Movement control systems are altered by the aging process. A growing body of research exists that explains the known changes that occur with aging, and many of those changes are related to central nervous system (CNS) effects. This article reviews motor control and learning issues related to CNS information-processing effects of aging and the effects of practice and physical conditioning on reactive capacity. The extensive variability in motor-performance abilities of older people is addressed, and the significance of individual differences is emphasized. [Light KE. Information processing for motor performance in aging adults. Phys Ther. 1990;70:820-826.]

**Key Words:** Aging, Geriatrics, Learning, Motor activity, Motor skills, Movement.

Research in the field of motor control and learning is growing, and physical therapists are developing important principles to apply to the practice of movement training and retraining. Research on the aging process and its implication for movement control has also increased considerably during the past few decades. The purposes of this review are to identify and explain important motor control and learning issues related to information processing and the effects of practice and physical training and to emphasize the individual differences in the elderly population.

**Information Processing**

**General Factors**

Purposeful movement involves integrated activity of the central nervous system (CNS) with the body periphery. In order to function with appropriate movement behaviors in a changing environment, the CNS must be able to identify and perceive sensory input, determine useful actions, and then execute those actions with correct movement sequencing, timing, and coordination. All of this brain activity is referred to as **information processing**.

Information processing for motor control has been described by several models, each offering an interesting conceptual view of what the brain must do to control movement. The number and labeling of processing stages in the various models differ slightly, but the models agree in basic content. The simplest information-processing model, and perhaps the one most easily understood at a basic level, is the model described by Schmidt. Schmidt’s model includes three sequential stages for neural processing of information related to movement output: (1) stimulus identification, (2) response selection, and (3) response programming. The Figure depicts this process.

Each stage of information processing requires time expenditure. The additive requirements for all stages accounts for most of the time delay in movement initiation. The experimental methodology commonly used to study information-processing time is called **chronometric measurement**, which includes reaction-time (RT) instrumentation and design. The rationale for using RTs to measure information-processing time is quite simple. Certain environmental factors are clearly related to the time requirements of specific information-processing stages, while not affecting other stages. The testing of movement initiation or RT, while experimentally manipulating an environmental factor, allows an indirect look at how that factor influences central processing time.

If we consider the simple stages of information processing in Schmidt’s model, the effect of a few known factors can be addressed. The stage of stimulus identification involves sensing, encoding, and perceiving significant environmental stimuli. Factors known to affect the time necessary for this stage are stimulus clarity, stimulus...
Response selection is the information-processing stage in which the response decision is made about what motor output is appropriate. One obvious factor influencing the response-selection stage is the number of alternative choices that must be considered. Certainly, we have all experienced the reality of output slowdown when being bombarded with decisions and choices. The slowdown is actually predictable by Hick's Law, which is a mathematical statement that the relationship between RT and the logarithm for the number of choice alternatives is a linear function.

Another factor known to affect response-selection time is stimulus-response (S-R) compatibility, that is, the degree of fit or the ease of matching between the stimulus and the movement required to respond to the stimulus. Stimulus-response compatibility can be illustrated by two simple examples. The first example is the well-learned, and therefore S-R-compatible, condition of a green traffic light indicating to the driver to proceed without stopping. The second example is the condition in which a road construction crew is directing traffic through a single lane that ordinarily is open only to traffic approaching from the opposite direction. Even though the construction crew signal the continuance of one lane of traffic, a driver may be hesitant to proceed quickly when looking down the road at oncoming traffic. Clearly, the second condition offers less S-R compatibility than the first condition.

Response programming is the last stage of information processing. This is the stage for movement output planning and structuring, the stage in which actual response execution begins by central activation. Response programming is influenced by alterations in the movement being made and therefore is the stage we manipulate most in our physical therapy programs. Because of its importance, response programming will receive special attention in this review. Factors thought to affect response programming include movement complexity and movement duration, in addition to a less-understood phenomenon known as response-response (R-R) compatibility. Movement complexity refers to the difficulty of the movement response and has been investigated experimentally since Henry and Rogers noted that more complex movements required more time to program than did simple movements. The search for complexity factors, or for what the CNS perceives as complexity in a movement, has led to an array of research reports. The defining of movement complexity has great significance to physical therapy. In that the motor programming of a task is influenced by the movement complexity, an understanding of movement complexity could improve the teaching progression of the task.

