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Research Article

Influence of Augmented Reality-based Dual Task Training on Balance, Visuo Motor and Cognition during Simulated Visual and Auditory Impairment

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ABSTRACT

Background/Objectives: The purpose of this study is to evaluate the effects of augmented reality (AR)-based dual-task training on balance, visuomotor skills, and cognitive function.

Methods/Statistical analysis: This study was conducted on 20 healthy adults from S University located in City A, South Korea. The participants were divided into an augmented reality-based dual-task training group and a general balance training group. Before and after the experiment, the balance ability, visuomotor skills, and cognitive function changes in each group were evaluated using the Time Up and Go (TUG) test, COTRAS-PRO, and COSAS assessments, measured twice as pre- and post-tests.

Findings: Both the augmented reality-based dual-task group (DG) and the general balance training group (CG) showed significant improvements in balance ability, but there were no significant differences between the two groups ($p > 0.05$). In terms of visuomotor skills, the DG group showed significant improvements ($p < 0.05$) and demonstrated significant differences compared to the CG group ($p < 0.05$). However, the CG group showed no significant differences ($p > 0.05$).In terms of cognitive function, the DG group showed significant improvements in visuoperceptual ability ($p < 0.05$) and showed significant differences compared to the CG group ($p < 0.05$).The CG group showed significant improvements in memory ($p < 0.05$), but there were no significant differences between the two groups in terms of memory ($p > 0.05$).

Improvements/Applications: The dual-task training using augmented reality technology showed significant improvements in the balance, visuomotor skills, and visuoperceptual ability processing abilities of participants simulating visual and auditory impairments. This suggests that AR-based training has a high potential to be utilized as an effective tool.

Keywords: Dual task, Augmented reality, Coordination training, Cognitive function, Balance, Visuo-motor skills

1. Introduction

Individuals with combined visual and auditory impairments experience complex effects on balance, visuomotor skills, and cognitive abilities, leading to numerous difficulties in daily life[1, 2, 3]. The deficiency of both visual and auditory inputs causes significant challenges in maintaining balance[3, 4]. While visual feedback and auditory signals play a crucial role in maintaining equilibrium, the absence of these cues results in difficulties for individuals with dual sensory impairment in adjusting their posture or avoiding falls[5, 6]. This negatively impacts mobility and independent living in daily activities. Furthermore, visuomotor skills are also impaired. Visuomotor skills refer to the ability to adjust movements based on visual information, and when visual information is insufficient, movement accuracy and agility decline. Inefficient and awkward movements may occur during routine tasks such as grasping objects or reaching towards a target[7]. Lastly, cognitive abilities are also affected. The lack of visual and auditory cues leads to a decline in attention, memory, and problem-solving skills, which further exacerbates difficulties in learning and social interactions[1, 2].

Dual-tasking involves performing two tasks simultaneously, providing additional benefits compared to single-task training. Previous studies have reported that dual-task training positively impacts both the cognitive and motor functions of individuals with visual and auditory impairments[8]. In particular, dual-task exercises that combine motor and cognitive stimuli have been shown to significantly improve cognitive abilities. Another study suggested that dual-task exercises also contribute positively to the improvement of daily living skills in individuals with combined sensory impairments[9, 10, 11].

With the rapid advancements in modern medicine and information technology, healthcare professionals are increasingly adopting augmented reality (AR)-based dual-task training. AR is defined as a technology that superimposes computer-generated images onto the real-world environment that the individual sees, allowing virtual objects to be overlaid on the actual environment without the need for additional devices[12, 13]. AR can provide detailed visual and auditory feedback, offering greater specificity, continuity, and lower latency than feedback provided by a therapist[14]. Thus, AR can assist individuals with specific learning disabilities in performing and developing various functional skills. Furthermore, AR technology has been well-received by rehabilitation patients due to its engaging nature, repetition, fast feedback, and motivational effects[15].

Previous studies have shown that AR-based dual-task training has positive effects on improving the physical abilities of individuals with visual and auditory impairments[16], and cognitive-motor training using AR devices has been found to significantly enhance various cognitive functions, such as working memory, cognitive flexibility, and attention[13]. Recent studies have also reported that dual-task training combined with AR is effective in improving social interactions and cognitive outcomes in children with visual and auditory impairments[18]. These findings suggest that dual-task training using AR is a promising approach for enhancing a wide range of cognitive and motor functions in individuals with sensory impairments.

