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Effect of Multisensory Intervention on Locomotor Function in Older Adults with a History of Frequent Falls

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Abstract

Falls are common, costly, and a leading cause of death among older adults. The major predisposing factors of a fall may include age-related deterioration in the dynamic system composed of auditory, somatosensory, vestibular, visual, musculoskeletal, and neuromuscular subsystems. Older adults with a history of frequent falls demonstrated significant reductions in gait velocity, muscle force production, and balance performance. These altered neuromechanical characteristics may be further exaggerated when faced with conflicting multisensory conditions. Despite the important contribution of multisensory function on the sensorimotor system during postural and locomotor tasks, it remains unclear whether multisensory intervention will produce dynamic balance improvement during locomotion in older adults with a history of frequent falls. Therefore, the purpose of this paper is to address important factors associated with falls in elderly adults and provide theoretical rationale for a multisensory intervention program model.

Key Words: Falls; Locomotion; Multisensory intervention; Older adults.

Introduction

Falls are common, costly, and a leading cause of death among people 65 years and older (Englander et al, 1996; Hoyert et al, 1999; Sattin, 1992; Tinetti et al, 1988). In the United States alone, one of every three adults 65 years or older experiences a serious fall each year (Sattin, 1992; Tinetti et al, 1988). The estimated costs of fall-related injuries are anticipated to reach $32.4 billion by 2020 (Englander et al, 1996). Falls are ranked as the sixth leading cause of death among older adults (Sattin, 1992). Therefore, there is great demand for effective training for both prevention of and rehabilitation from falls.

The impact to patients can be devastating as illustrated in the following comment by the author's client (1999): "I was a 70-year-old who volunteered as a cross-guard in an elementary school. I was physically and mentally healthy. One day I was taking a little child to cross a lively road. All of sudden, my attention during walking was distracted by the sound of a car honking and I fell on the ground. I found out later that I had a nonunion hip fracture, which left me wheelchair-bound for the rest of my life".

The major predisposing factors of a fall, as illustrated above, may include age-related deterioration in the dynamic system composed of auditory, somatosensory, vestibular, visual, musculoskeletal, and neuromuscular subsystems (Baltes and Lindenberger, 1997; Blanpied and Smidt, 1993; Brocklehurst et al, 1982; Grabiner

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and Jahnigen, 1992; Horak et al, 1989; Kenshalo, 1986; Lord et al, 1991; Maki and McIlroy, 1996; Paige, 1991; Skinner et al, 1984; Verrillo and Verrillo, 1985; Vandervoort, 1992). Age-related changes in the visual system include reductions in visual acuity, contrast sensitivity, depth perception, dark adjustment, and the ability to differentiate low spatial frequencies (Baltes and Lindenberger, 1997; Lord et al, 1991; Maki and McIlroy, 1996). The vestibular system progressively loses labyrinthine hair cells, vestibular ganglion cells, and nerve fibers, thereby altering vestibulo-occular reflex control (Maki and McIlroy, 1996; Paige, 1991). The somatosensory system undergoes a reduction in acuity of proprioception and cutaneous sensations, which are essential sensory feedback resources during postural tasks (Brocklehurst et al, 1982; Kenshalo, 1986; Skinner et al, 1984; Verrillo and Verrillo, 1985). Schmidt and Lee (1999) suggested that sensory information encompasses details about accurate spatial reference of the limb and body movements, forces, pressures, and tension required for precise motor control. Individuals with lower entering proprioceptive acuity (LEPA) might be less adept at effectively responding to postural perturbations than those with higher entering proprioceptive acuity (HEPA) (Meeuwsen et al, 1993). Specifically, ankle injury in younger adults has been found to be primarily caused by improper ankle-foot alignment or positioning during cutting or landing movement (Garrick JG and Regua, 1988). However, most falls during locomotion in older adults resulted from trips as they negotiate obstacles and cracks in their pathways (Overstall, 1980). Both improper positioning and trips were associated with joint perceptual errors because overestimation or underestimation of actual position indicated that young adults could land with excessive (overestimation) plantarflexion and inversion while older adults may compromise obstacles with less toe-clearance (dorsiflexion: underestimation) than they perceived, thereby leading to frequent fall-related injuries (Garrick and Regua, 1988; Whipple and Wolfson, 1987).