Response-response compatibility, or the way two responses affect each other either when being performed simultaneously or when serving as the movement-response alternatives in a choice reaction-time situation, has been only vaguely addressed in the literature. It appears that the R-R compatibility issue for choice responses did not emerge until Komblum's 1965 study of RTs for the index and middle fingers of both hands. Komblum demonstrated that the RT for a particular finger is dependent on the choice alternative with which it is paired. It was found that choosing between contralateral fingers was significantly faster than choosing between ipsilateral fingers. Komblum suggested that his findings supported the hypothesis that much of the time consumed in an RT task is a result of inhibitory processes for competing incorrect response alternatives.

The use of RT latency to predict programming difficulty is based on the simple idea that more preparation time implies more CNS activity to access and coordinate the movement output. The factors that have been explored for their effects on programming include movement duration, movement timing, movement direction, movement force, extent of movement, number of movement parts, and side of body controlled.

Figure. A simple model of information processing (CNS = central nervous system). (Adapted from Schmidt)
Effects of Aging on Information Processing

One of the most reported age-related effects on information processing in the research literature is that of response and movement slowdown.29-31 A considerable body of literature exists to explain the multitude of physiological factors involved in this slowdown. The age-related deterioration of movement response speed, in reaction to an environmental stimulus, is generally accepted by researchers in aging to be determined more by CNS processes than by peripheral processes such as nerve conduction velocity, muscle contractile speed, or synaptic transmission delays.31

The effects of age on CNS function have been explored by numerous investigators, using information-processing experimental paradigms. Interest has been generated in the examination of age-related effects for each stage of information processing in order to isolate factors that are most accountable for the information-processing slowdown. The age effect cannot be isolated to a single stage of information processing, because all stages appear to be influenced by aging.29-31 Which stages are most affected by age and how much they are affected continue to be controversial questions among researchers.

Sensory losses associated with the aging process obviously affect the stimulus identification stage of information processing. The decline of sensory receptor function is commonly believed to account for most of the sensory processing difficulty observed with aging. Central nervous system alteration for stimulus recognition and sensory encoding, however, appears to be more responsible for the sensory processing slowdown than the sensory transducer changes. Borwinick addressed this point by functionally equating stimulus intensities for all subjects in his RT study and found that RTs continued to be significantly slower in the older subjects. This result suggested that the main age effect for sensory processing slowdown was related to CNS processing rather than to input or transducer factors.

Improved sensory information processing in older adults is possible when significant stimuli are made clear, intense, and with a high contrast between the signal and the background.31 The importance of considering environmental stimuli when training older people in the physical therapy clinic deserves emphasis. I contend that a busy, noisy, and environmentally cluttered physical therapy clinic is not the appropriate instructional atmosphere for older individuals to begin a motor learning task. Older people should be allowed to develop motor learning in a quiet, uncluttered, and calm environment. As the older individual progresses in motor learning, the clinical setting becomes more appropriate and more manageable.

The second stage of information processing—response selection—has received considerable attention and has been demonstrated to be greatly affected by advancing age.29-31,35-38 Welford reported that both the factors of choice alternative number and S-R compatibility have a more significant effect on older individuals than on younger individuals. Welford found that extremely simple RT tasks, such as pressing or lifting a finger away from a response key, were only minimally affected by age. Progressively adding choices increased the age difference, and a much greater difference between younger and older subjects was observed when the choices involved some difficulty of matching the stimulus to the response.31 Rabbitt also reported that the information-translation rate in choice RT paradigms was affected by the relationship between the signal and the response. A partial explanation for the difficulties observed in response selection by older individuals is the notable decline of their abilities to anticipate signals or to shift selective attention when signals and response requirements changed.

