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ACADEMIC LITERATURE REVIEW

Effects of motor practice on cognitive disorders in older adults

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Abstract The demographics of our societies have changed drastically during the past few decades. The general population is aging rapidly as human life spans continue to expand and more adults are set to mature during the next quarter century. This aging process has numerous implications for the way we live and will have particularly important impacts on health and healthcare. In particular, substantial evidence suggests that cognitive–motor function deteriorates considerably as the result of inactive life style, biological aging, and cognitive impairments. The number of individuals with Alzheimer's disease (AD), an aging-related cognitive disorder, is expected to increase significantly during the next 40 years. The development of mild cognitive impairment (MCI) or AD can exaggerate the functional declines observed in cognitive or motor performance. The functional declines affect an array of social, cognitive, mental, physical, and motor activities in our daily lives. However, recent studies suggest that cognitive, physical, motor practice, or skill learning can improve motor speed, smoothness, and accuracy in both MCI and AD patients and their age-matched healthy peers. From theoretical and practical perspectives, this paper addresses several critical aspects of motor deficits and the kinematical characteristics of motor skill development in MCI and AD populations. Empirical data will be presented relative to the sensory–motor functions of MCI and AD, the motor skill acquisition, exercise rehabilitation in older adults with memory loss, as well as the implications for therapies. Finally, this review concludes with thoughts and suggestions for future research in these areas.

Keywords Aging · Cognitive impairment · Physical activity · Training · Rehabilitation

Introduction

According to the latest census data, adults aged 85 and above are the fastest-growing segment of the United States population. In 2007, about 5.1 million Americans suffered from Alzheimer's disease (AD) or a related dementia [6]. As a result of the increasing proportion of senior citizens in the US population, around a quarter of a million more people will develop AD in the US every year [37]. It has been estimated that the number of people with AD will nearly triple by 2050, between 13.2 and 16 million [19]. The consequences of AD are severe, as this disease damages brain cells, causes motor and cognitive problems, and reduces functional abilities of daily living. As the fourth leading cause of death in the US at present, AD is a major health issue for senior citizens and places additional pressure on healthcare providers. As a result, there is a growing global effort to find an effective means of preventing and treating AD.

Mild cognitive impairment (MCI) is usually considered a transitional or intermediate step between normal aging and AD. Although there are many different causes of MCI, including AD, cerebrovascular disease, metabolic problems, and other degenerative disorders (e.g., Lewy body dementia, Parkinson's disease, frontotemporal dementia), individuals with this disorder are at an increased risk of

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developing dementia [30]. In fact, estimates suggest that between 10% and 15% of individuals with MCI will convert to dementia, particularly AD, every year. Furthermore, the prevalence of MCI is twice as high as that of dementia [26]. Given these alarming statistics and the fact that MCI can have negative effects on the quality of life of both individuals with the disorder and their caregivers [20], researchers are becoming increasingly interested in the accurate diagnosis, treatment, and potential rehabilitation of MCI [38, 43]. Early detection and treatment of MCI may reduce the risk of conversion to AD or other forms of dementia [1].

Given the absence of valid biomarkers, the diagnosis of AD and MCI is based primarily on clinical findings from neurological, neuroimaging, and neuropsychological examinations [23]. MCI patients typically report a subjective memory loss and score at least 1.5 standard deviations below the mean of their age-matched healthy peers on objective tests of episodic memory [29]. However, the same individuals usually perform within the normal range on other tests of cognitive functioning and show no major deficits on measures of functional abilities [7]. MCI subjects do not appear to experience problems with finger tapping, but those with mild AD are impaired on this simple movement task [18]. Researchers have recently discovered that MCI is a very heterogeneous disorder and that the motor control and movement performance of MCI patients can differ considerably [43]. Diagnoses of MCI based on the traditional neuropsychological or psychomotor tests are, therefore, not always accurate [26].

