified strategies for learning the motor task. However, only 15 of the 24 older subjects indicated a strategy for learning the movement task. The role of cognition in motor learning, and particularly with respect to aging, represents a fruitful avenue for future work. Clearly, there is much to learn about how older adults learn motor skills.
REFERENCES


AUTHOR NOTES

Laurie R. Swanson is a doctoral student in the Dept. of Biomedical Sciences at McMaster University. Timothy D. Lee is an Associate Professor in the Dept. of Physical Education at McMaster University. Support for this research was supplied by a fellowship awarded to the first author by the R. Samuel McLaughlin Centre for Gerontological Health Research, and by an operating grant awarded by the Natural Sciences and Engineering Research Council of Canada to the second author. We thank two anonymous reviewers for their helpful comments on an earlier version of this paper. Correspondence should be sent to Timothy Lee, Dept. of Physical Education, McMaster University, Hamilton, Ontario, Canada, L8S 4K1.
Figure 1
Performance of all groups during acquisition and retention for |CE|
Figure 2
Performance of all groups during acquisition and retention for VE
Figure 3

Performance of the young, blocked group during acquisition when |CE| was calculated chronologically

(Note: The filled symbols denote movement segments that were receiving KR during those respective blocks of trials. The unfilled symbols refer to movement segments that were either no longer receiving KR or had not yet received KR.)
Figure 4

Performance of the older, blocked group during acquisition when $|\text{CE}|$ was calculated chronologically

(Note: The filled symbols denote movement segments that were receiving KR during those respective blocks of trials. The unfilled symbols refer to movement segments that were either no longer receiving KR or had not yet received KR.)
Chapter 4: THE EFFECTS OF AGING AND REDUCED RELATIVE FREQUENCY OF KNOWLEDGE OF RESULTS ON MOTOR LEARNING

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ABSTRACT

Although there is evidence for age-related differences in both cognition and motor control, very little is known about the effect of age on motor learning. The present experiment addressed the interaction between aging and the role of knowledge of results (KR) in a motor learning task. Using a three segment movement timing task in which each segment had specific timing goals, three different manipulations of KR relative frequency were compared in young and older adults. The KR relative frequency conditions were: a) 100% KR, b) 67% KR, in which the KR was faded over trials, and c) 25% KR, in which the KR was faded over the segments within each trial. Following 90 acquisition trials, all subjects performed retention, transfer, and reacquisition tests. There were overall age-related effects for movement accuracy and consistency in acquisition, and in both the retention and reacquisition tests. There were no important age differences in the transfer test. Surprisingly, there was no effect due to the fading of KR by either trials or segments. In general, these results indicated that young and older adults use KR in a similar way to learn a motor skill.
INTRODUCTION

Declines in motor performance that accompany increasing age are well documented. Some of these declines result from physiological and neurological changes that affect motor and sensory transmission (Williams, 1989). Other changes can be attributed to deficits in the cognitive processing operations that translate sensory stimulation into action (see Anshel, 1989, and Spirduso & MacRae, 1990 for reviews).

In rapid discrete movements for example, research has shown that increased slowness with advancing age is due to increased time in the "homing-in", or error correction portion of the movement (Goggin & Meeuwsen, 1992; Warabi, Noda, & Kaō, 1986). One reason for this slowing is that older adults generally prefer to trade off speed for better accuracy (Salthouse, 1979; Welford, 1951). An alternative reason for slowing however, is that older adults process visual feedback slower than young adults (Jordan, 1978). By slowing the homing-in portion of an aimed arm movement an older adult would gain more time to process visual feedback in order to reduce aiming error.

Research on aging-related changes in motor performance is abundant (Welford, 1959, 1965, 1985; Goggin & Stelmach, 1990). Rather surprisingly however, there has been very little research directed at the effects of aging on motor learning (Kausler, 1991). Much of the work that does exist on learning and aging suffers from one of two general limitations. One limitation has been a failure to distinguish between performance and learning effects. Performance effects are differences due to either the capabilities of the subjects (such as speed and balance differences), or to temporary changes in performance levels that are brought about by a particular independent variable (such as
motivation and fatigue). Learning is usually defined as a relatively permanent change in performance capabilities, and is often examined using retention and transfer designs (Schmidt, 1988). Changes in performance that occur during acquisition of a motor task can be a combination of temporary and more permanent changes. In order to assess the permanency of the change, in other words, the learning, performance is assessed in retention and transfer tests (see Schmidt & Bjork, 1992, for some examples). Much of the motor learning research with aging populations has not considered the consequences of this performance/learning distinction, calling into question the issue of how many of the previously described learning effects were, in fact, learning and/or performance effects (e.g. Wiegard & Ramella, 1983; Wright & Payne, 1985).

A second general limitation is that many of these studies have compared the age-related effects of extensive practice on reaction time tasks (see Spirduso & MacRae, 1990; Welford, 1985, for reviews). Although motor responses comprise the primary overt activity in reaction time tasks, the processes that change with practice are the cognitive translation operations that mediate perception and action. These experiments provide important evidence about the changes in cognitive operations that occur with practice, but tell us very little about motor learning.

A useful, alternative strategy to examine aging effects in motor learning is to manipulate an independent variable that affects the learning of motor skills, and assess the impact of this variable in separate age groups of young and older adults. We used this strategy recently to assess the influence of aging on the role of knowledge of results (KR) in learning a movement timing task (Swanson & Lee, 1992). In that study, young
and older adults learned a serial, multi-segment movement timing task. KR was provided about one of the movement segments on each trial. Separate groups of subjects (within each age group) were provided with KR regarding either the same segment over repeated trials, or regarding a different segment on each successive trial. Similar to a previous study using young adults (Lee & Carnahan, 1990), we found that randomly assigning the segment to receive KR on each successive trial was beneficial to both the acquisition and learning (retention) of the task. As well, young adults performed better than the older adults during both acquisition and retention trials. However, the most important finding was an absence of age-related interactions of this KR variable during either the acquisition or retention phases of the study. Thus, we made the tentative conclusion that in spite of performance differences between the age groups, young and older adults were equally capable of using the available KR to learn the motor skill. To further explore this tentative conclusion we conducted an experiment using a similar research methodology, the same task, but manipulating a different KR variable.