The effects of age on the last stage of information processing—response programming—have received the least research attention, but have been demonstrated to slow down with aging.6,29-40 Response programming is probably the information-processing stage most manipulated by physical therapists when they progress the task complexity of their rehabilitation requirements. Therapists commonly progress training programs by increasing the complexity of tasks, adding components to movements, altering the sequencing of movements, or increasing the number of movement components that must be controlled simultaneously. These movement manipulations affect movement complexity and R-R compatibility, two of the factors of the response-programming stage of neural processing of information.

Response programming is difficult to isolate experimentally. A controversy has existed for many years about the type of experimental paradigm necessary to ensure isolation of the response-programming stage, while also ensuring that the total amount of time spent in the information-programming process is measured. Ivry and Klapp and colleagues have provided strong justification for the necessity of using choice RT paradigms if all of response programming is to be measured.

Recent Research on the Age Effects of Response Programming Factors

Light and Light and Spirduso have explored the age effects for the response-programming factors of movement complexity and R-R compatibility. Light and Spirduso used a two-choice RT paradigm to study the effects of age on very small gradations of movement complexity across young, middle-aged, and senior adults. Four hand movements (ie, right index flexion, right pinch, bilateral index flexion, and bilateral pinch) were studied. These movements were selected because they allowed the carefully graded progression of movement complexity by manipulating the number of digits and the number of sides of the body.
controlled. The results of this study demonstrated a robust interaction effect for movement complexity and adult aging. The usual age-related slowdown was clearly seen. Sensitivity to movement complexity was also found to be an age-related phenomenon. The senior age group differed significantly in RTs for all four movements, indicating a response-programming difference in complexity for each movement. The young adults did not differ significantly between the two unilateral responses or between the two bilateral responses, but the unilateral reaction times were significantly faster than those of the bilateral responses. The middle-aged group differed significantly between the RTs for the two unilateral responses, but not between the two bilateral responses. As in the younger and older age groups, the middle-aged subjects' unilateral responses were significantly faster than their bilateral responses.

These results are important to physical therapists who work with the elderly. The sensitivity of the aging motor systems in healthy adults to small gradations in movement complexity clearly indicates the difficulty that older individuals have for programming new movements. Older individuals require more time to process neural information, a more gradual progression in the learning requirements, and more time to accommodate to small changes in task demands than do younger subjects.

Light also explored the age effects for the R-R compatibility factor of response programming. As seen for the movement-complexity factor, the older adult group demonstrated more sensitivity to R-R compatibility than did the younger adult and middle-aged adult groups. The sensitivity appeared to be age-related, in that the middle-aged adult group also revealed more significant differences in RTs for different levels of R-R compatibility than did the younger adult group.

The general ranking of compatible pairs of choice responses from least to most difficult was similar for all age groups. Response-response compatibility appeared to be a function of commonality or motor equivalence, as suggested by Heuer. The most compatible responses were the unilateral responses of a particular type (ie, right index flexion or right pinch) when the competing choice alternative was a bilateral movement of the same type. It appeared that in this condition, where the right-hand movement was common, the movements could be programmed more easily. The least compatible responses were those in which the competing choice alternative had no common component with the correct response, such as occurred when the bilateral index flexion response was paired with the correct pinch response.

In conclusion, the factors of movement complexity and R-R compatibility play an influential role in response programming. The degree to which small gradations in these factors affect response programming is dependent on adult aging. As movement complexity increased, response programming time increased, but the significant differences among the movements were age-dependent. Older people were much more sensitive to small changes in movement complexity than were younger subjects. The same result was observed for R-R compatibility, in that as R-R compatibility decreased, response programming time increased, but the increase was age-dependent. Older individuals were more sensitive to the differences in R-R compatibility than were younger subjects. The age differences were observed to increase as the levels of movement complexity increased and R-R compatibility decreased.