When MCI is associated with an isolated loss of episodic memory, it is generally referred to as amnestic MCI (a-MCI). Research suggests that this subtype of MCI is usually associated with an increased risk of incident AD [26, 29]. This has spurred research interest in the early detection of a-MCI subtype and MCI in general and the development of potential therapeutic agents to slow down the decline and delay the onset of clinically diagnosed AD [3, 5, 21, 38]. One important area of behavioral research that has so far received little attention is the assessment of movement kinematics of motor performance or control as a means of providing useful information that will enable clinicians to better identify MCI. This is a line of research that might also result in a better understanding of the effects of behavioral assessments in diagnosis and treatments for functional capacities for cognitively impaired individuals [9].

This article reviews relevant studies reporting sensory–motor performance of individuals with MCI or AD and the effects of physical activities on late-life cognitive and motor functions (e.g., attention, memory, perception, decision-making, movement responses, or performance). The contents are divided into four major sections. The first summarizes evidence regarding motor disorders and intact functions of normal cognitive aging, MCI, and AD. The second section discusses the effects of practice or motor training on sensory–motor function for MCI and AD. The third section introduces selected studies that show the benefit of physical practice on neural changes. The concluding section discusses new developments in the clinical rehabilitation in older adults with memory complaints and also draws attention to their practical implications and suggests future directions for research.

Sensory–motor disorders associated with aging

Sensory–motor dysfunctions are often associated with cognitive aging, MCI, or AD. The findings of numerous studies indicate that cognitive–motor functioning declines considerably as the result of cognitive aging or impairments. For example, healthy seniors aged 65 years or older demonstrate longer reaction times (RTs), greater variations in RTs, slower movement speeds (longer movement times [MT]), and less smooth movements than children and young adults (Fig. 1; [42, 45, 46]). Age-related sensory–motor deficits or neural “noise” in the central nervous system are assumed to account for the observed movement deterioration associated with normal aging [30, 39].

During the past two decades, a number of theories have been proposed to explain the processes of cognitive aging in perceptual–motor performance (e.g., the speed, accuracy, quality, or efficiency of responses). The explanations include deficits in sensory functioning, cognitive resources, processing speed, inhibition, and recollection (see a detailed review by Dennis and Cabeza [12]). Specifically, these approaches hypothesize that the poor cognitive and motor performances of older adults are due to significant deteriorations in numerous behavioral domains. More specifically, inadequate sensory inputs from visual and auditory systems, reduced levels of perceptual or attentional sources for on-going cognitive activities, decreased speeds of information processing or longer preparation times (RT), inability to suppress irrelevant stimuli for goal-directed sensory or motor control (inhibitory control), or memory loss of past events or experience (episodic memory) can individually or collectively affect late-life cognitive and motor performances [12]. As a result, older individuals may adopt compensatory mechanisms to overcome some of the cognitive and motor deficits [42].

Clearly, the functional deterioration seen in the movement performance of healthy older adults can be exacerbated by the development of MCI or AD. The onset of this deterioration differs considerably in individual cases and can be accelerated in people with neurodegenerative disorders such as AD [8, 16, 27, 28]. In particular, individuals with AD exhibit a significant behavioral decline or disturbance in their motor and cognitive

