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Augmented reality technology combined with three-dimensional holography to train the mental rotation ability of older adults

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ABSTRACT

A decline in the cognitive ability of mental rotation causes a poor sense of spatial direction and environmental cognitive capacity. Currently, training tasks for the elderly thus affected are still presented in 2D form. However, clinical research indicates that this strategy generates a cognitive load that reduces the interest of the trainees and diminishes the effects of training. In contrast, augmented reality (AR) is a rising solution that effectively reduces cognitive load, improves the sense of spatial direction of the elderly, and helps increase interest in training. We recruited 28 elderly (age $\geq$ 65 years) for this study. Fourteen were randomly assigned to an active Intervention group and were given AR-based 3D hologram (AR-3DH) mental rotation training, and 14 were assigned to a group that used the traditional 2D model. Both groups took ABA-designed pre-and post-tests that required inferring the rotating shapes' states from standard mental rotation tasks. Change scores for the two groups were compared using error rates and reaction times as covariates. After six-week of training, the mental rotation ability of the Intervention group improved through the use of AR-3DH training system during the intervention phase. The practical and developmental implications of the findings are discussed.

1. Introduction

Mental spatial rotation is the ability to mentally rotate two-dimensional (2D) and three-dimensional (3D) objects in an imaginary space (Shepard & Metzler, 1971). Neurobiological research associates it with the human ability to navigate and with other spatially related functions (Banich & Heller, 1998; Buckner, 2004; Podzebenko, Egan, & Watson, 2005; Roberts & Ann Bell, 2003; Vingerhoets, De Lange, Vandemaele, Deblaere, & Achten, 2002); moreover, mental rotation ability greatly affects a person's life. For instance, wayfinding and map reading are associated with mental rotation ability. Reading a map requires cognitive alignment that creates a correspondence between the forward perceptual views of the world to a location on a map. Mental rotation is seen as a central cognitive operation in this alignment (Aretz & Wickens, 1992).

In addition, mental rotation requires the maintenance and mental manipulation of abstract visual stimuli, which is similar to map reading, which also requires maintaining and mentally inspecting a visual configuration (Pazzaglia & Moe, 2013). Thus, practicing mental rotation tasks (MRTs) should be beneficial for learning navigational skills and how to read a map (Parsons, Courtney, Dawson, Rizzo, & Arizmendi, 2013). When people grow older, however, their mental rotation ability declines (Hedden & Gabrieli, 2004; Jenkins, Myerson, Joerding, & Hale, 2000; Peich, Husain, & Bays, 2013). For example, clinical evidence indicates that older adults with Alzheimer's disease have difficulty with mental rotation, which negatively affects their real-world wayfinding (Chu & Kita, 2011). A decline in mental rotation ability leads to poor wayfinding, map reading, and other spatial cognition problems for older adults (De Beni, Pazzaglia, & Gardini, 2006; Jansen & Heil, 2010; Lee & Kline, 2011). Therefore, if the degradation time of mental rotation ability can be postponed, it will positively affect older adults and improve their quality of life (QoL). Because the degradation of mental rotation ability can affect anyone, even those who age normally, this problem needs to be dealt with.

2. Related work

The degradation time of mental rotation can be delayed by

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undergoing considerable mental rotation training (Hertzog, Kramer, Wilson, & Lindenberger, 2008; Mahncke, Bronstone, & Merzenich, 2006; Mowszowski, Batchelor, & Naismith, 2010). This is also true for younger people; e.g., the performance of orienteering tasks improved for college students who underwent mental rotation training, which indicated that mental rotation skills are significantly correlated with wayfinding and other spatial skills (Malinowski, 2001). Much research has been done to analyze the age differences associated with mental rotation ability. For instance, older adults tend to have lower scores than do younger people on mental rotation tests and in map reading (De Beni et al., 2006). In addition, females generally do not score as well as do males, regardless of the type of measurement used; the problem remains that MRTs might be too difficult for older people (Jansen & Heil, 2010; Maitland, Intrieri, Schaie, & Willis, 2000).

Conventional 2D presentation modes on MRTs are typically used for mental rotation training (Shepard & Metzler, 1971). In a formal test, participants need to judge whether two stimuli are the same or mirrored, and then write down their answers on paper. Specifically, sometimes the stimuli are 3D objects presented as 2D, e.g., images of cars or animals, which are not suitable to be presented in 2D form. If MRT stimuli are shown using 2D pictures, then obvious depth cues, such as shadowing or light effects, also need to be provided (McCarthy, 2010; Wright, Thompson, Ganis, Newcombe, & Kosslyn, 2008), because that is conducive to the ability of older adults to encode the stimuli (Tsai, 1988). There are tools that allow the test to handle a mental rotation controller. In some specific cases, for example, participants are allowed to use a manual controller to rotate the stimuli (Gardony, Taylor, & Brunye, 2014; Wiedenbauer & Jansen-Osmann, 2008; Yeh et al., 2014) or to simulate the rotation process (Chu & Kita, 2011; Goldin-Meadow & Beilock, 2010; Hostetter, Alibali, & Bartholomew, 2011). Those case studies all support the notion that this type of manipulation helps facilitate mental rotation skills (Hoyek, Champely, Collet, Fargier, & Guillot, 2014; Wexler, Kosslyn, & Berthoza, 1998; Wraga, Thompson, Alpert, & Kosslyn, 2003).