One promising approach to the study of KR effects in motor learning is to use a "fading technique" (Winstein & Schmidt, 1990; Wulf & Schmidt, 1989; Young & Schmidt, 1992). In this technique, KR is presented frequently early in practice, then reduced (or faded) over trials, such that KR is provided infrequently at the end of practice. Presumably, KR should be more important for the learner during the initial stages of learning than during the later stages (e.g., Adams, 1971). In every previous study reported in the literature that has used a fading technique, the relative frequency of KR has been reduced over trials (i.e., the frequency of KR following a trial is
reduced). The serial movement timing task used in the present study provided the opportunity to examine the fading of KR in a different way. Since KR could be provided about performance on any combination of the three timing segments that comprised the serial task, we faded KR by reducing the number of segments that received KR after each trial. Thus, the additional purpose of the present study was to examine the effect of reduced relative frequency of KR using two different fading techniques. Relative frequency of KR was manipulated in three independent groups: a) with KR about each movement segment after every practice trial, or by gradually reducing either b) the number of trials following which KR was provided about each segment, or c) the number of segments about which KR was provided after every trial. Separate groups of KR relative frequency were formed for both a young and an older group of subjects, to examine the age-related effects on motor learning.

The comparison of the two different fading schedules of KR was designed to further elucidate the role of KR. According to the guidance hypothesis, KR has two opposing roles (Salmoni, Schmidt, & Walter, 1984). On the positive side, KR provides information that can be used to improve the next movement. As well, it is motivational, encouraging the learner to continue to practice. On the negative side, KR can become a crutch to performance and, as a result, can interfere with learning. There are several possible mechanisms that are blocked by KR (Schmidt, 1991). One possibility is that KR can prevent the utilization of intrinsic information and interfere with post-movement error-detection. Another possibility is that KR promotes perpetual changes in performance (or maladaptive short-term changes -- Schmidt, 1991), as the learner
attempts to produce the perfect movement. As a result, a consistent level of performance is never attained. Yet another possibility is that KR interferes with the active problem solving process necessary in the early stages of motor learning (Adams, 1971). Regardless of the specific mechanism, the negative effect of KR is that learning as measured in no KR retention tests will be adversely affected. The situations in which the detrimental effects of KR occur are those practice situations in which KR is readily available such as 100% relative frequency.

In relation to the present experiment, the guidance hypothesis would predict that both the 100% KR relative frequency and the faded segments KR schedule (in which some KR was provided on every trial) would interfere with learning. The faded trials KR schedule would be most beneficial to learning as there are some trials in which information is provided while there are other trials without KR in which the learner can develop the intrinsic capabilities necessary for retaining the motor skill.

The other issue addressed in this experiment was the combined effect of age and the influence of the KR frequency schedules. Given that older adults have more difficulty with increased processing requirements (Salthouse, 1991), they may benefit from a KR schedule that provides less information at one time. Consequently, they may learn more effectively in a faded segment KR schedule. In both the 100% relative frequency and the faded trials KR schedules, KR is provided at one time about all three segments of the movement thus increasing the amount of processing necessary to improve the next movement. Based on the guidance hypothesis and the cognitive and performance deficits associated with normal aging, the young adults were expected to learn better than
the older adults. In addition, the young adults were expected to benefit most from the faded trials KR schedules, while the older adults were expected to learn more effectively in the faded segments schedule.

METHOD

Subjects

Thirty-six young adults from McMaster University (M age = 19.8; range = 19 to 23 years) and 36 older adults from Hamilton and the surrounding community (M = 66.2; range = 60 to 73 years) volunteered to participate in this experiment. The young adults were recruited from an undergraduate class taught by the second author. They received course credit for participating in the study. The older adults were recruited from the community by means of various media announcements. Volunteers were excluded if they had a cognitive, orthopedic, or neurological problem that would interfere with participation in the experiment. They were not paid for participating. All subjects were healthy as measured by a self report. Of the older subjects, half of each of the experimental groups exercised a minimum of one-half hour, three times a week. The average years of schooling was 15.1 years for the young subjects and 13.4 years for the older subjects. The average age-specific scaled scores on the Forward and Backward Digit Span (young = 11.3; old = 12.0) and the Digit Symbol Substitution subtests (young = 10.0; old = 11.3) of the Wechsler Adult Intelligence Scale- Revised (WAIS-R; Wechsler, 1981) were the same for both age groups. The Forward and Backward Digit Span subtest is considered a measure of working memory and the Digit Symbol
Substitution is thought to be a measure of perceptual motor skill. Although the subjects were naïve to the purposes of the research they were told the general nature of the experiment and signed an informed consent before the start of the study.

Apparatus

The task required subjects to produce a continuous movement with three distinct timing requirements. The apparatus was constructed with three distinct spatial segments (Swanson & Lee, 1992). The first segment required a 25 cm movement forward and 45° to the left. The second segment then required a 40 cm movement forward and 27° to the right. The final segment was a further movement of 40 cm forward and 27° to the left. The first movement segment began with the release of a microswitch. Each movement segment was terminated by knocking down a small wooden barrier (attached to a wooden base and hinged to fall in the direction of the movement). Electromagnetic switches were attached to the barriers and the base such that an impulse was generated when the barrier was tipped over. All switches were connected to a Lafayette Performance Pack such that the duration of the initial movement to the first barrier was the movement time for segment 1, the duration from the first barrier to the second barrier was the movement time for the second segment, and the second to the third barrier was the segment 3 movement time. Small cards, attached to the base of the apparatus, provided information about both the direction and the goal movement time for each segment. The visual presentation of KR was provided by a digital display that, depending on the KR condition, was available at the completion of the movement.
Procedure

The subject’s task was to produce a continuous movement with the right arm from the start position to the three consecutive barriers with the intent that each movement segment be completed as close as possible to a goal movement time. The goal movement times for the three segments were 360 msec (segment 1), 680 msec (segment 2), and 450 msec (segment 3). These times are well within the speed capabilities of both the young and older adults, and are identical to the goal times used in our previous research (Swanson & Lee, 1992).