The sensitivities that older individuals have for information-processing factors have been well established, but are there ways to improve reaction and movement performance in the elderly? Certainly, the answer is yes. The next few sections of this article will address possible means of motor performance improvement in older people.

**Effects of Practice for Older Versus Younger Adults**

Even though general response speed declines with age, functional performance speed is a reasonable goal in the elderly population. Many older people need to improve the speed and consistency of their movements for safe functioning within their everyday environments. Functional task practice is one way to improve or maintain adequate functional speed. A well-established motor-learning principle is that practice or repetition of a task improves movement and response time for that task. Older individuals are capable of improving movement performance and response times with practice, just as are other age groups. In a comprehensive report on the effects of age and practice, Salthouse and Somberg identified three important possible mechanisms that could account for the practice-related skill improvement seen in the elderly: (1) a change in the type of information being processed, (2) a change in the method of information processing (eg, some parts performed in parallel versus serially or the omission of certain information-processing stages), and (3) a reduction in attention requirements.

The establishment of new motor programs or a shift toward automatic information processing is possible for elderly subjects with practice. Hoyer et al theorized that the slowdown observed with aging results from a lack of appropriate movement practice and failure to receive reinforcement for activity. Hoyer and colleagues demonstrated that practice of three low-difficulty paper-and-pencil tests for two sessions by elderly subjects not only led to an increase in response speeds on the training materials, but also transferred to improved performance on 11 other intellectual, verbal, and perceptual speed tests.

Although older people can improve performance with practice, the answer to another important question has yet to be decided. Could the age differ-
ences observed in movement and RTs between young and older adults be eliminated with practice? Murrell and colleagues suggested that this question had important practical significance and demonstrated that age differences could disappear if older subjects were extremely well practiced. Other researchers have found practice-related improvements in both young and older adults, but that the age differences between the two groups were maintained. Numerous experimental control factors, such as the complexity of the physical requirements of the task, could account for the diverse findings among these studies.

A recent study by Light and colleagues provided evidence in favor of Murrell’s hypothesis that the age-effect difference could be diminished with practice. Forty young adult and older adult subjects were divided randomly into four groups of equal size: young control (X = 23 years of age), young practice (X = 24 years of age), older control (X = 67 years of age), and older practice (X = 70 years of age). Over a 3-day period, the practice groups performed 320 practice trials of two reaching tasks that varied in movement complexity. As expected, both the young and older practice groups improved significantly in RT, movement time, and consistency of performance, whereas the control groups demonstrated no change. An unexpected finding, however, was that the older practice group improved significantly more than the younger practice group in RTs for both levels of complexity, in RT consistency, and in movement-time consistency.

Surprisingly, the older practice group’s RTs, RT consistency, and movement-time consistency equaled the young practice group’s performance on the posttest of the simple task. On the more complex task, the older practice group equaled or surpassed the performance scores of the young control group and appeared to approach the performance of the younger practice group on the measures of RT, RT consistency, and movement-time consistency. Hypothetically, with more practice, the older practice group would have been able to match the young practice group on the more complex task. Although RT, RT consistency, and movement-time consistency improved more in the older practice group than in the young practice group, this result was not observed for movement-time performance. Both the young and older practice groups demonstrated improved movement times for each level of complexity, but the age-effect difference between the young and older practice groups remained almost the same throughout the practice sessions and the posttest. This result indicated that the two groups improved at the same rate for movement time.

The RT results of this study demonstrate the motor learning ability of older individuals. Not surprisingly, the age effects for measures related to peripheral control (eg, movement speed) are not similarly affected by practice. Although practice leads to movement speed improvement in all age groups, practice alone will not suffice to reduce the age difference related to peripheral mechanisms of neuromuscular control. Perhaps the most important influence on movement speed is physical fitness level. As will be reviewed later in this article, physical conditioning not only improves the functioning of the body periphery, but also has a positive effect on central reactive capacity.