The primary problem with current mental rotation skills training is that tasks either use 2D materials, e.g., printed shapes or images, or else the tasks are presented on a 2D liquid-crystal display (LCD) monitor. Despite the availability of 3D computer monitors or the possibility of using virtual reality (VR) as a training system (Wiedenbauer & Jansen-Osmann, 2008), the stimuli are still presented in 2D form. When participants need to figure out spatial information using a 2D format, a heavy cognitive load is generated during training (Chandler & Sweller, 1991; Sweller, Van Merriënboer, & Paas, 1998) because people need to indirectly imagine the 3D patterns shown on the 2D display, and must, therefore, spend a great deal of energy to comprehend the 3D target object. In addition, most difficult methods of training are unpopular and, therefore, ineffective. Thus, training methods need to incorporate novel, useful, and effective aspects, such as 3D stimuli and manual spatial manipulation, which is what using AR technology can provide. Hence, we designed an integrated AR-3DH system to train the mental rotation skills of older adults. AR-3DH uses a Leap Motion (https://www.leapmotion.com/product/vr) controller that has a USB interface which allows users to manipulate 3D virtual reality images by moving their hands and fingers. It can be used as a MRTs system because of its multisensory (3D visuals and perceptual motor control) feedback and interaction. Some studies (Van Gerven, Paas, Van Merriënboer, Hendriks, & Schmidt, 2003) report that using multimedia techniques increases training efficiency and positively stimulates the interest of older as well as younger people. Moreover, AR interfaces can directly provide real-time 3D visual support and promote spatial visualization, which is related to mental rotation ability (Kaufmann & Schmalstieg, 2003; Martín-Gutiérrez et al., 2010; Shelton & Hedley, 2002). They can also reduce learners' cognitive loads and increase their interest in being trained (Hedley, 2003; Klatzky, Wu, Shelton, & Stetten, 2008; Shelton & Hedley, 2004). Furthermore, because AR technology can present fully 3D holography, it can help people directly see the 3D model and does not require the user to translate from the 2D flat image.

3. Methods

3.1. Participants

Thirty-four elderly (≥65 years old) people were recruited from Tainan senior citizen centers, but only 28 (mean age: 67.3 years; 17 women; 5 left-handed participants) met our inclusion criteria (Table 1). They were all fluent fluency in Mandarin Chinese or Taiwanese; and attend senior citizen centers for exercise at least three times a week. Our therapists evaluated whether their physical health would allow them to participate in our study. We recruited only healthy participants because the goal of this research was to postpone some of the negative effects of aging. Using participants who were already seriously aging or who had already developed Alzheimer's disease would have biased our experiments and their results, especially our training to manipulate virtual reality objects and to continue to pay visual attention to transformed and rotating 3D models.

Before the experiment began, a physiatrist (an MD specialized in physical and rehabilitation medicine) administered a revised Chinese version (Guo et al., 1988) of the Mini Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975) to all participants to ensure that their cognitive abilities were within normal range. The MMSE focuses on five cognitive aspects: orientation, registration, attention and calculation, recall, and language. We recruited 4 additional participants in our pilot test who scored >24 on the MMSE to collect the fundamental data of the mental strategies they used to handle MRTs tasks. The inclusion criteria were (1) ≥65 years old, (2) MMSE score ≥ 24 out of 30, which indicated that the person was cognitively sound enough to participate, (3) no other specific disease causes symptoms like dementia or Alzheimer's disease, (4) not taking medications for physician- or self-diagnosed mental illnesses, (5) no physician-diagnosed comorbidities, (6) not undergoing any other therapies at the time of the testing, and (7) vision and hearing within the normal range for the person's age. All testing was done by the same group of physiatrists and therapists. National Cheng Kung University (NCKU) Hospital's Internal Review Board (IRB) approved the study (IRB No: B-BR-104-160). All participants signed an informed consent.

All 28 participants were randomly divided into a Control group (n = 14) and an Intervention group (n = 14) to compare their learning curves after the intervention phase. Only Intervention Group was given AR-3DH training (focus on 3D MRTs training) during the intervention phase. The Control Group was given 2D MRT with extra instruction. The experiment in both groups consisted of three phases: [1] a pretest that lasted for 4 weeks in which baseline information on the participant was collected; [2] intervention that lasted for 1.5 months in which two kinds of the training (2D MRTs with extra instruction vs. AR-3DH) were used to promote their mental rotation ability; and [3] a posttest that lasted for 4 weeks. There was an 8-week hiatus after the intervention was completed to reduce recall interference in order to determine whether and how much the mental rotation ability of the Intervention group improved (Fig. 1).

3.1.1. Control group

The standard MRTs test is empirical evidence of their mental rotation ability (Shepard & Metzler, 1971) and recently, a clinical