The experiment was divided into four phases: 1) acquisition, 2) retention, 3) transfer, and 4) reacquisition. All subjects completed each of the four phases in the same order. The nature of practice differed according to the KR condition used during the acquisition phase. However, the same procedures were performed by all subjects on the remaining three phases.

1) Acquisition

All subjects practiced the movement timing task for 90 trials during the acquisition phase. Three separate groups of subjects, corresponding to different KR treatment conditions, were formed within each age group. One KR treatment condition received KR regarding all three movement segments after each acquisition trial (100% KR groups). The other two treatment conditions received, overall, two-thirds of the amount of KR provided to the 100% condition. For one of these treatment conditions, the amount of KR was reduced by progressively eliminating the proportion of trials after
which KR was provided. These groups of subjects will be referred to as the "Faded Trials" groups. KR was progressively eliminated in the other treatment condition by reducing the proportion of movement segments about which KR was provided after each trial. These groups will be called the "Faded Segments" groups.

For the Faded Trials groups (young and older adult groups), when KR was scheduled to be provided, it was given for all three segments of the movement. However, the proportion of trials after which KR was provided (on all three segments) was progressively reduced (faded) over practice: KR on all three segments was provided on 100% of the first 30 trials, on two-thirds of the next thirty trials, and on one-third of the final thirty trials. The determination of trials that were followed by KR was randomized in successive blocks of six trials, such that four out of every block of six trials during trials 31-60 received KR, and two out of every block of six trials during trials 61-90 received KR.

For the Faded Segments groups, some KR was provided after every trial during the acquisition phase. The amount of KR was progressively reduced by fading the number of segments that received KR after each trial: KR about all three segments was provided on the first thirty trials, on two of the three segments on the next thirty trials, and on one of the three segments during the final thirty trials. The segments that received KR (on trials 31-90) were assigned randomly, but with the limitation of counterbalancing across successive blocks of six trials. On trials 31-60, KR was provided about each segment on four of the six trials, twice in combination with each of the other two segments. On trials 61-90, KR was provided about one segment on each
trial, such that each segment was provided KR twice during each successive block of six trials.

A standard, 15 sec intertrial interval was used for all groups. Each trial began with a start tone. The subjects were told that they could choose when to execute the movement after the tone (i.e., the movement was not to be made as a rapid reaction to the tone). The actual movement time (in msec) was the KR that was provided to subjects. This information was both visually displayed and orally presented following completion of the movement.

A 30 minute retention interval was provided to all subjects following the last acquisition trial. During this retention period all subjects completed the Forward and Backward Digit Span and the Digit Substitution subtests of the WAIS-R. In addition, all subjects learned a computer game that required psychomotor skills.

2) Retention

The subjects' task during this phase of the experiment was to perform 18 trials without the provision of KR. The intertrial interval was 10 sec.

3) Transfer

During these 18 trials the subject was asked to perform the movement task with the same relative timing relation among the movement segments that had been learned, but with an overall slower absolute time. Specifically, subjects were instructed to produce a movement that was proportionally slower with the following goal movement
times: 420 msec (segment 1), 795 msec (segment 2), and 525 msec (segment 3). The goal times of this transfer test preserved the relative timing pattern between segments that had been learned during the acquisition trials (.241 -.457 -.302), but required slower overall absolute timing (Wulf & Schmidt, 1989). All of these transfer trials were conducted without KR.

4) Reacquisition

The final 18 trials of the experiment required the subjects to perform the practiced task again. However, during this phase all subjects received KR on all segments, after every trial. The intertrial interval was 10 sec.

Data Analysis

a) Dependent Variables

Timing accuracy and consistency were the primary dependent measures. Both measures were calculated from the error difference between the performance time for a segment and its associated goal time. These error scores were grouped into blocks of six trials. The absolute value of the arithmetic mean of the six error scores, averaged across the three segments (called absolute constant error, or |CE|), was the measure of timing accuracy. The standard deviation of CE for a segment (called variable error, or VE), was averaged across segments and provided a measure of timing consistency (see Schmidt, 1988, for further information on the calculation and interpretation of these error measures).
b) Statistical Analyses

Each dependent measure was analyzed in a separate analysis of variance (ANOVA) for each phase of the experiment. The acquisition data were analyzed using a 2 (Age: young vs. older adults) X 3 (KR: 100%, faded trials, faded segments) X 3 (Acquisition phase: first third, second third, or last third of the trials) X 5 (Blocks of trials per acquisition phase), mixed ANOVA (repeated measures on the last two factors). The retention, transfer, and reacquisition tests were analyzed using a 2 (Age: young vs. older adults) X 3 (KR: 100%, faded trials, faded segments) X 3 (Blocks of trials) mixed ANOVA (repeated measures on the last factor). Post-hoc contrasts on significant ANOVA effects were performed using the Tukey HSD procedure. All significant effects are reported at \( p < .05 \), unless otherwise noted.

RESULTS

Acquisition

Summaries of the acquisition results for \(|CE|\) and VE are illustrated in Figures 1 and 2. Overall, the young adults were more accurate and more consistent than the older adults, resulting in age main effects for both \(|CE|\) (\( F(1,66) = 32.09, MSe = 4247.12 \)) and VE (\( F(1,66) = 5.36, MSe = 4774.94 \)). Age did not interact with any acquisition variables for \(|CE|\), nor were there any KR treatment effects. Performance accuracy improved with practice, as revealed by main effects for phases, blocks, and a phase by block interaction (\( F(8,528) = 9.91, MSe = 527.77 \)). This interaction resulted from improvements across blocks 1, 2 and 3 in the first third of the trials, across blocks
1 and 2 in the second third of the trials, but no further improvements in the final 30 acquisition trials.

