Effects of Sensorimotor Adaptation Training on Functional Mobility in Older Adults

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The goal of this study was to determine if prolonged exposure to perceptual-motor mismatch increased adaptability and retention of balance in older adults. Sixteen adults, aged 66 to 81 years, were randomized to one of two groups: either the control group (n = 8) or the experimental group (n = 8). Both groups first completed six trials of walking an obstacle course. Participants then trained twice a week for 4 weeks. In the training, the control group walked on a treadmill for 20 minutes while viewing a static visual scene and the experimental group walked on a treadmill for 20 minutes while viewing a rotating visual scene that provided a perceptual-motor mismatch. Following training, both groups were post-tested on the obstacle course. The experimental group moved faster through the obstacle course with fewer penalties. This training effect was retained for 4 weeks. Exposure to perceptual-motor mismatch induced an adaptive training effect that improved balance and locomotor control in older adults.

Key Words: Functional mobility—Perceptual-motor mismatch—Sensorimotor adaptation.

The most important factors underlying morbidity in the older adult population are injurious falls and the restriction of activity as a result of falls (Wild, Nayak, & Issacs, 1981). Approximately 25% to 35% of community-dwelling persons older than 65 years of age fall at least once a year, and approximately 40% to 50% of fallers experience two or more falls (Nevitt, Cummings, Kidd, & Black, 1989). Research indicates that fall rates are related to the decline in the ability to successfully maneuver around obstacles in the environment (Di Fabio, Kurszewski, Jorgenson, & Kunz, 2004). As a result of falling, older adults often become fearful of falling again. Their fears compromise their independence and their quality of life (Walker & Howland, 1991).

Age-related sensory changes in older adults can contribute to their difficulty in preventing a fall when they are moving around obstacles in the environment. Falls in older adults have been associated with visual changes, including decreased visual acuity, impaired depth perception, and degradation in contrast sensitivity (Abdelhafiz & Austin, 2003; Lord, 2006; Lord, Clark, & Webster,1991; Lord & Dayhew, 2001; Nevitt et al., 1989). Older adults with visual impairment, whether measured by visual acuity or by depth perception, have an increased risk of recurrent falls (Nevitt et al.). Age-related declines in vestibular otolith processing can also result in deficits in support, balance, sensory input, central organization, and compensatory abilities (Farman & Redfern, 2001; Studenski & Rigler, 1996). Therefore, visual and vestibular changes can result in poor balance among older adults.

Visual information is important for navigating toward objects and around obstacles in the environment. The visual system detects information about the features of an object and provides feedback for the control and guidance of movement (Gibson, 1966). The motor system uses that information to coordinate the appropriate movement to maneuver around the object successfully (Turvey, 1990). This issue is particularly relevant to locomotion. The accuracy of perceptual-motor coordination depends on how well the person updates on his or her distance from the object. Adaptation of the perceptual-motor systems occurs when biomechanical activities adjust to changing visual information in the environment (Warren, 2006). By utilizing the information from the environment, a person perceives changes in body position to target location and thus can avoid obstacles.

Previous research has demonstrated that adaptive behavior occurs when there is a sensory mismatch between visual information presented in the environment and biomechanical activities (Mulavara, Richards, Marshburn, Buccello, & Bloomberg, 2003; Mulavara et al., 2005; Rieser, Pick, Asmead, & Garing, 1995; Weber, Fletcher, Gordon, Melvill Jones, & Block, 1998). In these studies, biomechanical adjustments were made to adapt to optical flow rates and patterns that varied. The adaptation of the perceptual-motor systems resulted in successful movement.

Several studies have examined practice strategies to enhance perceptual-motor adaptation to novel tasks (Bock, Schneider, & Bloomberg, 2001; Catalano & Kleiner, 1984; Connins, Cunningham, Harvey, & Derek, 2003; Roller, Cohen, Kimball, & Bloomberg, 2001; Shea & Morgan, 1979; Welch et al., 1993). Adaptability to novel perceptual-motor tasks has been termed adaptive generalization (Welch et al.). In general, people adapt faster to novel tasks when they are visually trained under variable perceptual-motor conditions. Sensorimotor adaptation...
Table 1. Pretrial Characteristics for the Experimental and Control Groups

<table>
<thead>
<tr>
<th>Pretrial Characteristics</th>
<th>Experimental Group (n = 8)</th>
<th>Control Group (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average age</td>
<td>72.6 (5.4)</td>
<td>71.8 (5.1)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Female</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Average height (cm)</td>
<td>170.2</td>
<td>167.6</td>
</tr>
<tr>
<td>Average weight (kg)</td>
<td>77.56</td>
<td>86.18</td>
</tr>
<tr>
<td>Average Berg Balance score</td>
<td>54.8 (1.6)</td>
<td>55.3 (1.4)</td>
</tr>
<tr>
<td>Number of subjects who wore glasses when walking</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Number of subjects who fell in past 6 months</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Number of subjects who tripped in past 6 months</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Number of subjects who were fearful of falling</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Number of subjects who exercise on regular basis</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

will generalize to sensorimotor tasks that utilize similar relationships between the perceptual-motor systems (Bock et al.). Therefore, for adaptive generalization to occur, sensorimotor training should include perceptual-motor relationships that are similar to the novel task.