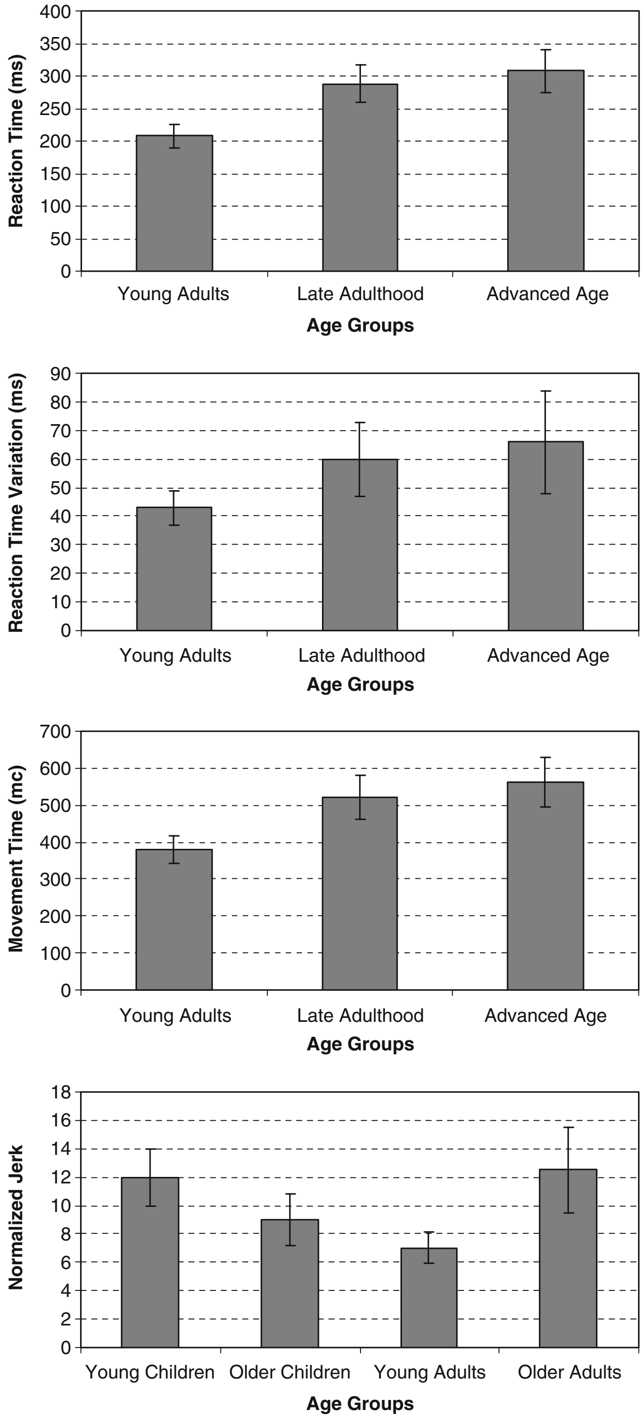

Fig. 1 Age-related differences in simple RTs, RT variations, MT (for a 24-cm movement distance), and movement smoothness (normalized jerk). Late adulthood refers to subjects aged 54–64 years and advanced age refers to subjects aged 65–80 years. Young adults were 20–30 years old. *Error bars* are the 95% confidence intervals (95%CI) above/below the means. Used by the permission of the author [45]

performance [16, 20, 27, 30]. A recent study of handwriting in AD and MCI patients indicates that a compromised motor performance is the behavioral manifestation of cognitive impairments [44]. This study describes reduced levels of sensory–motor performance in fine movement control and motor coordination of AD and MCI, as reflected in several patterns of handwriting movements. Kinematic analysis showed that AD and MCI patients are slower, jerkier, less coordinated, and less consistent in selected handwriting tasks than their healthy peers (Fig. 2; [44]).

From a theoretical or a clinical view, the changes seen in MT and smoothness of handwriting performance in MCI and AD patients may be used in conjunction with more traditional tests to further improve the early identification of impaired individuals. The results and assumptions may lead to further studies of the links between deficits in motor performance, dysfunctions of the brain (the basal ganglia or hippocampus), and potential peripheral disorders (e.g., tremor). Behavioral studies of AD or MCI can also, to a certain extent, facilitate our understanding of the relationship between the executive level (information processing, memory, or decision-making) and the effector level (movement planning, integration, or implementation). Motor tests enable specific changes in the functioning of older adults to be tracked accurately, as they are not influenced by the variables of language, education, or cultural background. These confounding factors often result in problems in the administration and interpretation of cognitive tests [43, 44].

The effects of practice on motor control and skill learning

In recent years, the topic of motor skill learning in seniors has aroused considerable interests among researchers in the fields of neurology, psychology, motor behavior, and gerontology. Several studies have been designed to test the hypothesis that motor learning or physical practice can enhance the capabilities of motor control and performance in healthy or normal controls and patients with a diagnosis of AD and MCI, resulting in better motor performance [41, 43]. While an individual's cognitive and motor functions may decline with advancing age or cognitive impairments, recent studies indicate that both healthy adults and MCI and AD patients can improve their motor performance in movement speed, smoothness, and accuracy as a function of cognitive–motor practice (e.g., memory and physical training; [41, 43]). From a clinical perspective, this review addresses critical features of motor deficits and the kinematical characteristics of motor skill development in MCI and AD populations. The practical implications will also be discussed.

