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Investigation of the effects of cognitive tasks on balance performance in young adults

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ABSTRACT

Introduction: Individuals routinely perform cognitive tasks concurrent to balance functions. The attention is one of the most important cognitive functions and it has effects on vestibular system. This study aims to investigate the connection between balance and cognitive tasks under different conditions.
Methods: Visual attention tasks (VAT) and auditory attention tasks (AAT) were given to 30 healthy adults (40.42 ± 11.22 years) during functional balance tasks. Sensory Organization Test (SOT) and Adaptation Test (ADT) were used for the evaluation of postural stability and adaptation. The sounds were presented from the computer speakers in AATs, and VATs were presented in the virtual reality (VR) environment.
Results: The first SOT condition had a statistically significant difference between all dual VAT (DT-VAT) and single task (ST) ($p < 0.001$), but there was no statistically significant difference between ST and DT-AAT ($p = 1.00$). In the fourth SOT condition, there was a statistically significant difference between all DT-VATs versus ST and DT-VA ($p < 0.001$); there was no statistically significant difference between ST and DT-AA scores ($p = 0.80$). While there was a significant difference between DT-VA and ST and DT-AA ($p < 0.001$), no statistically significant difference was observed between ST and DT-AA in the ADT ($p = 0.321$).
Conclusions: Balance performance gets worse with VAT in a VR environment. VR technology can be used to effectively evaluate balance and cognitive performance. The use of experimental environments in standard postural evaluations increases the efficiency of the postural stability tests.

1. Introduction

Postural control is critical for movement. People routinely perform high-level cognitive functions while maintaining their balance. The academic literature on the vestibular system has revealed the emergence of several projections from the vestibular nucleus to the cerebral cortex [1]. The balance and cognitive processing centers share common resources in the central nervous system [2]. Vestibular signals related to the spatial memory transmitted to the upper centers of the brain, are more complex and multi-modal than initially thought [3].

Studies of mental tasks have shown that as the difficulty in maintaining posture orientation increases, the response time also increases, however the accuracy in a dual task study decreases [4]. Balance is automatically maintained when performing a cognitive task. Although the cause of the balance problem is mostly a disorder in the vestibular system, there is also evidence that attention deficit and cognitive decline, significantly contribute to the risk of falling [5]. However, the attention becomes necessary for postural control in balance tasks that require compensation or the presence of some conflicting sensory stimuli [6]. Previous studies have explored the relationships between cognition and the vestibular system, and several authors have considered the effects of attention on postural stability [7–9]. These studies clearly indicate that there is a relationship between attention and balance. On the other hand, the generalizability of this research remains controversial. There are still questions about the point at which attention tasks start to disrupt balance performance. Most studies use the same experimental conditions; they have some limitations in real life conditions especially in terms of showing the effects of visual and auditory attention on postural control.

Thus, different conditions were created including virtual reality conditions. In recent years, there has been an increasing amount of literature on virtual reality technology. Virtual reality (VR) technology is widespread in many areas and is used to mimic real-life situations. The VR is a simulation of the real world environment produced by computer software and experienced through a human-machine interface by the user [10]. Recently, functional motor imagery studies have

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shown that the same brain regions are used to live and relive the experience; activity has been detected from the regions of the brain responsible for movement with an utterly cognitive process [11]. Thus, it is possible to activate any region of the brain using simulation without generating a motor movement. Presenting cognitive tasks in a virtual reality environment can provide a sense of space and depth and can give more reliable and valid test results that are consistent with everyday life. Due to these features, especially nowadays, it is thought that people having to stay at home for reasons like epidemics (COVID-19), social isolation, etc. will increase the importance and use of virtual reality technologies. In addition to the simulation applications used to imitate the daily living conditions, the increase in the use of virtual reality technologies for entertainment purposes has made it obligatory to have knowledge about balance performance in VR conditions. In this study, the relationship between balance and attention in a virtual reality environment was studied. In the evaluation of balance performance, it is aimed to systematically evaluate the balance performance by using computerized dynamic posturography while cognitive tasks are given in a virtual reality environment to simulate situations encountered in everyday life.