**Individual Differences with Aging**

**Increased Variability with Aging**

I believe a general belief exists in our society that most older people are “all the same.” I observe more stereotypes about older people than about any other age groups. Ironically, in terms of motor performance, stereotypes could be more fairly applied to young adults than to the elderly. Significantly greater intrasubject and intersubject variability can be found in the movement skills among older adults than among young or middle-aged adults. Although many older adults demonstrate nonfunctional reaction and movement speeds, other older adults can outperform their younger peers on selected movement tasks. I contend that the ability of elderly individuals to perform a selected movement task must be judged on the basis of individual assessments.

Many factors could account for the tremendous variability of performance observed in the older population. Genetic differences exist, and, as reviewed earlier, practice at a task will account for greater differences within the older population. Other factors that have been considered have included differences in motivation or arousal and differences in physical conditioning. These factors deserve special consideration.

**Motivation**

Welford found that arousal toward a specific task did not decline with age, and when special incentives were offered, both older and younger subjects improved almost equally in performance. Another interesting point is that when electric shock was used as a motivator, to ensure the best RT performance in an earlier human study or in more recent work with animals, the age decrement remained. These collective research findings suggest that the RT age deficit is not caused by motivational differences between young and older adults.

**Effects of Physical Conditioning on Reactive Capacity of Older Adults**

One of the most exciting areas of aging motor systems research concerns the effect of physical training on performance abilities. Physical conditioning has been found to have an important influence on both RTs and movement times. In both animal and human models, chronic exercise appears not only to improve movement-time ability, but also to contribute to the maintenance of psychomotor speed over the life span.
Studies concerning the effect of physical conditioning on the central-processing abilities of older individuals have offered encouraging results. Comparisons of senior versus young adult men who were sedentary versus regularly active in racket sports have revealed that the young active and older active groups had similar simple and choice RTs. The older sedentary group, however, was dramatically slower than the old active, young sedentary, or young active groups. Because these findings could have indicated not only the importance of exercise training but also the effect of practicing fast reactions, Spirduso and Clifford developed a second study to analyze the difference between young and older men who had jogged non-competitively for many years. The physically active individuals in this study were aerobically trained (eg, by jogging), but had not participated in fast reactive-type sports such as racquetball. Again, the results clearly demonstrated that the physically active older men performed as well on simple and choice reaction tasks as did the young men, whereas the older sedentary men were remarkably slower. The analysis of performance consistency revealed similar results; both the young men and the older men who jogged routinely were equally consistent in their performance.

Similar findings have been reported for studies of older women and also for carefully controlled training programs with an animal model (ie, older rats). Data on the effects of physical conditioning on cognition have suggested that fluid intelligence (ie, the capacity for abstract reasoning) is related to physical fitness and age. Regardless of age, however, a high level of physical fitness resulted in significantly better total fluid-intelligence scores than did a low level of physical fitness. After extensive study, Spirduso has suggested that a lifetime of moderate physical activity may play a more important role in the determination of reactive capacity and movement speed than the age factor. Spirduso has suggested that modification of the neuroendocrine and cardiovascular systems via a lifetime of physical conditioning could possibly aid in the prevention of premature CNS aging.

**Summary**

Aging leads to a slowdown in motor performance as CNS information-processing ability declines. Each stage of information processing is affected by advancing age, and older adults are more sensitive to small changes in motor-control factors such as movement complexity and compatibility than are young or middle-aged adults. A common stereotype is that all older people are slow in their daily activities, and this slowdown is commonly assumed to be related to a lack of motivation. Researchers have found this assumption to be untrue and have demonstrated that older people vary enormously in their RT and movement-time abilities.

Although every individual experiences a decline in motor performance related to age, older people differ from one another much more than do younger people. Two important factors that account for much of the age-related variance are practice and overall physical conditioning. Both practice at a task and maintenance of physical fitness help to ensure a high level of motor performance speed and consistency as we grow older.

**References**

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