However, studies focusing on AR-based dual-task training for individuals with visual and auditory impairments remain limited. Most previous studies have focused on either physical abilities or cognitive functions, with few investigating the simultaneous improvement of both[6]. In studies comparing dual-task with single-task exercise programs, the effects of dual-task exercises were not clearly observed, and children with sensory impairments performed worse than their peers in dynamic balance tasks, cognitive tasks, and fine motor tasks[18]. These results highlight the need for further research on the long-term effects of multiplayer game-based dual-task training using augmented reality[17]. Moreover, current studies are small in scale, heterogeneous, and lack sufficient control, making it difficult to draw definitive conclusions from these findings[19].

In order to improve training and rehabilitation strategies for individuals with visual and auditory impairments, an AR-based dual-task exercise experiment was proposed in an environment simulating sensory impairment using normal adults. For this purpose, participants wore Fatal Vision Goggles (FVG) and performed exercises in a continuous noise environment. FVG is designed to distort visual perception, preventing the wearer from accurately recognizing their surroundings, thereby impairing motor and balance senses[20]. Additionally, the 95 dBA noise negatively impacts both cognitive and physical functions[21]. Through such experiments, the goal is to replicate the challenges faced by individuals with visual and auditory impairments and to use this data as a foundation for designing more effective rehabilitation strategies.

FVG is designed with embedded Fresnel and lenticular protrusions in the lenses, distorting and displacing the image to prevent the wearer from accurately perceiving their surroundings. As a result, it induces motor impairment, loss of balance sense, and visuoperceptual awareness, hindering performance abilities[20]. Additionally, when participants were exposed to noise levels of 95 dBA, there was a significant decrease in mental workload capacity and visual and auditory attention. These findings suggest that high-intensity noise environments negatively impact cognitive and physical functions, contributing to a more realistic simulation of the challenges faced by individuals with visual and auditory impairments in daily life[21].

By utilizing this method, we can experimentally induce the visual-motor coordination issues, reduced balance sense, and cognitive overload experienced by individuals with visual and auditory impairments in healthy adults in their 20s. This approach is expected to provide foundational data that will aid in the more effective development of training and rehabilitation methods for individuals with sensory impairments. This study aims to verify the effectiveness of a dual-task exercise program using AR technology, contributing to the improvement of both physical and cognitive functions in individuals with visual and auditory impairments.

2. Materials and Methods

2.1. Participants

This study was conducted on university students between the ages of 20 and 25, enrolled at S University located in City A, South Korea. The study participants were limited to 20 healthy adults who were capable of physical activity within the parameters defined by the research protocol. During the recruitment process, individuals who required an Individualized Education Program due to physical disabilities, or who had orthopedic issues that could significantly limit motor performance (e.g., chronic musculoskeletal disorders, acute injuries), were excluded from the study. All participants received a thorough explanation of the study's purpose, procedures, and potential risks and benefits, and were only selected after providing written informed consent based on the ethical standards of the study. The selection process for study participants was rigorously based on predefined criteria, ensuring that their physical health status was suitable for the study's objectives. The characteristics of the participants are shown in [Table 1].

Table 1. General characteristics

	DG(n=10)	CG(n=10)
Sex(F/M)	5/5	5/5
Age(years)	21.30±2.10	21.30±1.73
Height(cm)	167.6±8.31	168.10±8.96
Weight(Kg)	68.30±15.17	64.10±12.34

DG = AR-based dual-task training group / CG = General balance training group

***Mean ± standard deviation**

2.2. *Sample size calculation*

The experimental procedure of this study was conducted according to the sequence presented in [Figure 1]. Participants were divided into the experimental group and the control group, and to assign them randomly, the names of each group were written on 10 pieces of paper, placed into separate envelopes, and shuffled. The researcher then closed their eyes and randomly drew papers to assign participants to the experimental or control group. This randomization method was implemented to ensure the randomness of the study and to minimize bias.