Although the finding that older adults can acquire new motor or cognitive skills as a result of motor practice [31, 41] is scarcely surprising, the fact that individuals with mild-to-moderate AD and MCI can also become skillful in some motor or cognitive tasks as a result of training [14,

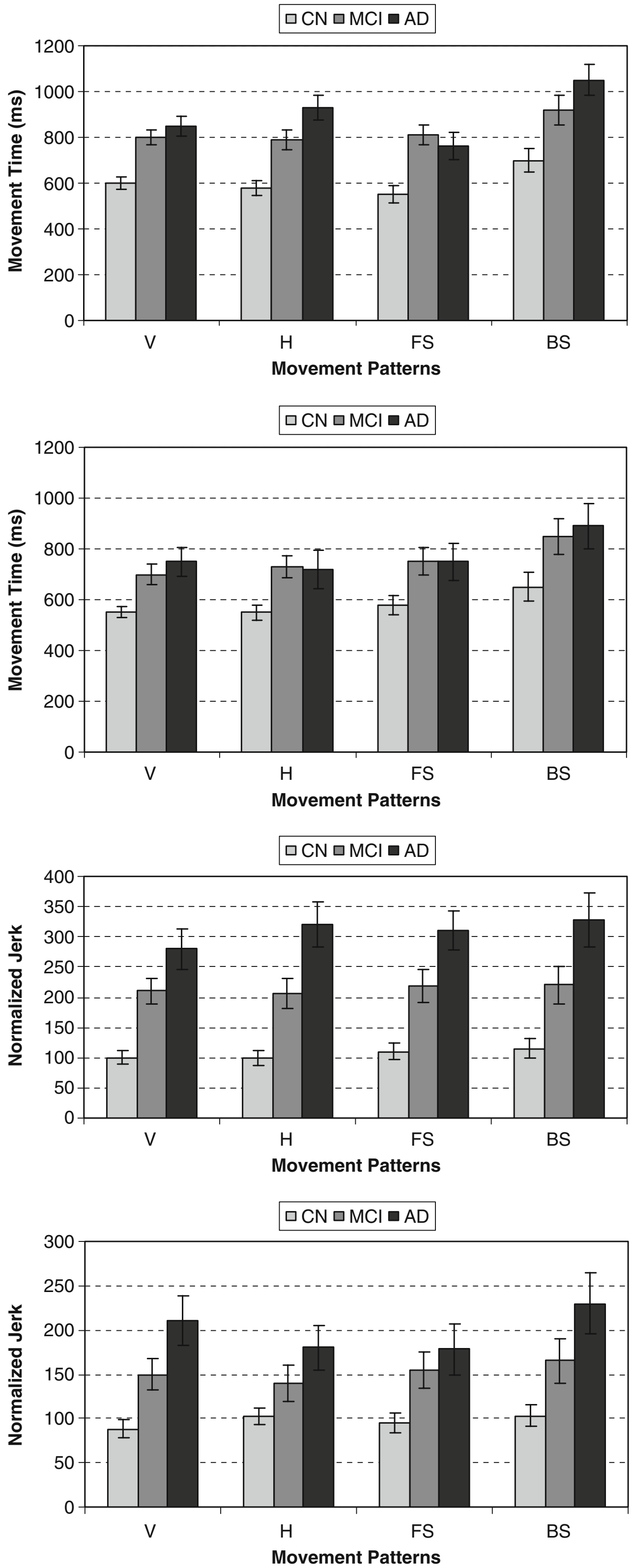

Fig. 2 Average MT and normalized jerk per stroke in two-stroke and four-stroke handwriting actions for the four movement patterns (*V* vertical, *H* horizontal, *FS* forward slanted, and *BS* backward slanted) among controls (*CN*), MCI, and AD. *Error bars* are the 95% CI above/below the means. Used by the permission of the author [44]