2. Material and methods

2.1. Participants

Thirty healthy young adults aged between 18 and 40 years participated in the study. It consisted of 15 female (27.6 ± 1.14) and 15 male (27.6 ± 1.15) with no complain or medical history of vestibular, cognition, hearing, eyesight, and anxiety problem. The participants had a university (90%) and university entry high school degree (10%). Ethical approval was obtained from the Ethics Committee of Hacettepe University (GO 17/870). They were evaluated between June and November 2018 at Hacettepe University Hospital, Audiology Department. Participants were given information regarding all research procedures and provided written informed consent.

The Dizziness Handicap Inventory [12], Generalized Anxiety Disorder [13], and Montreal Cognitive Assessment (MoCA) [14] were used to measure the status of anxiety, dizziness, and cognitive problems in participants.

The inclusion criteria included the following:

1. Scores were below the cut off scores of 16 and 4 for the DHI and GAD, respectively. Scores were above the cutoff of 21 for MoCA.
2. No visual, hearing or vestibular problem
3. Educational attainment of at least primary school
4. Age between 18 and 40 years.

2.2. Study design and procedure

Postural and cognitive tasks were presented to the participants. In the first stage of the study, five different virtual reality scenarios were created, and software engineers turned them into three-dimensional images compatible with virtual reality glasses (Oculus Rift, Oculus VR, USA). Three different auditory attention task combinations were created using the Praat 64-bit program. These were presented at the most comfortable loudness level through the computer speakers.

Visual and auditory attention tasks were presented to the participants simultaneously with postural tasks. A computer-based system was designed to present the attention tasks properly. The VR system's motion sensors were located in the upper corners of the CDP because this is thought to be the least affected area by device movements. The computer was placed outside the CDP device to allow the test manager to control both tests and initiate SOT and attention tasks simultaneously (Fig. 1). Prior to the dual-task condition, participants became familiar with the attention tasks by completing 2-minute seated practice trials.

Fig. 1. Photograph of the experimental set up.
Computerized Dynamic Posturography. Computer screen is seen by clinicians and also participants with VR glasses simultaneously. Movement sensors are on the upper corners of CDP.

2.3. Postural control tasks

Postural control performance was measured by Computerized Dynamic Posturography (Neurocom Smart Balance Master, Neurocom® International, Inc., Clackamas, OR). CDP evaluates the balance condition of individuals by monitoring the sensory (vestibular, visual, and somatosensory) and motor functions. Participants were asked to wear a special safety harness with connections to the equipment to prevent falling. They stood barefoot in stance position by putting their feet in the designated places on the platform.

The SOT and ADT protocols of the CDP were used for assessment. The SOT identifies and quantifies the sensory functions involved in balance control. The maximum equilibrium score is 100, and the minimum score is 0 in SOT. This test consists of six test conditions that are proceed from the easiest to the most difficult. The SOT conditions are listed below:

Condition 1 (C1): Fixed surface, eyes open.
Condition 2 (C2): Fixed surface, eyes closed.
Condition 3 (C3): Fixed surface, sway-referenced vision.
Condition 4 (C4): Sway-referenced surface, eyes open.
Condition 5 (C5): Sway-referenced surface, eyes closed.
Condition 6 (C6): Sway-referenced surface, sway-referenced vision.

ADT measures the ability of the individuals to respond to sudden changes and irregularities on the ground and to reduce their body sway. The test consists of two parts: In the first part, the platform is suddenly backward (toes up) for five times. In the second part, the platform moves forward (toes down) five times. In contrast to the SOT, low scores on the ADT results indicate that the adaptation process of the subject is good. Individuals whose consecutive equilibrium scores were

Table 1
Visual and auditory attention test conditions.