Trained sensorimotor adaptation can be retained for relatively long periods of time. Manual control adaptability effects can be retained for 27 months (Martin, Keating, Goodkin, Bastian, & Thach, 1996), and improved gait stability as a result of perturbation training can be retained for up to 12 months (Bhatt & Pai, 2005; Bhatt, Wang, & Pai, 2006). In addition, a hand-and-eye coordination study in older adults who were trained for 3 days in a mirror-tracing task showed partial retention of a learned sensorimotor skill after a 5-year interim (Rodrique, Kennedy, & Raz, 2005).

Virtual reality training may improve sensorimotor function in stroke patients who have difficulty producing movement patterns for successful movement (Bisson, Contant, Sveistrup, & Lajoie, 2007; Fung, Richards, Malouin, McFadyen, & Lamontagne, 2006; Katz et al., 2005; Merians, Poizner, Boian, Burdea, & Adamovich, 2006). Research has demonstrated that virtual reality training improves strength, functional performance, and gait speed in poststroke patients (McComas & Sveistrup, 2002). Virtual reality training provides optimal conditions for individuals to explore biomechanical activities in a simulated environment instead of an environment that could be more dangerous (Todorov, Shadmehr, & Bizzi, 1997). Given these findings, we wanted to determine if virtual reality training would be useful to train older adults to explore locomotor variability for successful navigation and balance control.

Our purpose in this study was to determine the extent to which sensorimotor adaptation training in older adults improved mobility performance on a complex and challenging obstacle course. We tested the hypothesis that older adults would improve their navigational skills and balance on the obstacle course after they experienced visual sensorimotor adaptation training.

**METHODS**

**Participants**

The participants were 16 adults, aged 66 to 81 years. We recruited the participants from the Sealy Center of Aging Volunteer Registry at the University of Texas Medical Branch. We screened the participants by using a sociodemographic, health, and fall status questionnaire; the Snellen Visual Acuity Test; and the Berg Balance Scale. Participants were required to have a visual acuity within normal limits or corrected within limits, and a score of 45 or higher on the Berg Balance Scale (Berg, Wood-Dauphinee, Williams, & Maki, 1992). A score of 45 or lower indicates the need to use an assistive device (Chiu, Au-Yueng, & Lo, 2003). We excluded volunteers if they had orthopedic, neurologic, or cardiovascular problems that precluded them from walking on a treadmill. Although we did not screen the participants for cognitive status, they were all able to follow directions and complete tasks without any problems. Table 1 shows the pretrial characteristics for the experimental and control groups.

**Materials and Apparatus**

**Training apparatus.**—All participants walked on a motorized treadmill at 2.9 km per hour for 20 minutes while viewing the interior of a three-dimensional virtual scene projected on a screen that was 139.7 cm high and 170.2 cm wide and located 1.5 m in front of the participant. The scene moved at the same speed that the participant walked on the treadmill. The scene was a virtual picture of an office. The office scene consisted of floor plants, a desk, floor office lamps, wall pictures, a clock on one wall, and desk chairs. The experimental group viewed the rotating virtual scene as constant self-motion equivalent to walking around the perimeter of a room to one’s left. While viewing the rotating visual scene, participants walked straight on the treadmill, causing a perceptual-motor mismatch. The control group, however, viewed the scene as static, or not rotating. We had the control group view a static scene so that we could examine the effects of sensorimotor adaptation training between the two groups at each testing period. Participants wore a safety harness while walking on the treadmill.

**Evaluation apparatus.**—As previously mentioned, research indicates that fall rates are related to a decline in the ability to successfully maneuver around obstacles in the environment (Di Fabio et al., 2004). In an effort to test maneuverability performance through a complex and challenging environment, we developed an obstacle course consisting of 13 obstacles that were lightweight, soft, and could be easily knocked over. We placed the obstacles on a matted floor covered with low-density foam that was 5.1 cm thick and 137.2 cm × 772.2 cm in size (Amerifoam). The course included one set of the following: a cluster of four pylon gates, each gate constructed of two columnar foam pads; two sets of the following: a cluster of two pylon gates, each gate constructed of two columnar foam pads; three foam steps; a ramp that measured 15.24 cm up from the
ground at its highest point; and a tap-on light. Figure 1 shows the layout of the obstacle course. Each participant wore a lightweight harness that was attached to the ceiling by a cable. The cable was attached to a trolley that ran overhead parallel to the obstacle course.