In addition to the main effect difference between age groups, the VE results also revealed significant phase and block main effects, as well as a phase by block interaction, an age by KR group by block interaction, and a four-way interaction of age, KR group, phase and block \( F(16, 528) = 1.69, \text{MSE} = 389.20 \). As revealed in Figure 2, the locus of both the three-way and four-way interactions was the generally poor performance of the older subjects under the faded segments condition during blocks 3 and 4 of phase 1 (the filled squares). This effect should be considered with caution however, because the experimental procedures for this group did not differ from either the faded trials or the 100% KR groups during this portion of the experiment.

Retention

Performance of all groups of subjects on the retention trials without KR is illustrated in the left panels of Figures 3 and 4. As may be observed in these figures, the overall better performance that was achieved by the young subjects during the acquisition trials was maintained during retention. This difference was verified by age group main effects for both |CE| \( F(1, 66) = 5.68, \text{MSE} = 1912.09 \), and VE \( F(1, 66) = 17.93, \text{MSE} = 404.14 \). There were no other main effects or interactions.

Transfer

Performance on a version of the acquisition task that preserved the same relative timing, but with slower overall absolute timing, is illustrated in the middle panels of
Figures 3 and 4. The most important finding of the transfer phase of the experiment was the absence of the performance advantage for the young subjects, as had been seen during both the acquisition trials and the retention trials. In fact, there were two indications that the older subjects were better than the young subjects on this transfer task. First, the \(|CE|\) results revealed a three-way interaction between age, KR group and blocks of trials (\(F(4,132) = 2.65, \text{MSe} = 1492.58\)). As revealed by Figure 3, this interaction resulted from the deterioration of the performance of the young subjects in the faded segments groups over trials (the open squares). In general, all of the older subjects maintained relatively accurate performance over the transfer trials. The second indication of a performance advantage for the older subjects was an age main effect for VE that was reliable at only \(p = .10\) (\(F(1,66) = 2.68\)). Although this effect did not achieve conventional levels of statistical significance, it is noteworthy in that the older subjects (\(M = 67\) ms) were more consistent during the transfer trials than the young subjects (\(M = 77\) ms). With the exception of significant trial blocks main effects for both \(|CE|\) and VE (\(p's < .01\)), there were no other significant main effects or interactions during the transfer phase.

Reacquisition

Performance on the practiced task in which all subjects received 100\% KR is illustrated in the right panels of Figures 3 and 4. As had been found previously during the acquisition and retention trials, the young subjects performed the practiced task better than the older subjects. This conclusion was supported by age main effects for both
| CE | (F(1, 66) = 13.40, MSe = 1173.70), and VE (F(1, 66) = 3.83, MSe = 663.82, p = .051). Additionally, both groups of subjects improved their performances at the same rate when provided again with KR, as revealed by main effects for blocks for | CE | (F(2, 132) = 9.50, MSe = 308.02), and for VE (F(2, 132) = 11.76, MSe = 220.45). There were no further main effects or interactions.

DISCUSSION

Much of the research concerning the effects of aging on motor skills is limited to performance on speeded reaction and movement tasks (e.g., Welford, 1985). Relatively little is known about the performance of older adults on other types of motor skills, and even less is known about the influence of aging on the acquisition of new motor skills. Together with a previously published study (Swanson & Lee, 1992), the results of the present experiment suggest some interesting new evidence on the effects of aging on motor performance and learning of a movement timing task.

Movement timing tasks require subjects to estimate the time elapsed between two spatial contact points, such that the elapsed time approximates a goal as closely as possible. In the present experiment this timing task was made more difficult by combining three timing tasks into one serial sequence. The impact of these task requirements as a function of the age of the subject was immediate, as the older subjects were less accurate (as defined by | CE |) and less consistent (as defined by VE) from the beginning of the acquisition trials. Moreover, the older adults remained less accurate and consistent at this task, as revealed by their performance across the acquisition trials (with
KR), on the retention trials (without KR), and on the reacquisition trials (with KR). This finding reveals a fundamental difference in the ability of older adults to perform the movement timing task. Although the locus of this difference is unknown, possibilities include a decrement in a central time-keeping mechanism that is responsible for motor outflow, or due to an inflow decrement, such as the use of proprioceptive feedback for timing (Buckolz, Guay, & Alain, 1984; Christina, 1976; Greene & Williams, 1993).

Although this fundamental decrement in timing differences between the young and older adults existed in various aspects of their performance, there were no age differences in the learning of this motor skill. Evidence for age differences in learning could have been revealed in a number of ways. First, some have argued that an interaction of age and trials during acquisition does reveal learning deficits (Wright & Payne, 1985; but see Schmidt, 1988, for an argument against the use of acquisition data to make inferences about learning). But, even if this performance/learning distinction is ignored, the absence of an age by trials interaction argues against a differential learning effect.

Second, evidence for an age difference in learning would have been supported by an interaction of age and trials during the reacquisition portion of the experiment. This phase of the experiment does not suffer the same contamination to the examination of learning effects as did the acquisition trials since, during the reacquisition trials, all subjects were performing under the same treatment conditions (100% KR). The presence of an age main effect, but no interaction of age and trials, again supports the conclusion
of a fundamental difference in timing ability, but no difference in the learning of this task.

Finally, and most importantly, evidence for an age-related learning effect would have been most clearly pronounced given an interaction between age and KR treatment conditions during the retention, transfer, and/or reacquisition portions of the experiment. The absence of any age by KR group interactions for most of these phases of study further supports the contention that older subjects used KR in a similar way, and to an equivalent extent, to learn the motor skill in this study. It is interesting to note that the only significant interaction that was found in this regard revealed that older subjects in the faded segments group performed more accurately on blocks 2 and 3 of the transfer test than did their younger counterparts.

For both the young and older subjects, the KR relative frequency conditions did not have a differential influence on performance during any of the phases of the present experiment. Previous studies of motor learning (with young adults) using a fading technique found that learning was facilitated when KR was gradually withdrawn over trials (Winstein & Schmidt, 1990; Wulf & Schmidt, 1989; Young & Schmidt, 1992). One possibility for the failure to replicate these findings could be due to the length of the retention interval. In the Wulf and Schmidt (1989) and Winstein and Schmidt (1990) experiments, it was found that the influence of faded KR was enhanced after longer retention interval (days later) compared to relatively brief retention intervals (minutes later). The present experiment was designed to shorten the time in which the temporary effects of KR would dissipate by using a filled one-half hour retention period in which
the subjects participated in motor and cognitive activities including learning a new perceptual motor skill. It remains unknown whether a similar pattern of results would have emerged after a longer delay in the present study.