15, 20] is very encouraging. Yet, the declines in cognitive functioning (e.g., attention, inhibitory control, memory, or execution) may contribute to the difficulties observed in acquiring new skills in older people or individuals who suffer from AD [35]. From a theoretical point of view, further investigation into the brain function and its role in controlling motor responses should provide a clearer picture of the brain and body relationship. From a clinical standpoint, studying motor skill learning or acquisition in this particular population is important because the findings will facilitate the development of exercise programs that enhance motor–cognitive performance for both healthy seniors and individuals with clinical disorders. At the issue is the determination of the underlying mechanisms responsible for skill improvement in AD or MCI. For instance, how does internal processing (motor planning or programming) or memory affect motor execution or performance in MCI and AD patients?

It is also important to understand why or how practice improves motor skills and to identify the parameters that will change as a function of learning or motor practice [42]. The model proposed by Meyer et al. [24] seems to provide a framework for addressing these questions. This model specifically suggests that for a rapid goal-oriented motor task, the primary submovement (PS) of the movement is under internal or central control (by a motor program). The secondary submovement (SS), however, is under peripheral control (by using visual feedback) to hit the target. This framework has advantages over others in terms of identifying or quantifying movement parameters that are related to the effects of practice [39]. Yan and Dick [43] used this model to examine the role of central and peripheral contributions to motor control and to shed light on some of the factors implicated in skill acquisition in MCI and AD patients.

More specifically, Yan and Dick [43] investigated the possibility that practice could result in an increased level of central control (as reflected by an increased PS and faster movement) and a reduced proportion of on-line corrective movements (as indexed by a shorter SS and more consistent movements). Mild AD patients, MCI patients, and a group of age-, sex-, and education-matched seniors either received or did not receive practice on a rapid aiming arm movement on a digitizer. Three dependent variables of movement were assessed (MT, percentage of PS, and motor jerk; Fig. 3). The researchers found that, despite the fact that the mild AD and MCI patients demonstrated considerable motor or cognitive deficits in baseline tests (e.g., inability to plan or execute motor responses shown), all participants benefitted equally from practice in terms of movement speed and smoothness, as well as the proportion of the movement under central control. Theoretically, this line of study offers insights into the mechanisms of motor