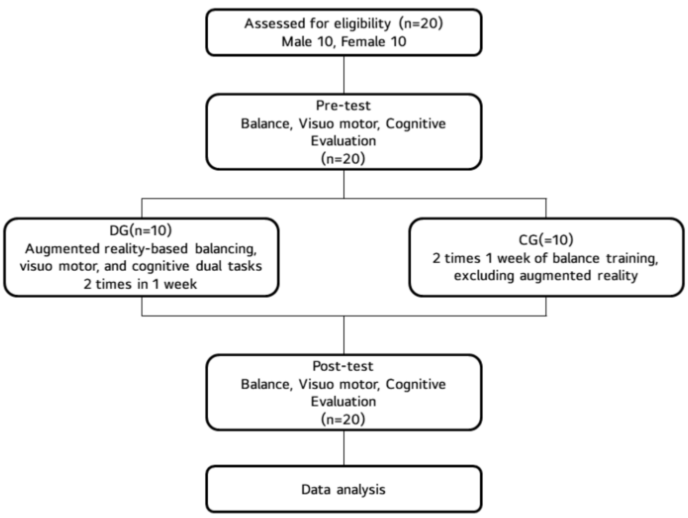

Figure 1. Experimental Procedure

2.3. *Measurement Tools and Method*

To collect baseline physical information from the participants, their height and weight were measured before the experiment. For the assessment of balance ability, visuomotor skills, and cognitive function, the Time Up and Go (TUG) test, COTRAS-PRO, and Cosas-s tools were used, respectively. These assessments were conducted twice, before and after the intervention, and to ensure reliability, the same researcher consistently carried out all measurement procedures. In particular, FVG (Fatal Vision Goggles) and headphones were used to simulate visual and auditory impairments. FVG was used to induce visual and balance impairments, mimicking the motor restrictions experienced by individuals with sensory impairments, while the headphones created a noise environment to simulate cognitive overload and reduced attention.

2.3.1 Balance measurement

The Time Up and Go (TUG) test was performed to measure balance ability ([Figure 2] reference). The experimental tools included a standardized armchair (46 cm seat height, 65 cm armrest length), a marker cone placed 3 meters away, and a stopwatch. The participant sat in the chair with their arms comfortably resting on their knees or sides, and the test began at the therapist's 'start' signal. The participant stood up from the chair, walked to the target point 3 meters ahead, and then returned to the chair to sit down. The time taken for this process was measured using a stopwatch. Each participant performed the test only once without prior practice, and the recorded time was used as the final result. No external physical assistance was provided during the experiment, allowing for an objective assessment of the participant's voluntary balance and mobility skills.

Figure 2. Time up and go test

2.3.2 visuo-motor measurment

The evaluation of visuomotor ability was conducted using the reaction time measurement module of the COTRAS-PRO application, and the results were compared and analyzed before and after the intervention. The evaluation consisted of five stages, with the test set at stage 3, and a total of 20 problems were presented .Each problem required the participant to select the shape on the screen that matched the displayed image within a 10-second time limit. Participants had to select the correct image as quickly and accurately as possible. The evaluation metrics included average accuracy, average response time, and total time taken ([Figure 3] reference).