The results of this study did not support the predictions that were based on the guidance hypothesis and the expected effects of aging. According to the guidance hypothesis, performance during acquisition should be enhanced with more access to KR. However, there were no acquisition differences due to the frequency of KR in either accuracy or stability of performance. In retention, according to the guidance hypothesis, the KR condition that created the most dependence during acquisition would be the most detrimental for learning. In the KR conditions where the learners received KR for every segment on every trial (100% relative frequency) or when they received KR for at least one segment for each trial (faded segments groups), it was expected that the guidance effects of the KR would block learning. However, there was no difference between the KR conditions in any of the retention tests. These findings put into question the generalizability of the guidance hypothesis of KR.

The effect of age related changes in cognitive functioning were hypothesized to influence how KR would be used to enhance learning. In both the 100% KR relative frequency and the faded trials conditions, the requirements of storing KR for each segment, comparing this information to movement outcome, and generating an improved movement program was predicted to create a condition of information overload. The faded segments condition was thought to be most beneficial to learning as some KR was provided on each trial. The only indication that this hypothesis had some merit was in
the transfer condition, where the older faded segments group was more accurate than the young faded segments group, suggesting that the older group learned the generalized motor program better with the faded segments KR schedule (cf. Wulf & Schmidt, 1989).

Based on the findings of this experiment, further work is needed to understand the role of KR in motor learning, particularly as it relates to more complex tasks such as a serial, multisegment timing task. Perhaps in a more complex task with multiple sources of KR available, the learner develops a cognitive strategy that allows for focusing on different aspects of the movement and the related KR as learning progresses. As well, further work is needed to clarify the role of KR in enhancing motor learning in older adults.

Despite the limitations noted above however, the present results are quite consistent with the overall general finding, that motor learning can be facilitated when KR is presented relatively infrequently (see Schmidt, 1988, 1991, for further discussion of this new interpretation of the role of KR in motor learning). Contrary to earlier views on motor learning (e.g., Adams, 1971), KR does not need to be presented as often as possible in order for the potential benefits to be maximized. The present findings extend this general view to an elderly population as well. Older adults can learn a movement timing task as well with reduced information during practice as with very frequent KR.
REFERENCES


Figure 1

|CE| performance of all groups during acquisition trials

(Note: The 67% (S) and the 67% (T) refer to the faded segment and faded trial groups respectively.)
Figure 2
VE performance of all groups during acquisition trials
(Note: The 67% (S) and the 67% (T) refer to the faded segment and faded trial groups respectively.)
|CE| performance of all groups during the retention, transfer, and reacquisition trials

(Note: The 67% (S) and the 67% (T) refer to the faded segment and faded trial groups respectively.)
Figure 4
VE performance of all groups during the retention, transfer, and reacquisition trials
(Note: The 67% (S) and the 67% (T) refer to the faded segment and faded trial groups respectively.)
Chapter 5: DISCUSSION

This final chapter will review the overall purpose and rationale for the thesis. The findings from the two experiments will be summarized, followed by a description of the theoretical and practical contributions of this work. The methodological merits and limitations of the experiments will be described. The chapter will close with a discussion of future directions.

OVERALL PURPOSE AND RATIONALE

There is a perception in society that older adults have difficulty when learning new skills. This perception encompasses all facets of cognitive and motor learning (Kausler, 1990; Salthouse, 1991). Yet, there is evidence that older adults are capable of learning both cognitive and motor skills, albeit not necessarily to the same level of younger adults. In contrast, little is known about whether older adults learn in the same way as young adults. As noted by Welford (1984a), there is a dearth of work in this area.

The overall purpose of this thesis was to begin to address the issue of whether older adults learn motor skills in the same way as young adults. The method chosen was to evaluate variables known to influence motor learning in young adults, and to compare how these variables influence motor learning in older adults. Several variables have been
identified in the literature that enhance motor learning in young adults (as identified in Chapter 2), but direct application to the aging population of this work on young adults is not plausible.

The rationale for this thesis was based on the findings in the literature that older adults demonstrate changes in how they prepare and execute movements (as discussed in Chapter 1). Furthermore, aging is associated with cognitive changes, and cognitive processes are an integral part of the early stages of motor learning (as discussed in Chapter 2). The combination of age-related changes in motor control and cognition was the basis for the hypothesis that older adults use learning variables differently than young adults.

The justification for this work was based on the premise that the findings would have both practical and theoretical value. In relation to practical merit, older adults engage in new motor learning situations in work, leisure, and rehabilitation settings. With the increase in the aging population and the need to optimize the functional capabilities of older adults, an understanding of how to enhance learning is essential. Of particular interest is the application of these findings to rehabilitation of older adults who have suffered a loss of abilities due to injury or disease. Although many of these individuals also suffer from cognitive dysfunction, the first step in developing principles for retraining is to understand the learning process in normal older adults. Once an understanding of normal is gained, future work can focus on the effects of age combined with disability on motor learning.
SUMMARY OF EXPERIMENT 1

The first experiment evaluated the combined effects of age and the manipulation of the schedules of KR on the performance and learning of a multisegment task. A comparison was made between blocked and random schedules of KR on learning by younger and older adults. The results of this study indicated that younger adults were more accurate and consistent during both skill acquisition and retention. Generally, all groups improved their accuracy over the acquisition phase, but the random KR schedule had an adverse effect very early in practice. Later in acquisition, this trend was reversed, and performance improved with the random KR schedule compared to the blocked KR schedule. In the retention phase, there was clear evidence that the random KR schedule had a greater effect on learning for both age groups. The beneficial effects of a random schedule on both acquisition and retention were similar to the findings of Lee and Carnahan (1990) who used a young adult sample.