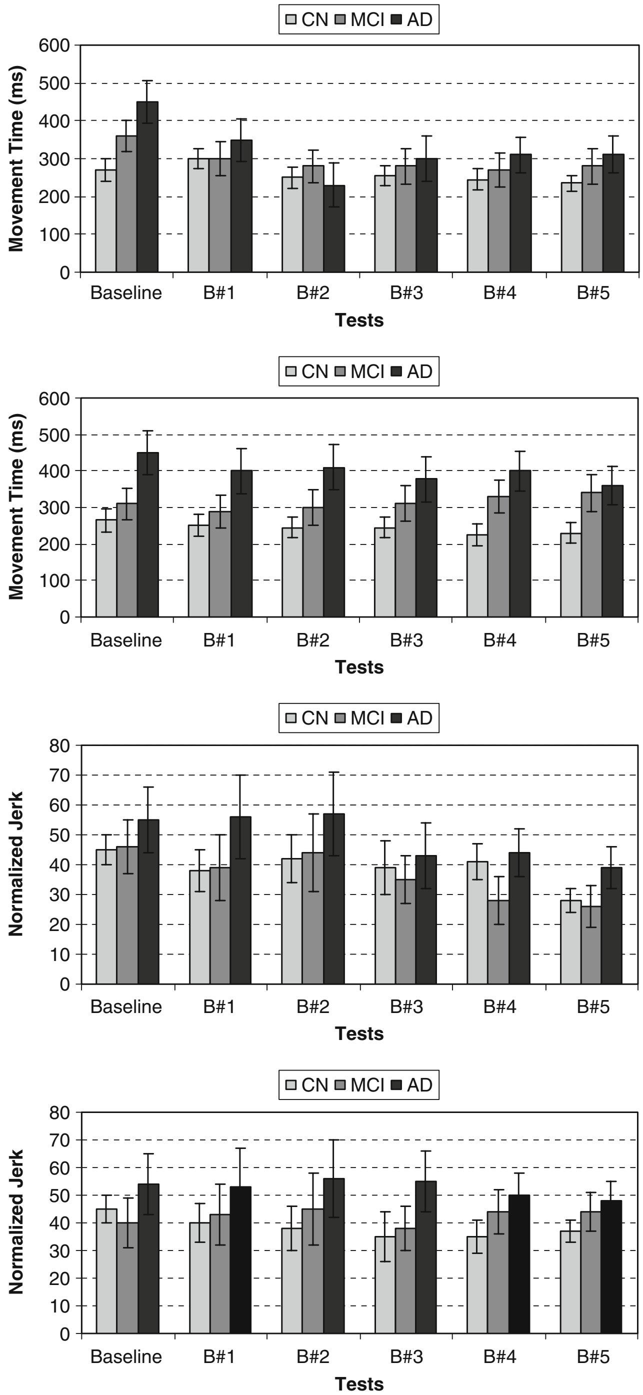

Fig. 3 The differences and changes among the three groups of subjects receiving practice and receiving no practice across six blocks of testing in MT and movement jerk. *Error bars* are the 95%CI above/below the means. Used by the permission of the author [43]

control in AD or MCI patients. Equally important, studying the effects of practice on motor and cognitive function may lay the foundations for the development of future behavioral treatments for AD patients.

The findings of a number of studies performed at the University of California Irvine, Alzheimer's Disease Research Center also supported the contention that motor practice or learning can facilitate or strengthen motor and cognitive performance for AD and MCI patients. Although the laboratory-based evidence needs to be validated in a clinical setting, many of these investigations have important practical implications. For instance, using a rotary pursuit task (a fine motor task), mild AD patients significantly improved their movement accuracy as the results of extensive motor practice. Most importantly, these impaired participants retained the benefits of practice for up to 1 month following the end of behavioral intervention [17]. Another study indicated that mild-to-moderately impaired AD patients improved their motor performance of a beanbag tossing task (a gross motor task) after practice [15]. The findings of these studies, which demonstrated different patterns of motor skill control and learning, call for further investigation. For example, the optimal training regimen for this population in terms of the intensity, duration, or frequency of motor practice remains unclear. If AD or MCI patients only retain the learned motor skills for a short period of time after practice, it is important to discover optimal ways of maintaining the skill levels by providing them with some post-practice "booster" activities. More clinical studies are also needed to determine how physical or motor training is best integrated with the traditional therapies for AD or MCI patients.

Effects of training or practice on brain function

Geriatric research suggests that both aging and cognitive impairments (e.g., MCI and AD) can reduce the cognitive vitality of the elderly [30]. In consequence, we often observe significant aging-related reductions in the speed of information processing, attention span, long-term or short-term memory, and motor performance among this population group [7, 18]. It should be noted that the age of onset and the severity of declines in cognitive and motor performance of the elderly are subject to considerable individual variations [43]. To a certain extent, the onsets of cognitive–motor deteriorations can be delayed and the speed of progression can be reduced by actively or habitually engaging in skill learning, social interaction, cognitive and mental rehabilitation, or physical exercises [36].

In recent years, a growing body of studies on animals and humans has provided direct or indirect evidence for the benefits of mental and physical activities in stimulating and promoting active brain responses critical for healthy or normal cognitive and motor functioning. Training or practice is assumed to result in enhanced capacities of both motor performance and brain functions. It appears that healthy life styles, frequent or habitual exercises, and enriched environments, by providing physical activities and decision-making opportunities, facilitate the development of these two important neural processes, and under these conditions, the changes occurring in the brain can be long-lasting (e.g., [11, 40]).

More specifically, during our lifetimes, neurons undergo on-going or continuous changes, a process called "neural plasticity." "Synaptogenesis" refers to the neural processes of increased synaptic connections between the neighboring brain cells. "Neurogenesis" is the occurrence of the birth of new neurons. It has been reported that habitual physical exercise or motor learning facilitates the preservation of cognitive function through a number of processes or mechanisms. In this context, "exercise everyday keeps Alzheimer's away" is a simple yet accurate expression of the benefits of physical activities for the elderly [11]. Exercises, physical practice, skill learning, or stimulating mental activities are assumed to prompt the creation of new connections among brain cells and the formation of neurons (e.g., [10, 43]). This slows down the progress of aging processes and cognitive deteriorations would slow down and helps to preserve the quality of life for the elderly [40].