We timed the participants’ performance on the obstacle course by using a stopwatch, and we recorded it by using a digital video camera (Panasonic, Syracuse, NJ). Participants completed six trials of walking the obstacle course. We used the stopwatch to score the first outcome variable, which was time to complete each trial. We averaged the raw data represented as time (in seconds) for the six trials for each participant. We used the digital video camera to determine the second outcome variable, which was the number of penalties obtained for each trial. The penalty scores were computed after the data collection by one viewer watching the trials as recorded on digital videotape. We created a scoring system to represent obstacle course penalty changes. If the participant did not hit an obstacle, then she or he received no penalty score. Therefore, if the participant successfully maneuvered around the obstacle, then we recorded no penalty score. Scores ranging from 1 to 3 were given when an obstacle was not successfully cleared. The score of 1 represented the minimal obstacle penalty and a score of 3 indicated the maximal penalty. Table 2 shows the penalty scoring system. We represented the raw data as the total number of penalty points measured by observation of each of the six trials. We averaged the penalty scores for the six trials for each participant.

Procedure
We conducted the study by using a completely randomized design in which we randomized the 16 participants into two groups: either the experimental group (n = 8) or the control group (n = 8). We measured each participant at each of six trials during each of three evaluation periods: pretest, post-test, and retention.

Pretest.—Participants traversed the obstacle course while wearing socks, for six trials. At the start of each trial, an investigator instructed the participant to walk through the obstacle course as quickly and accurately as possible, beginning by standing on the floor off the course at the start point. When the investigator instructed the participant to begin, the investigator started the stopwatch with the participant’s first step onto the foam. The investigator stopped the stopwatch when the participant stepped off the foam at the end of the course, marking the end of the trial. Participants rested for 20 minutes before beginning the first training session. The first training session occurred for every participant on the same day as the pretest. Likewise, the last training session was conducted the same day before completion of the posttest.

Training Sessions 1–8.—During training sessions, participants wore tennis shoes and goggles when walking on the treadmill. The goggles restricted the participants’ view of the periphery to enhance immersion in the visual scene. An investigator instructed each participant to straddle the treadmill as the treadmill started to move. Once the participant was comfortable, she or he stepped onto the treadmill. The treadmill speed gradually increased to 2.9 km per hour, and the investigator started a stopwatch to time the 20-minute session. Every 3 minutes, the investigator asked the participant to look down for a 1-minute rest period while continuing to walk on the treadmill. We used the rest period to give the participant time to look away from the visual scene in an effort to reduce visual fatigue. At the end of the training session, the visual scene was extinguished, the speed of the treadmill was reduced, and the participant walked slowly as a cool-down period for 1 minute. We had the participants train twice per week for 4 weeks. All participants were required to finish each week’s training by Friday, and they could not begin the next week until Monday.

Post-test.—Participants completed the obstacle course by following the same protocol that was used during the pretest session.

Retention.—Participants completed the obstacle course 4 weeks after the post-test session. The protocol used for the

Table 2. Penalty Scoring System

<table>
<thead>
<tr>
<th>Obstacle</th>
<th>1-Point Penalty</th>
<th>2-Point Penalty</th>
<th>3-Point Penalty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft-Foam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obstacles</td>
<td>Tap</td>
<td>Sway</td>
<td>Knock Over</td>
</tr>
<tr>
<td>Ramp</td>
<td>Stop</td>
<td>Stop and Sway</td>
<td>Stop, Sway, Step Off</td>
</tr>
<tr>
<td>Tap-on Light</td>
<td>Stop and Tap</td>
<td>Stop but Miss Tap</td>
<td>Avoid Tap Altogether</td>
</tr>
</tbody>
</table>
pretest and post-test sessions was followed during the retention session.

**Statistical Analysis**

We analyzed the data by using a two-way analysis of variance with repeated measures on the factor of test periods. We averaged the six trials for each participant at each test period, and we used this average as the response variable for assessing the significance of the experimental and time-related effects. We tested the differences among groups by using the pooled between-subjects variance within groups (error a). We tested both the difference among test periods and the Group × Test Period interaction by using the pooled Subject × Test Period interaction within groups as the error variance (error b). We conducted analyses separately for each variable. We used the Tukey–Kramer procedure specifically to assess the significance of study group differences at each test period for each variable. We analyzed all data by using NCSS (NCSS, Kaysville, Utah).