These results suggest that although there are age-related differences in the ability to learn sequential motor skills, the way younger and older adults used KR in the learning process seems to be similar. For both age groups, the blocked schedule of KR resulted in poorer learning which is consistent with the guidance hypothesis. The repetition of KR for one segment benefitted performance for that segment by providing information and guidance. However, blocked KR also created a dependency on the feedback. Once KR was changed to another segment, performance deteriorated on the segment where KR had been withdrawn. According to the guidance hypothesis, this reliance on KR may have prevented the development of error detection capabilities based
on processing sources of intrinsic information, causing poor retention after KR had been removed.

On the other hand, the random schedule of feedback created a better learning environment. In this type of schedule the learner had to attend to and organize a greater variety and amount of incoming and outgoing information. In both types of schedules, the learner needed to focus on KR from one segment, apply this input to movement memory, detect the errors, and then correct for them in the next movement commands. In addition, the learner in the random KR schedule group needed to adjust other segments in response to previous KR and in anticipation of incoming KR. With this more complex processing, there was less dependence on KR, resulting in better motor learning.

One of the hypotheses of this study was that due to changes in cognitive functioning, older adults would have difficulty with the random KR schedule as a result of the more complex cognitive processing requirements. However, there were no age-related changes in how the KR schedules affected learning. It is not clear why older adults generally could not perform the task at the same level as younger subjects. One of the common problems identified with older adults is the speed of processing (Salthouse, 1985). In this study, the post-KR interval was under the subjects' control allowing the individual to complete processing before proceeding to the next trial. Perhaps, rather than speed of processing, in this situation, the older adults may have had more difficulty organizing effective cognitive strategies. When asked about what approaches were used during learning, all of the younger adults could identify strategies,
while only 15 of the 24 older subjects could indicate how they tried to learn the movement task.

This first study provided the first evidence that older adults seemed to use KR in the same way as young adults to learn a multisegment task. The next experiment was designed to extend this work by examining a different manipulation of KR using the same task.

SUMMARY OF EXPERIMENT 2

Having found that young and older adults are better able to learn a movement timing task when using a random schedule of KR compared to a block schedule, the second experiment was designed to evaluate another manipulation of KR which involved a reduced relative frequency combined with faded KR. Using the same task, three different manipulations of KR relative frequency were compared during acquisition, transfer, and reacquisition.

With the lack of literature in this area, it was difficult to make clear predictions. When learning a timed sequential arm movement, the learner in a 100% relative frequency condition receives KR about each segment after each acquisition trial. Given the cognitive changes in older adults, it is possible that this KR schedule would constitute information overload and reduce performance. In the faded relative frequency conditions, the reduction of information could either have an age-associated detrimental effect, because of the lack of information combined with the requirement for more complex processing, or be beneficial as predicted by the guidance hypothesis. The
further manipulation of KR by fading over trials or segments was intended to evaluate the guidance hypothesis. In the younger adults, the fading of KR over trials was predicted by the guidance hypothesis to be most beneficial for learning in that there were some trials where no information was given. The fading over segments manipulation was expected to produce the detrimental effects of KR in that KR was provided on each trial, and as a result would block some of the essential processes involved in learning. For the older adults, again it was difficult to predict. The working hypothesis was that the older adults would benefit most from the faded segments schedule in that given the cognitive changes, some information on each trial would be necessary to maximize learning. In the faded trials situation, the complex processing involved in maintaining KR information over trial would be detrimental.

Further to the first experiment, young adults were more accurate and consistent in acquisition, and on both the retention (without KR) and reacquisition (with KR) tests. However, there were no age differences during transfer. Surprisingly, the effects of fading KR, either by trials or segments, were not significantly better than the 100% KR for either age groups.

As in the first experiment, in general, there was no evidence that aging resulted in differences in the manner by which KR was processed to learn a motor skill. The combined findings of these two experiments provided contributions to both theoretical and practical application.
THEORETICAL ADVANCEMENTS OF PRESENT RESEARCH

Aging

The major contributions arising from this work in relation to aging are first the finding that although normal older adults are not as effective performers as young adults, they can learn new motor skills. Of primary importance is the finding that the learning process seems to be the same in young and older adults. Older adults responded in a similar manner to the two manipulations of KR - scheduling of KR and relative frequency of KR. This finding was somewhat surprising given that motor learning is dependent on motor performance and the underlying information processing stages involved in producing motor output, as well as cognition involving the underlying information processes of encoding, storage, search, and retrieval. Despite the indications from the literature that older adults are known to exhibit differences in motor performance and cognition, they still were able to utilize information to enhance learning in a similar way to young adults.

Guidance Hypothesis of KR

This thesis extends the guidance hypothesis of KR in two directions. The first is the role of KR in learning a multisegment task with timing goals for each of the segments. In the past, there has been a limited amount of work on this type of task (Langley & Zelaznik, 1984; Lee & Carnahan, 1990; Wulf & Schmidt, 1989). The finding from the first experiment confirms earlier findings that learning of multi-segment tasks is facilitated using a random schedule of KR (Lee & Carnahan, 1990). The results
of the first experiment of this thesis extend these findings, suggesting that the guidance hypothesis applies to older adults. The random schedule of practice is better at facilitating the processes involved in learning when compared to a blocked schedule of KR.

The second experiment represents the first exploration of the different combinations of fading and reduced relative frequency schedules in a multi-segment task that has different explicit timing characteristics. The findings suggest that regardless of the fading schedule, the reduced relative frequency is as effective for learning as the 100% KR schedule. In one way this finding confirms the guidance hypothesis that a reduced relative frequency is at least as beneficial to learning as 100% KR. Yet, in another way, these results bring into question the extension of the guidance hypothesis to multi-segment, multi-goal tasks. The guidance hypothesis suggests that the no-KR trials during practice are beneficial to learning in that the development of the error detection processes involved in learning are encouraged. Thus, at least in the young adults, the expectation was that the fading of KR over trials would be most effective. The fading over segments schedule provided KR on every trial and was expected to block the intrinsic activities. No difference between the groups suggests that perhaps there are limitations to direct application of the guidance hypothesis to this type of task. However, despite these potential limitations, the other contribution of this thesis is that the application of the guidance hypothesis can be extended to normal older adults.
PRACTICAL CONTRIBUTIONS

The practical contribution of the findings from this work is toward the training of older adults. In order to have some practical application, the choice of the task is critical. The choice of tasks to use in basic research, and their relation to everyday tasks and skills, involves an understanding of the types of tasks that are likely to be learned by older adults. One view on the factors in this issue is presented by Van Galen and Wing.