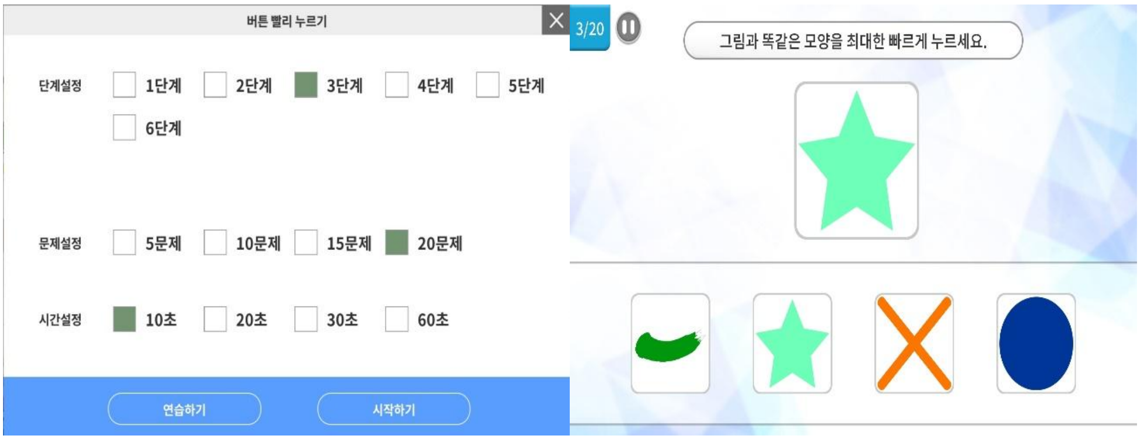

Figure 3. Cotras-pro visuo motor test

2.3.3 COGNITION measurment

Cognitive ability was assessed using the COSAS discrimination test. This test was developed as a brief neurocognitive function test and was compared and measured before and after the intervention. It consisted of 29 problems, and the total score for each area was calculated based on a maximum of 100 points. The assessment included the following categories: orientation (15.15 points), memory (12.12 points), attention and concentration (21.21 points), visuoperceptual ability (15.15 points), language ability (18.18 points), and higher-order cognition (18.18 points). The evaluation was analyzed based on the number of correct answers, average accuracy, and response time, with the results being further analyzed in detail by each category in addition to the total score ([Figure 4] reference). This allowed for a quantitative assessment of memory, attention, visuoperceptual ability, language skills, and higher-order cognitive functions.

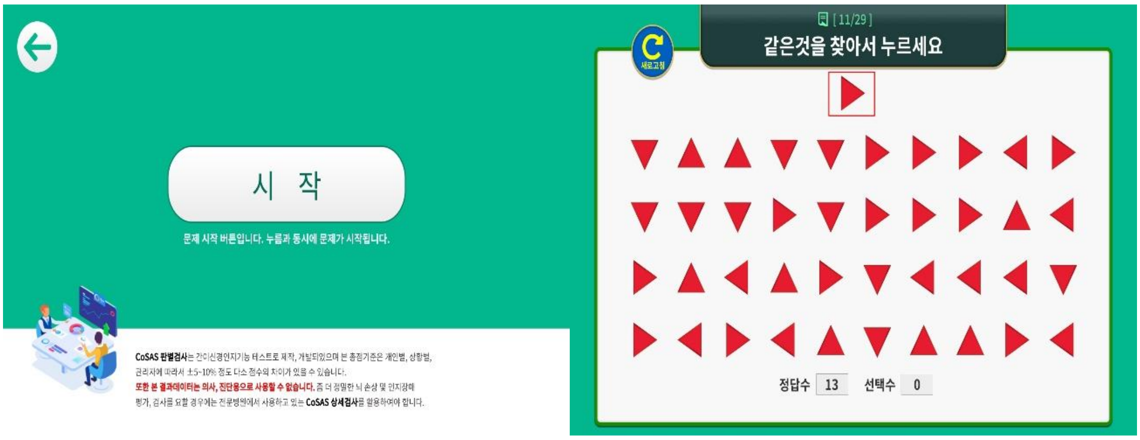

Figure 4. Cosas-s cognition test

2.4. Intervention method

This study was conducted by dividing participants into two groups: an AR-based dual-task training group and a general balance training group. The AR-based dual-task training group performed exercises on a balance pad using an augmented reality (AR) cognitive program, with the goal of simultaneously improving cognitive and visuomotor skills, as well as balance, by solving cognitive tasks while maintaining physical balance. This program provided visual and motion-based stimuli, and real-time feedback was designed to help participants perform the exercises more effectively. On the other hand, the general balance training group performed balance-enhancing exercises on a balance pad without using AR technology, following the verbal instructions of the researcher. Both groups followed the same procedure, and a single researcher was responsible for minimizing individual differences and maintaining consistency in the experiment. Before the experiment, participants received a thorough explanation of the research procedures and exercise programs, and they were given prior education to ensure a clear understanding of necessary instructions during the experiment. The research team prioritized participant safety throughout the experiment by continuously monitoring the experimental environment and deploying additional researchers to prevent accidents such as falls. In particular, to simulate sensory impairments, Fatal Vision Goggles (FVG)and headphones were used ([Figure 5] reference). FVG simulated visual impairments by distorting vision[22], while headphones provided auditory restrictions, experimentally replicating the various sensory difficulties that individuals with visual and auditory impairments may experience in real life[23].