Some investigators have attempted to use computer-based technologies for memory training or rehabilitation in elderly populations (e.g., [34]). For instance, Rasmusson et al. [33] indicated that senior participants significantly improve their cognitive functions as the results of group memory training, auditory memory training, and computer-based memory training. Moore et al. [25] extended these findings to the cognitively impaired and showed that memory rehabilitation programs could facilitate the memory performance of mild to moderate AD patients in tasks of daily living. They recommended that this type of training should be integrated with other therapies for an optimal result. Based on a review of the literature and behavioral characteristics of the elderly persons, Mayhorn et al. [22] integrated a number of strategies and developed a systematic approach for effective computer training with the elderly. These activities successfully facilitated learning and also improved cognitive overall functioning [4, 13, 34].

Summary

This review article provides evidence about movement disorders and the effects of motor practice on sensory–motor function for healthy seniors and MCI and AD patients. The empirical data discussed in the preceding sections clearly demonstrate the contributions of motor skill learning and performance, exercise and physical activities to the physical and cognitive functions of elderly populations. A growing body of evidence indicates that a suitable exercise program may help to slow the progressive cognitive and motor deterioration seen in individuals with AD or MCI. Thus, behavioral interventions or treatments are assumed to be appropriate for the elderly, both those who are healthy and those who suffer from mild cognitive impairments or memory losses associated with the aging processes. In other words, a number of practical and clinical implications can be drawn from the empirical findings from several recent studies (e.g., [2, 32, 36]).

First, clearly cognitive and motor dysfunctions are often associated with normal aging, MCI, or AD. Although behavioral evidence shows that the MCI and AD patients react and move slower, are more variant, and show more hesitations (e.g., jerks) in their movements than their age-, sex-, and education-matched peers or younger adults, the neuropsychological and neurophysiological mechanisms that account for these sensory–motor characteristics are not completely clear and call for further investigation. For instance, examining the executive component of working memory can provide new information about motor disorders among seniors. Fresh insights into the cognitive or motor processes underlying this deterioration will facilitate the planning and design of effective behavioral intervention for this population.

Second, it is apparent that motor learning or physical practice can enhance the capabilities of cognitive and motor control in both healthy seniors and those with AD and MCI and consequently results in better motor performance. How to effectively assess motor skill learning and understand aging-related characteristics in various types of motor behavior, however, is less clear. Traditional measures of cognitive and motor skill have yet to address the behavioral heterogeneities seen in aging populations (including MIC and AD patients). The assessments should be simple and practical, make use where possible of movements found in normal daily activities, and measure the efficiency of these movements (e.g., speed, smoothness, accuracy, inhibitory control, and economy of effort). A better understanding of the critical features of movement deficits and the associated kinematical characteristics of motor performance in MCI and AD populations is important to practitioners.

Third, although the findings of a number of preliminary research studies investigating the effects of practice on motor learning and control in MCI and AD have been encouraging (e.g., [43, 44]), relatively little is known about optimal strategies or approaches. For instance, sleep appears to be critical for motor memory consolidation and skill learning in general. However, more research is needed to determine exactly how sleep influences motor skill learning of seniors or people with cognitive impairments. Recently, the author of this chapter has explored the impacts of daytime naps and overnight sleep on motor skill learning of seniors with memory loss or cognitive dysfunctions (timing accuracy). It is anticipated that, in future therapeutic programs for individuals who suffer from MCI or AD, the control of sleep (e.g., timing and duration) will be incorporated into the routine of treatments.

Finally, as computer technology becomes increasingly commonplace, we would expect that various computer-assisted techniques will be utilized in memory training or rehabilitation of the elderly. However, some daily physical or mental activities or a combination of both physical and mental activities may still be the most effective ways of enhancing seniors' motor and cognitive functions and accomplish an optimal outcome.

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