**RESULTS**

**Average Time to Complete the Obstacle Course**

The Group × Test Period interaction was significant at $F(2, 28) = 9.41, p < .05$. Figure 2 shows the average times for both groups at each test period. Because this indicated the group differences were not the same for each time period, we then used the Tukey–Kramer procedure to evaluate the significance of study group differences at each test period, with the critical difference at $p < .05$ being 1.86. There were no significant average time differences between groups at pretest. However, the average times between groups were different at both post-test and retention test periods. The average time scores for the experimental group decreased by 3.7 seconds at post-test, and the average time scores for the experimental group at retention decreased by 2.6 seconds.

**Average Penalty Scores on the Obstacle Course**

The Group × Test Period interaction was significant at $F(2, 28) = 21.03, p < .05$. Figure 3 shows the average penalty scores for both groups at each test period. Because this indicated the group differences were not the same for each time period, we again used the Tukey–Kramer procedure to evaluate the significance of study group differences at each test period, with the critical difference at $p < .05$ being 1.33. There were no significant average penalty differences between groups at pretest. However, the average penalties between groups were different at both post-test and retention test periods. The average penalty scores for the experimental group decreased by 5.3 penalties at post-test, and the average penalty scores for the experimental group at retention decreased by 3.9 penalties.

**DISCUSSION**

In the current study we investigated the extent to which visual sensorimotor adaptation training in older adults improved their ability to navigate and balance through a complex and challenging environment. In addition, we examined if the improved navigational and balance performance was retained. The participants who received the adaptation training maneuvered through the obstacle course faster and with fewer penalties than those who did not receive the training. The performance difference noted at post-test between groups was retained when we tested for it 4 weeks later. These results indicate that the sensorimotor adaptation training improved navigational skills and balance in older adults.

These findings add to current perceptual-motor adaptation literature (Mulavara et al., 2003, 2005; Rieser et al., 1995; Weber et al., 1998) by demonstrating that the perceptual-motor systems of older adults can adapt to conflicting sensory information. Viewing the virtual rotating scene allowed study participants to perceive the optical flow patterns representing the features of a virtual room. Immersion in the virtual rotating room resulted in a situation in which the older adults perceived successful movement around the office objects presented in the scene. Training the perceptual-motor mismatch between the rotating visual scene and walking straight on the treadmill afforded participants the perception of coordinating movement to successfully maneuver through the virtual environment. Adaptation was then tested by performance on the complex and challenging obstacle course. The experimental group’s improved performance, in contrast to the control group’s, showed the learned ability to adapt perceptual-motor systems for successful movement. This result supports assertions by Gibson (1966) and Warren (2006) that the motor system uses visual information to coordinate successful movement.
The experimental group utilized the learned perceptual-motor relationships for successful movement through the virtual environment and generalized the learned adaptation to performance on the obstacle course. These findings add to the existing literature (Bock et al., 2001; Catalano & Kleiner, 1984; Commins et al., 2003; Roller et al., 2001; Shea & Morgan, 1979; Welch et al., 1993) by showing that the adaptive perceptual-motor effects generalized to a novel task in older adults. The use of perceptual-motor mismatch was effective in training adaptability of the sensorimotor systems. The older adults used the learned ability to adapt biomechanical activities to the changing visual information while maneuvering the obstacle course. By learning to use visual information from the environment to change body position in relation to obstacle location, the adults avoided obstacle collisions when they were traversing the obstacle course. Age-related sensory and motor changes did not preclude the healthy older adults in this study from generalizing learned perceptual-motor relationships to mobility performance on the obstacle course. Prior research has shown that perceptual-motor adaptation of an eye–hand coordination task does not deteriorate with normal aging (Roller, Cohen, Kimball, & Bloomberg, 2002). The present study augments these findings by demonstrating that healthy older adults can adapt perceptual-motor systems to improve performance on a locomotor obstacle avoidance task.

In addition, these findings support and extend previous findings that older adults can retain sensorimotor skills through training (Rodrique et al., 2005). This study demonstrates that older adults can retain functional movement training through the environment with sensorimotor adaptation training. Walking on the treadmill afforded the visually trained group the opportunity to explore locomotor variability in response to the visual rotating scene. The perceptual-motor adjustments learned through visual training, while the person was walking on the treadmill, generalized to the movements necessary to maneuver through the obstacle course. The trained ability to adapt the perceptual-motor systems to maneuver successfully through a complex and challenging environment was retained for 4 weeks.

Conclusions
The present study demonstrated that prolonged exposure to perceptual-motor mismatch in older adults increased the adaptability of balance and improved mobility performance on the obstacle course. The learned adaptive perceptual-motor effect was retained for at least 4 weeks. This paradigm may be useful for developing rehabilitation paradigms for older adults at risk for falling.

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References


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