Figure 5. Fatal Vision Goggles(FVG)

2.4.1. AR BASED DUAL TASK TRAINING GROUP

The AR-based dual-task exercise group used UINCARE AR (augmented reality) equipment, receiving visual and auditory feedback while performing the dual-task exercise program. The exercises were conducted on a balance pad, incorporating various exercise tasks built into the UINCARE AR system. The primary tasks included pattern memorization, quick touching, ball catching, and sequence linking, all aimed at simultaneously improving balance, visuomotor skills, and cognitive abilities. The exercise program consisted of 2 minutes of warm-up, 6 minutes of main exercise, and 2 minutes of rest, totaling 10 minutes per session, conducted twice a week for 1 week. Throughout the exercises, participants received real-time feedback to adjust the accuracy and speed of their movements in response to visual stimuli. Detailed information about the program is provided in [Table 2], where the specific steps and detailed content of each exercise can be reviewed.

Table 2. AR-based Dual-task Exercise

<table>
<tr><th colspan="2">1. Sequence Connection</th></tr>
<tr><td>
</td><td>Difficulty: Hard, Cognitive Mixed Task, Holding Time: 1 second

Arrange the numbers from 1 to 14 in order using both hands sequentially and measure the time taken to complete the task.</td></tr>
<tr><th colspan="2">2. Pattern Memory</th></tr>
<tr><td>
</td><td>Difficulty: Hard, Speed: Fast, Holding Time: 1 second

This task involves remembering the pattern of 2 out of 9 squares shown on the screen and accurately selecting them. The task lasts for 2 minutes.</td></tr>
<tr><th colspan="2">3. Quick Touch</th></tr>
</table>

	Difficulty: Hard, Speed: Fast, Holding Time: 1 second On the screen, 2 out of 9 squares are highlighted for 20 seconds. The task is to touch the highlighted squares with your hand within the allotted time. This task lasts for 2 minutes.
4. Ball Catching	
	Difficulty: Hard, Speed: Fast This task involves controlling the ball on the screen with your hand and guiding it into a square frame for 2 minutes. The dominant hand is used for this task.

2.4.2. Normal balance training GROUP

The general balance training group performed exercises on a balance pad following verbal instructions from the researcher. This group received only verbal instructions from the researcher to carry out the exercises, and auditory feedback was provided to allow participants to adjust their movements during training. The program consisted of 2 minutes of warm-up, 6 minutes of main exercise, and 2 minutes of rest, totaling 10 minutes per session, conducted twice a week for 1 week. Detailed information about the exercises performed is provided in [Table 3].

Table 3. General Balance Exercises

1. Side-to-Side Steps	
	Stand with feet together on the balance pad and shift your weight completely to the right foot. Then, slowly lift the left leg and hold for 3 to 4 seconds before lowering it again. Repeat this movement for 2 minutes.
2. Toe Raises	
	Stand with feet together on the balance pad, lift your toes as high as possible, and then slowly lower them back to the starting position. Repeat this movement for 2 minutes.
3. March in place	
	Stand with feet together on the balance pad, lift one foot at a time, and perform a walking motion in place. This movement is performed for 1 minute.
4. Step-Ups	

	Stand behind the balance pad, step onto the pad, hold the position for 2 seconds, and then step back down. Repeat this movement for 2 minutes.

2.4.3 *Data Analysis*

All statistical analyses were performed using SPSS Statistics (Version 29.0.1.0). Descriptive statistics were applied to calculate and compare the mean (M) and standard deviation (SD) of each group. To compare the pre- and post-intervention changes in balance, visuomotor skills, and cognitive abilities between the experimental group, which underwent AR-based dual-task training, and the control group, which underwent general balance training, paired t-tests were used. Independent t-tests were applied to analyze differences between the groups. In all statistical analyses, the significance level (α) was set at 0.05 or below.