Movement of the hand to bring a cup of tea to the mouth is complex in the sense that it requires simultaneous control of several joints. However, a characteristic of many skills that is lacking in the cup of tea example is the sequencing of a number of logically separate components. In some skills it may merely be a matter of repeating a single component or a small number of components, perhaps with occasional minor modification. This might be an appropriate way of characterizing the steps taken in walking over flat ground. In a large number of other activities our ability to sequence a number of separate movements each with different spatiotemporal characteristics is central. Examples of this range from the sequencing of finger movements in keyboard skills such as typing or playing the piano to activities such as dressing or making a cup of tea. These skills require a very specific ordering of movements, often in relation to objects in the environment. (van Galen & Wing, 1984, p. 153).

The laboratory task chosen for this thesis has similar characteristics to many everyday activities such as dressing or making a cup of tea, and sports activities such as a tennis serve or a tee shot in golf. This type of task can be classified as serial (Schmidt, 1988) in that it is made up of discrete components which have different spatial/temporal goals. The results of these experiments can be applied to training the learning of serial tasks that are part of sports, work and rehabilitation. Not only can these findings be applied to training young adults, but they can be extended to training older adults.
METHODOLOGICAL ISSUES

There are several methodological issues associated with research on the effects of age (Birren & Schaie, 1985, 1990; Kausler, 1990). The intent is to highlight the specific methodological issues that are pertinent to this thesis.

Subjects

Until now, work in motor learning has focused mainly on young adults who are volunteers from university classes. As a result, there has been very little attempt to provide demographic, health or psychomotor information. The assumption is that the young adults are a relatively homogeneous population. This same assumption cannot be made of older adults, who usually are volunteers from the community with a potentially wide variety of functional, cognitive, and health status.

The intent of this research was to compare "normal" older adults with younger adults. The criteria used to define normal, and then screen for subjects who fit those criteria, is a difficult methodological issue. In reviewing both the cognitive and motor performance literature on aging, it became apparent that the information used to describe the "normal" older subjects varied widely between studies. Other criteria are necessary because age in itself is not predictive of functional status.

It was difficult to decide the best method of describing the older adults, and, as a result, different methods were used between the experiments. However, in both experiments information was collected on cognitive, functional (including education), and health (including fitness) status. In the first experiment, the Mini- Mental State
Examination (Folstein, Folstein, & McHugh, 1975) was used to screen both for cognitive impairment as well as to describe cognitive level. As well, a short questionnaire was administered that evaluated the level of functioning in the community (Fillenbaum, 1985). In addition, all subjects were asked to report on their fitness and health status. All subjects scored at the top end of the scales, which indicated that the functional level of the group of volunteers was beyond the scope of these measures. However, both measures were useful in that they provided a reliable and valid method of describing the older subjects.

The limitations of these assessment tools led to changes in the second experiment. In addition to self report of function and health, both younger and older subjects completed the Forward and Backward Digit Span and the Digit Symbol Substitution subtests of the Wechsler Adult Intelligence Scale- Revised (Wechsler, 1981). The intent of these assessment tools was to provide a more specific measure of cognitive and psychomotor functioning. By testing all subjects, a comparison of function could be made between the two groups.

In future work, a screen such as the Mini-Mental State Exam would be useful to exclude cognitively impaired subjects. Tests such as the Wechsler subtests are also useful for classifying and comparing groups on attributes that could influence motor learning. In addition, information on the use of medication and more formal measures of health status would be recommended to identify variables that could impair motor and cognitive function. Finally, the influence of physical fitness may need to be considered in a more systematic way. In the experiments in this thesis, fortunately there was equal
representation of physically fit (as defined by exercising at least one-half hour, three times per week) and more sedentary older adults. However, there is evidence that older adults who are physically active demonstrate faster reaction time and movement time when compared to younger adults (Spierso & Clifford, 1978). As well, there is some evidence that physically fit older adults demonstrate higher cognitive function (Toole & Abourezk, 1989). In future work, the level of fitness may need to be more systematically considered in the design.

In general with aging, differences between people become more pronounced. The use of measures to both screen and describe subjects will help to make the older cohort more homogenous and define the generalizability of the research. It should be noted that in these experiments, both the young and the older adults could be considered to be "elite". The young adults were university students in a physical education program and the older adults were healthy volunteers. Given that these groups are not necessarily representative of the greater population, caution needs to be taken in general application of the results.

Task

Choosing the appropriate task is a difficult decision in learning experiments. In this case, the task needed to be appropriate for both the age groups used and the KR issues that were to be explored in the thesis. Regardless of the laboratory task chosen, there would always be the question of the generalizability to a real world task (Kausler,
1990). But at this stage in the work, the merits of a laboratory task in relation to measurement capabilities outweighed the use of a more applied task.

The multisegment task with different timing goals for each of the segments was a good compromise. As mentioned previously, it is similar to many serial tasks that are performed everyday. It also permitted the examination of both the KR and the aging hypotheses. In relation to the guidance hypothesis, very little was known about how this hypothesis could be applied to multisegment movements. As for attempting to identify age-related differences in the effect of KR schedules on learning, the rationale was that a complex task was needed. It was clear from the literature that the age-related differences in both motor learning and cognitive function become apparent in more complex activities. This multisegment task had three segments with different timing and spatial requirements. As Welford states, "older people appear to have difficulty in overlapping the execution of movements with the making of decisions about subsequent movements" (Welford, 1984a, p. 255). In choosing this task, consideration was given to the motor performance changes in older adults that could potentially confound the results. The timing characteristics of the movement were not fast in order to eliminate the issue of slower movement time in older adults. As well, subjects could self-initiate the movement, eliminating the issue of slower preparation time in older adults.