Age-related declines in the musculoskeletal system entail a decrease in the size and number of muscle fibers and neuromotor cells. This may lead to muscle weakness and fatigue (Vandervoort, 1992). In addition, inefficient muscle stiffness recruitment patterns and decreased joint mobility were identified as factors that could influence postural and locomotor control (Blanpied and Smidt, 1993).

Age-related changes in the neuromotor system comprised gradual decreases in neuronal cells and dendrites, neuronal sprouting, and cerebral metabolism, including cerebral circulation and neurotransmitters (Lipsitz and Goldberger, 1992). Specifically, a severe reduction of giant pyramidal Betz cells within the motor cortex, dopamine neurotransmitters within the basal ganglia, and alterations in spinal motor neurons were associated with advanced aging (Scheibel, 1985). Alterations in the neuromotor system were manifested in reductions in nerve conduction velocity and reaction times (Maki and McIlroy, 1996; Scheibel, 1985; Stelmach et al, 1989). This reduction in motor response time was further functionally correlated with falling behaviors. Delayed postural response time may significantly contribute to falls among elderly persons (Grabiner and Jahnigen, 1992; Schmidt and Lee,1999).

The cognitive system is believed to be resilient to these age-related deteriorations. Only significant cognitive deficits, such as those events in dementia or Alzheimer's disease, impaired the performance of a functional motor task such as walking; otherwise, motor function was well preserved among elderly individuals (Knight, 2000). No significant age-related change in cognitive function was observed during a divided attention task where a subject was simply required to respond to two simultaneous visual displays (Hausdorff et al, 1997; Rankin et al, 2000). Because normal age-related decrements in the dynamic system, the reliability and automaticity of coordinative sensorimotor control processes involved in postural tasks may decrease. Consequently, if cognitive resources could not be re-allocated to specific contextual demands during the postural task, effective, efficient and timely completion of the task was impossible, resulting in loss of equilibrium (Baltes and Lindenberger, 1997; Knight, 2000). For example, the central nervous system (CNS) could adaptively re-allocate attentional resources to increasing contextual demand from postural tasks. A single limb stance phase of a gait cycle that has a narrower base of support (BOS) required more attention than a double limb stance phase that has a wider BOS (Lajoie et al, 1996). Brown and colleagues (1999) measured postural control strategies and the deviation of the center of pressure to determine cognitive demands during a balance recovery period, using a dual cognitive-motor task paradigm (backward counting of numbers while maintaining appropriate standing balance) in young versus elderly subjects. Older adults exhibited frequent loss of balance (i.e., stepping strategy), increased center of pressure (COP) deviations, and response times to reach the peak COP. This finding was further elaborated by the later study with a surface electromyography (sEMG) measurement. The amplitudes in both gastrocnemius and tibialis anterior muscle activities of older adults during the postural task were substantially reduced when compared to the young adults (Rankin et al, 2000).

Elderly individuals with a history of frequent falls demonstrated significant reductions in gait velocity, muscle force production, and balance performance (Hausdorff et al, 1997; Newstead et al, 2000). These altered neuromechanical characteristics may be further exaggerated when faced with conflicting multisensory conditions. Recently, we have conducted a preliminary study to examine the effect of cognitive-motor training on gait velocity of 28 elderly individuals with or without a history of frequent falls. Initially, we found that those individuals with a history of frequent falls, as compared to healthy elderly, showed decreased velocity during the dual cognitive-motor task. However, after a 4-week cognitive-motor intervention, the frequent fallers improved in their gait velocity and retained more words (You et al, 2002).

Another study compared balance and gait performances in older adults with and without a history of falls by examining gait parameters including spatiotemporal, kinematic, kinetic and electromyography (EMG) muscle activity patterns (Newstead et al, 2000). Older adults with a history of frequent falls exhibited significantly lower balance performance and decreased gait velocity, decreased ankle plantar flexion and hip extension moments, altered ground reaction force, and EMG muscle recruitment patterns (Newstead et al, 2000). There was an age-related decrement in the performance of the divided attention task as the task became more complex (McDowd and Craik, 1988). These findings appear to suggest that elderly individuals with frequent falls could display such neuromechanical alterations because they may have to employ a long-loop and complex re-allocation process of their cognitive resources during a dual-motor task (Hausdorff et al, 1997; Lundin-Oisson et al, 1997; McDowd and Craik, 1988; Newstead et al, 2000). Another study using a dual cognitive-motor task paradigm examined mean deviations of center of pressure (COP) to determine standing postural stability in older adults with and without a history of falls. Older adults with a history of falls demonstrated a significant increase in the deviations of COP and a decrease in accuracy of cognitive tasks when compared with older adults without a history of falls or young adults (Shumway-Cook et al, 1997). Lindenberger and collegues (2000) assessed age-related changes in walking performance as measured in speed and accuracy during a dual-task paradigm to test Welford's assumption. Welford hypothesized that the sensory and motor subsystems closely interact with the cognitive subsystem and that elderly individuals with age-related decrements in the sensor-motor subsystem are increasingly in need of cognitive modulation (Welford, 1958). Older adults displayed increased cognitive processing time (long-loop or long latency response time), whereas postural control time, and the ability to encode or to retrieve stored information associated with postural and locomotor control were decreased. This may be primarily attributed to age-related deteriorations in the sensory and motor subsystems (Grabiner and Jahnigen, 1992; Lord et al, 1991).