3. Results

This study implemented AR-based dual-task training in the experimental group to analyze its effects on balance, visuomotor skills, and cognitive function, comparing it with the control group that underwent general balance training.

To evaluate the pre- and post-intervention changes in balance ability for each group, paired t-tests were conducted. Both the experimental and control groups showed a significant decrease in TUG (Time Up and Go) times, indicating a significant improvement in balance ability ($p < 0.05$). However, independent t-tests comparing the intervention effects between the groups revealed no significant differences ($p > 0.05$), suggesting that both groups showed similar improvements in balance ability after training.

Additionally, to assess changes in visuomotor skills, paired t-tests were performed. In the experimental group, there was a significant increase in average accuracy and a significant decrease in average reaction time and total time, indicating improved visuomotor skills as measured by the COTRAS-PRO ($p < 0.05$). On the other hand, no significant changes were observed in the control group ($p > 0.05$). Independent t-tests comparing the intervention effects between the groups showed that the experimental group had significantly greater improvements in average accuracy and reaction time than the control group, with the experimental group also showing a significantly greater reduction in total time ($p < 0.05$).[Table 4]

Table 4. Comparison of balance ability and visuomotor skills within and between groups

	Between pre & post				Between group	
	group	**pre**	**post**	***t(p)***	**difference**	***t(p)***
TUG Time Up & GO *(Balance)*	**DG**	16.09±2.48	12.55.±2.08	5.541(.001***)	-3.55±2.02	.051(.960)
	CG	16.22±3.09	12.59.±2.15	2.674(.025*)	-3.62±4.28	
Average Accuracy *(visuo-motor)*	**DG**	.87±.15	.99±.02	-2.940(.016*)	.13±.14	2.113(.049*)
	CG	.96±.07	.99±.02	-1.103(.299)	.03±.07	
Average Response Time *(visuo-motor)*	**DG**	2.42±1.36	1.13±.58	3.985(.003**)	-1.29±1.02	-3.275(.007**)
	CG	1.74±.78	1.58±.75	1.340(.213)	-.16±.38	
Total Time Taken *(visuo-motor)*	**DG**	94.50±26.09	67.90±21.45	3.842(.004**)	-26.60±21.90	-3.945(.003**)
	CG	86.40±17.51	87.20±17.46	-1.445(.182)	.80±1.75	

$^{*}p<.05$, $^{**}p<.01$, $^{***}p<.001$; Mean ± SD

DG = AR-based dual-task training group / CG = General balance training group

In the evaluation of cognitive function changes, paired t-tests revealed that visuoperceptual ability significantly improved in the experimental group, while memory significantly improved in the control group (p < 0.5). Both groups showed significant improvements in reaction time and total scores (p < 0.5). However, for attention, language ability, and higher-order cognition, no significant differences were observed in either group (p > 0.5).

Independent t-tests comparing the intervention effects between the two groups showed no significant differences in memory (p > 0.5), with both groups showing similar improvements. No significant differences were found between the groups in attention, language ability, and higher-order cognition (p > 0.5). However, in visuoperceptual ability, the experimental group showed significantly greater improvement compared to the control group (p < 0.5). No significant differences were found between the groups for reaction time and total scores (p > 0.5).[Table 5]

Table 5. Comparison of Cognitive Abilities Within and Between Groups

	Between pre & post				Between group	
	group	pre	post	*t(p)*	difference	*t(p)*
Memory	DG	10.16±2.36	11.54±0.75	-1.990(.078)	1.38±2.20	-1.299(.210)
	CG	8.78±2.50	11.54±0.75	-3.397(.008**)	2.78±2.58	
Attention & Concentration	DG	17.06±3.60	19.24±2.83	-1.954(0.82)	2.19±3.54	.177(.680)
	CG	15.98±5.96	19.24±2.83	-1.402(.194)	3.27±7.38	
Visuo Perceptual ability	DG	8.21±4.56	13.33±2.32	-3.714(.006**)	4.50±3.92	2.449(.025*)
	CG	12.12±2.50	12.72±2.91	-.469(.650)	0.60±4.09	
Language ability	DG	17.88±0.95	18.18±0.00	-1.000(.343)	0.30±0.96	-.849(.407)
	CG	17.27±2.05	18.18±0.00	-1.406(.193)	0.90±2.05	
Higher-order Cognition	DG	15.76±3.12	17.57±1.91	-1.964(.081)	1.82±2.93	-.179(.860)
	CG	15.45±3.56	17.57±1.91	-1.500(.168)	2.12±4.47	
Response Time	DG	11.61±2.25	7.25±1.06	6.994(.001***)	-4.36±1.97	-1.034(.315)
	CG	10.58±2.17	7.26±1.06	4.248(.002**)	-.3.32±2.47	
Total Score	DG	84.29±11.10	94.16±5.23	-3.433(.007**)	9.87±9.09	.125(.902)
	CG	84.90±10.48	94.16±5.24	-2.358(.043)	9.26±12.42	