Generally, this task suited the purposes of these experiments. However, although it was a more complex task than used in many experiments on KR, it still could be considered to be relatively simple. Potentially, differences in learning between younger and older adults would become apparent with more complex tasks. In future work,
consideration needs to be given to using a task that incorporates more complex task requirements including timing, kinematic and kinetic goals.

Retention Phase

How long to delay the test of learning, or the retention test, was a design issue that was considered carefully. This issue was particularly relevant to the second experiment. Some studies which showed a benefit of reduced relative frequency of KR had initially found no difference in a 10 minute retention test, while identifying a difference only in a one-day delayed retention test (Winstein & Schmidt, 1990; Wulf & Schmidt, 1989). Yet, a more recent study found an immediate benefit for reduced relative frequency of KR (Vander Linden, Cauffman, & Greene, 1992). Consideration was given to the convenience of our older subjects. It was believed that it would be an inconvenience to ask older subjects to come back to the laboratory for a delayed retention test. This additional burden could limit enrollment of potential subjects. Instead, the study design incorporated a filled one-half hour retention period in which all subjects participated in cognitive activities and the learning of a psychomotor task. The intent of the filled retention interval was to dissipate temporary performance changes before the measure of learning. However, the results did not confirm the hypothesis that the reduced relative frequency would enhance learning. The question that remains is whether this finding was related to the use of the multisegment task, or whether similar results would have emerged in a delayed retention test.
Statistical Power

The second experiment failed to reject the null hypothesis that there was no
differential age effect on learning between the reduced relative frequency combined with
the faded schedule of KR and the 100% KR schedule. As suggested in the previous
section, this finding could be due to lack of a delayed retention test. Another possibility
is that the effect was present but not detected statistically (i.e., a type II error).

Two arguments can be made however, to suggest that this was not a type II error.
First, by visual inspection of Figures 3 and 4 of Experiment 2, it appears rather clearly
that the individual KR groups within each of the age groups tended to perform similarly.
Thus, the differences between the means do not suggest that such an effect was present.
Second, the adjusted variance explained (ω²) by the age main effect, in contrast with the
sum of the variances explained by the age by group and the age by group by block
interactions, also argue against a type II interpretation. For retention, the |CE| and VE
main effects accounted for between 5 and 13% of the total variance (ω² = .050 and .128,
respectively). In contrast, the interactions involving group and age accounted for a very
small proportion of variance (ω² = .0004 and .014, for |CE| and VE). For
reacquisition, the |CE| and VE main effects again accounted for much more of the
variance (ω² = .099 and .022) than the interactions involving age and group (ω² = .002
and .001). Clearly, these data provided no evidence to support a view that younger and
older adults differ in their use of KR to learn motor skills.
FUTURE DIRECTIONS

There are many directions that this work could be extended both in relation to investigating the guidance hypothesis of KR as well as further evaluating the effect of aging and the use of variables on motor learning.

Guidance Hypothesis of KR

Perhaps the most obvious direction for further work is to replicate and extend the second experiment by including a delayed retention phase in the study design. The findings from this experiment indicated that the reduced relative frequency of KR was as beneficial to learning as the 100% relative frequency schedule. However, the role of reduced relative frequency of KR combined with a faded schedule would be further verified using a delayed retention.

Another direction of further study is indicated by these results. The findings of this work suggest that there may be some limitations of the application of the guidance hypothesis of KR to more complex tasks. From the first experiment, it was clear that there are different questions that need to be asked when using more complex tasks. The differential effects of random versus blocked practice schedules is not a consideration in simpler tasks. And yet, the answer to this type of question helps to define the parameters of the guidance hypothesis. The findings from the second experiment lend support to the need to test the guidance hypothesis on more complex tasks. The experimentation with more complex tasks can include not only serial tasks as used in the current experiments, but other types of tasks such as bimanual co-ordination (Lee, Swinnen, & Verschueren,
1993; Swinnen, in press). In the past, the technological limitations prevented evaluation of KR on more complex tasks. With the development of new technology that can measure kinematics and co-ordination, more complex tasks can be the target of research.

Aging

This thesis represents a beginning for work focusing on the effects of aging on motor learning. There are many possible avenues for future work including examining different KR variables, to evaluating other variables that are known to affect learning such as practice schedules, observational learning and mental practice.

Based on the results of these experiments, future work could consider the use of more complex tasks. It may be that more complex tasks which are more typical of everyday activities will be better for identifying the effect of age on motor learning. If the results of this thesis are any indication, the findings from evaluation of different learning variables may well be that there is no difference in how older people learn. Furthermore, it is possible that given the motor performance and cognitive changes associated with age, that older adults use adaptive strategies to facilitate learning. In the first experiment, there was an indication that there were differences in strategies used to learn the task between younger and older adults. Another direction for future work which has been suggested by Welford (1984a) could be to identify age-associated changes in strategies.

An interesting finding from the second experiment was that there was no difference between younger and older adults in the transfer task which was slower, but
had the same relative timing requirements as the experimental task. This finding suggested that older adults were able to learn the generalized motor program as well as younger adults. Future work could explore the effect of age on learning the generalized motor program.

Another direction for further research is to address motor learning issues that are relevant to rehabilitating older adults with cognitive and physical disabilities. In fact, the physiotherapy profession has started to examine the relevance of motor learning theory on physiotherapy practice (Winstein & Knecht, 1990). Indeed, there have been several articles about the potential contributions of motor learning theory to clinical practice (Lee, Swanson & Hall, 1990; Schmidt, 1991b; Winstein, 1991).

CONCLUSION

Findings from this type of work using a laboratory task have the potential of enriching the lives of older adults. By identifying differences and commonalities on how motor skills are learned by young and older adults, strategies can be developed to capitalize on the similarities and either delay or compensate for the differences. Overall, the intent of this direction of research is to maximize physical abilities and minimize limitations in the aging adult.
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