Despite the important contribution of multisensory function on the sensorimotor system during postural and locomotor tasks, it remains unclear whether multisensory intervention will produce dynamic balance improvement during locomotion in older adults with a history of frequent falls. Traditionally, exercise programs that entailed total body movement, relaxation, stretching have often failed to yield effectiveness despite a long period of training (9~16 weeks) and scarce although some recent studies showed positive effects of balance exercise (Crilly et al, 1989; Hu and Woollacott, 1994a; Lichtenstein et al, 1989; Lord et al, 1993; Rose and Clark, 2000). In addition, although health disparity data revealed that African Americans in have a substantial higher incidence for cancer, heart, diabetics, and stroke that are major leading causes of physical disability such as gait and balance dysfunction, no study has previously investigated health disparity issue for falls and intervention outcome. Only one study represents the only effort to investigate the effect of short-term cognitive-motor training on gait velocity and accuracy between healthy young and older adults (Lindenberger et al, 2000). The young adult group demonstrated almost perfect levels of walking accuracy in a short period of practice sessions (4 sessions), whereas no significant training effect was observed in the elderly group. Older adults may take more time to encode, re-allocate, and process cognitive information (e.g., word lists) during dual-motor task (e.g., walking) because the cognitive subsystem may need to make amends for age-related alterations in the sensory, neuromotor, and musculoskeletal subsystems. Previous studies that examined the effect of balance training in older adults showed noticeable improvement after the completion of a 20-day period of training (Hu and Woollacott, 1994a; Hu and Woollacott, 1994b). Thus, it is reasonable to anticipate that longer-term cognitive-motor training may produce more tangible results. Additionally, this study did not have an age-matched control group, nor did it differentiate the potential contribution of non-cognitive stimulation on the motor function.

Hu and Wollacott (1994a) investigated the effect of a multisensory training on single-limb standing balance performance in healthy older adults. The training program included selectively manipulated sensory stimuli from the visual, vestibular, and somatosensory systems. Depending on an individual's specific needs, the training program was customized. This study showed that training subjects with multisensoy stimuli significantly improved postural stability. The retention test completed 4 weeks after completion of the training revealed that training subjects fell less frequently and were able to maintain balance longer as compared to the control group. However, this study did not examine the effect of cognitive input.

It has been theorized that elderly individuals could develop rich neural networks of declarative and procedural domain-specific cognitive-motor control knowledge in areas, which they frequently practice. This specialized motor control knowledge, in turn, decreases the reliance on the cognitive system for task performance within those domains (Allaire and Marsiske, 1999; Baltes, 1997; Rybash and Hoyer, 1994; Salthouse, 1991). The clinical implication of this theory is that if older adults with a history of frequent falls practice a cognitive-motor task that provides declarative and procedural cognitive-motor learning, they will eventually establish a domain specific cognitive-motor program or practice-dependent plasticity in human motor cortex (Ziemann et al, 2001). This will reduce cognitive demands during a dual-motor task, thereby diminishing risk of falls in older adults with a history of frequent falls.

Another model is dynamic system theory. This theory suggest that a system(s) impairment needs to be first identified and then the intervention tailored to provide specific sensory stimulation or multisensory stimuli to enhance cognitive, neural, or biomechanical factors that affect dynamic balance control during locomotion. Thus, it is anticipated that older adults with a history of falls will show greater gait and balance improvements from the multisensory intervention program than the subjects with no intervention or a conventional intervention.