***p<.05, **p<.01, ***p<.001 ; Mean ± SD**

DG = AR-based dual-task training group / CG = General balance training group

AR-based dual-task training showed significant improvements in balance ability and visuomotor skills, as well as positive effects on certain cognitive functions (reaction time). In contrast, the control group demonstrated less significant overall improvements. These findings suggest that AR-based training is a promising approach for enhancing the multifaceted abilities of individuals with visual and auditory impairments. Further research is needed to more thoroughly evaluate various cognitive functions and the long-term effects of this training.

4. Discussion

This study evaluated the effects of AR-based dual-task training on balance, visuomotor skills, and cognitive function in a simulated environment inducing visual and auditory impairments. The study also attempted a multifaceted analysis of the effectiveness of AR technology by comparing the experimental and control groups. In this discussion, the results are divided into three main topics: balance, visuomotor skills, and cognitive function.

The primary goal of the study, which was to improve balance ability, was assessed using the Time Up and Go (TUG) test, and both the experimental and control groups showed significant improvements. Both previous research and the current study confirm that general balance training and AR-based training are effective in improving balance ability[22]. The significant improvements observed in the control group suggest that traditional balance training methods remain effective. This implies that AR technology can be a useful tool to supplement traditional balance training methods[22]. Given the short duration of the study, it is likely that the effects of AR technology will become more pronounced with long-term training[23]. While AR may require an initial adaptation period, its effects become clearer once participants adjust to the technology[24]. Therefore, future research should assess the long-term effects of AR training and its role in sustaining balance improvements. Additionally, while the real-time feedback provided by AR training is beneficial for motivation and posture correction, excessive reliance on feedback may hinder the development of autonomous balance skills[25]. Thus, training programs should be designed to cultivate balance abilities that can be maintained without feedback.

The most noteworthy result in this study is the improvement in visuomotor skills, where significant improvement was observed in the experimental group that received AR-based training, but no changes were observed in the control group. Comparing the two groups, only the experimental group showed significant results. Previous studies have also confirmed that visual stimuli using AR technology can facilitate faster and more accurate responses[26], and similar results were observed in this study. In particular, the AR feedback significantly improved the response speed and accuracy of the experimental group compared to the control group, suggesting that the AR system helped participants process visual stimuli more intuitively and efficiently. These findings suggest that AR-based training could provide significant benefits in tasks that require visuomotor skills in real-life situations[27]. Especially in the rehabilitation process of individuals with visual and auditory impairments, where visuomotor skills are often compromised, AR training could serve as an effective tool[28]. However, as mentioned in other studies[29], the relatively short training period in this study calls for future research to evaluate the long-term effects. This study did not provide data across different age groups, so future studies should also include various age groups[30]. Moreover, a multifaceted approach should be considered to maximize the improvement of visuomotor skills. As suggested in previous research, combining auditory and tactile feedback with AR-based training could further enhance the ability of individuals with sensory impairments to respond more flexibly to diverse sensory stimuli[31].

There is a close correlation between balance ability and visuomotor coordination. When visuomotor skills improve, balance ability tends to improve as well, which is consistent with findings from previous studies[32], indicating that visuomotor coordination and balance influence each other closely. This correlation was also confirmed in this study[32].

The results on cognitive function showed that memory significantly improved in the control group, whereas no such improvement was observed in the experimental group. This suggests that general balance training may have had a positive impact on memory, possibly by stimulating the cerebellum and frontal lobes, contributing to memory retention and information processing[33]. These results are consistent with previous studies that suggest balance training is effective in stimulating cognitive function[34]. However, AR-based training did not show any effect on memory improvement, revealing a limitation in this area[35]. It is possible that the AR system, with its focus on visual feedback and immediate physical responses, lacked the necessary stimulation for memory improvement[36]. Additionally, increased reliance on feedback may have weakened cognitive autonomy, potentially leading to limited outcomes in higher-order cognitive functions. Therefore, to improve cognitive function more effectively through AR-based training, it will be essential to gradually reduce feedback to promote autonomy. Enhancing autonomous cognitive development will be a crucial challenge moving forward[37].

In the experimental group, visuoperceptual ability significantly improved. Visuoperceptual ability plays a key role in cognitive function by processing visual stimuli and converting them into physical responses. AR technology played a critical role in this process, as confirmed in previous studies[33]. In those studies, AR technology significantly enhanced the ability to process visual information and the accuracy of responses, and similar results were observed in this study. The effects of AR technology in processing visual stimuli are very encouraging. Previous studies have also reported improvements in visual information processing and physical coordination[38], and this study presents consistent results. This suggests that AR training has not only improved physical coordination but also had positive effects on cognitive function.

According to previous studies, improvements in balance ability are closely correlated with improvements in visuoperceptual ability[39]. This study also showed that improvements in balance ability positively influenced the improvement of visuoperceptual ability. This indicates that, because brain function and the visual-vestibular system interact during balance maintenance and visual information processing, improvements in balance can simultaneously enhance visuoperceptual ability[39].

Both the experimental and control groups showed significant improvements in reaction time and total cognitive scores, with no substantial differences between the two groups. This is likely because general balance training stimulated neural circuits in the brain, contributing to improved cognitive function. Physical training may have promoted neuroplasticity, which in turn enhanced information processing speed, and this could explain the improvements observed in the control group without the application of AR technology[40]. However, since this study was conducted over a relatively short period, it is possible that a longer intervention would result in more pronounced effects from AR-based training[23]. As time passes, AR training could provide stronger stimulation to neural circuits, leading to more differentiated outcomes in long-term cognitive processing speed and total scores. Therefore, future studies should evaluate the sustained effects of AR training from a long-term perspective.

Although this study did not reveal significant differences in reaction time and total cognitive scores, the strengths of AR technology became apparent in visuoperceptual processing, suggesting that AR-based training could serve as a highly effective tool for improving specific cognitive functions.

In conclusion, balance, visuomotor skills, and cognitive abilities are interrelated and complementary, and improvement in one area can lead to enhancements in another. In particular, AR-based training is evaluated as a highly effective method for integrating balance, visuomotor, and cognitive training[41]. Improvements in balance directly contribute to enhancements in visuomotor and cognitive functions, allowing for faster and more precise processing of stimuli. For the overall functional recovery of individuals with visual and auditory impairments, it is essential to implement programs that can simultaneously strengthen these abilities, and AR technology can serve as an optimal tool in this process. Additionally, the real-time feedback provided by AR systems can produce more efficient outcomes during training, making it a key factor in rehabilitation and functional recovery[42].

5. Conclusion

This study measured and compared the effects of augmented reality (AR)-based dual-task training on balance, visuomotor skills, and cognition in a simulation inducing visual and auditory impairments, using a general control group for comparison. The following conclusions were drawn:

First, both the experimental group that received AR-based dual-task training and the control group that received general balance training showed significant improvements in balance ability, but no significant differences were found between the groups.

Second, in terms of visuomotor skills, the experimental group that received AR-based training showed significant improvements, with greater enhancements in average reaction time and total time compared to the control group. This result suggests that AR technology helped the participants process visual stimuli more quickly and accurately.

Third, in cognitive function, memory improved significantly in the control group, while visuoperceptual ability improved more significantly in the experimental group.

These conclusions suggest that AR-based training is a promising approach for enhancing various functions in individuals with sensory impairments. It also highlights the need for further research on the long-term effects and various cognitive functions.

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