MI Protocol

Cognitive-motor intervention

The following dual-task paradigm is modified from the method developed by Lindenberger and colleagues (Lindenberger et al, 2000). There are two phases: encoding (or memorizing) and retrieving. The Cognitive-motor task requires that during the encoding phase, subjects will be instructed to walk a-30-meter long walkway as quickly and accurately as possible while concurrently memorizing the presented words (10 random words out of the total pool of 2000 words). At the end of the encoding phase, 10 seconds after the last word, the subjects will be asked to stop walking. During the retrieving phase, subjects will be asked to correctly recall the presented words in the proper sequence.

1. Improve cognitive attention by accentuating essential perceptual cues for the task and minimize the number of irrelevant stimuli from environment.

2. Improve problem solving ability gradually increase complexity of the task

3. Encourage declarative and procedural learning by means of verbally/and or mentally

rehearse sequences when performing a task.

4. Provide optimal level of arousal by manipulating the essential perceptual cues, environment or context of the task.

Somatosensory-vestibular-visual-motor intervention

(A) Somatosensory/Movement intervention: Subjects learn to improve performance accuracy by means of getting feedback about accurately repositioning a target angle utilizing ankle sensory resources from a computerized proprioceptive feedback system and exercise instruments.

(B) Combined somatosensory and vestibular intervention: The subjects will repeatedly practice walking under the eight training conditions: Firm even support surface, eyes open, head neutral; Firm even support surface, eyes closed head neutral; Firm even support surface, eyes open, head extended; Firm even support surface, eyes closed, head extended; Uneven support surface, eyes open, head neutral; Uneven support surface, eyes closed, head neutral; Uneven support surface, eyes open, head extended; Uneven support surface, eyes closed, head extended (Uneven surface may include grass, sand, ramp, and curve).

(C) Vestibular system intervention includes: Exercise to enhance vestibular adaptation/central compensation; exercise to promote postural stability and function of vestibular spinal reflex; exercise to promote Gaze stability; exercise to decrease visual dependence by introducing distractive visual stimuli.

(D) Visual awareness: The subjects will step up/over a various size of objects on the floor (start with smaller objects and advance to larger objects, later randomize them). Response walking: The subjects will walk while safely avoiding incoming objects and sudden 180 degree turns in response to a signal.

Musculoskeletal system intervention

Active stretching exercise: heel cord, knee and hip flexors; Muscle strengthening: all trunk and lower extremity muscles, particularly in ankle and hip using theraband, sit-stand transfer (eyes closed), and mini-squats.

Neuromotor system intervention

Reaction time: protective extension of upper extremity; Rapid proper stepping strategy; Balance strategy: ankle, hip, mixed strategy, and stepping; Unilateral and bilateral stance coordination; Reaching for a moving object, tap ups, single limb balance, braiding, tandem, and sharp Romberg stance (eyes closed and eyes open with head turns); Walking coordination: sideways walking, response walking, backward walking, and walking in place with eyes closed.

Summary

Falls among older adults are a crucial health issue. Age-related alterations in multisensory systems including the cognitive, vestibular, visual, somatosensory, motor, and musculoskeletal systems may contribute to falls, however examining the concept of multisensory intervention (MI) has never been explored as a vehicle to reduce falls and improve gait function (Horak et al, 1989; Lord et al, 1991). Conceptually, this intervention, based on the system model, requires an identification of an impaired system(s) and is designed to provide specific sensory stimulation or multisensory stimuli to enhance cognitive, neural, or biomechanical factors that affect dynamic balance control during locomotion (Hu and Woollacott, 1994a; Hu and Woollacott, 1994b; Woollacott and Shumway-Cook, 1990). For example, if an individual experiences difficulty in a dual motor task (walking and memorizing words) due to age-related deterioration in the cognitive system, an appropriate intervention program may involves performing a motor task (i.e., walking) while concurrently engaging in a cognitive task (i.e., memorizing words or counting numbers) (Baltes and Lindenberger, 1997; Brown et al, 1999; Hu and Woollacott, 1994b; Lindenberger et al, 2000). In theory, older adults with a history of frequent falls could establish a domain specific cognitive-motor program when trained with a dual task such as walking while memorizing words (Lindenberger et al, 2000; Salthouse, 1991). As a result, this intervention paradigm should help reduce and possibly prevent falls among older adults as they engage in functional dual tasks (Lindenberger et al, 2000). Therefore, it would be of great interest to examine the influence of the multisensory factors on motor performance in regard to fall prevention and rehabilitation.

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