Visual Attention 1 (VA1)	To find the target vehicles between the other vehicles in a traffic environment
Visual Attention 2 (VA2)	To find the target subject between the other walking people in a hall.
Visual Attention 3 (VA3)	To find the target words between the other words in a sentence.
Visual Attention 4 (VA4)	To find the target color of the words between the other words
Visual Attention 5 (VA5)	To find the target animals between the other animals in a forest
Auditory Attention 1 (AA1)	To find the target tones between the high and low frequency tones
Auditory Attention 2 (AA2)	To find the target tones between the long and short duration tones
Auditory Attention 3 (AA3)	To find the target words between the other words in noise

within the normal range were included. A clinician monitored all subjects during the test.

2.3.1. Visual attention tasks

People were asked to pay attention to specific visual stimuli in the presented images and to give feedback when they see these stimuli with VR glasses (Table 1).

The visual attention tasks were presented to the participants simultaneously with SOT C1 and C4, and balance and attention scores were recorded. VA5 was given the subjects during ADT conditions (toes up and toes down). Subjects performed cognitive tasks randomly with ADT and SOT.

2.3.2. Auditory attention tasks

In every experimental trial, participants listened to a random series of 22 stimuli. The participants gave verbal responses. In the dual-task with SOT, participants completed the auditory and balance task for 20 s while monitoring and subsequently reporting the number of high-pitched tones presented via computer speakers during all SOT conditions. Participants were instructed to prioritize the balance task. The duration of the auditory attention tasks (AAT) is set to match the duration of the balance test. Three different AAT were created (Table 1). Participants were asked to report auditory stimuli in accordance with the instructions given. Target words were presented at a fixed level of 75 dB SPL throughout the testing; none of the participants reported having any difficulties hearing the tones.

2.4. Statistical analysis

Analysis of variance (ANOVA) with repeated measures was used to compare the results with ST: C1 and C4 of the SOT as well as DT-AAT and DT-VAT in the case of four different tasks (VA1, VA2, VA3, and VA4). A paired samples *t*-test was used to compare ST and DT-AAT in all conditions of the SOT. The eye closed conditions of the SOT (C2 and C5) and all VATs were compared with the paired samples t-test. The sway energy scores of ST-ADT and DT-ADT (AAT, VAT) were compared with the repeated measure ANOVA. Mauchly's test of sphericity was used to test the assumption of sphericity in repeated measurements of ANOVA. For all ANOVAs, Bonferroni post hoc tests were used whenever necessary. The level of significance was set at $p < 0.05$. Statistical analyses were performed with SPSS 22 (SPSS Inc., Chicago, USA).

3. Results

Visual attention tasks and AATs were given to 30 healthy adults (40.42 ± 11.22 years) during SOT and ADT. In the C1 condition of SOT, a statistically significant difference was found between all dual VAT (DT-VAT) and single task (ST) scores ($p < 0.01$). There was a statistically significant difference between DT-VA2 and DT-AAT ($p = 0.027$), but there was no significant difference between the other VA tasks and DT-AAT ($p > 0.05$). In the C4 condition of SOT, there was a statistically significant difference between all DT-VAT and ST and DT-AAT scores ($p < 0.01$), and there was no statistically significant difference between ST and DT-AA scores ($p > 0.05$). The SOT results are shown in Table 2.

Table 2
Comparison of the mean equilibrium scores on the SOT (C1 and C4) between the single task and dual tasks.

Task		C1		C4	
		Mean ± SD	*p*	Mean ± SD	*p*
ST	DT-AA	91.53 ± 3.06	1.00	85.51 ± 5.85	1.00
	DT-VA1	92.96 ± 5.55	**0.001****	69.97 ± 7.99	**0.001****
	DT-VA2	66.06 ± 13.49	**0.001****	59.35 ± 11.74	**0.001****
	DT-VA3	91.06 ± 3.19	**0.001****	69.56 ± 9.83	**0.001****
	DT-VA4	91.80 ± 3.27	**0.001****	69.77 ± 9.95	**0.001****
DT-AA	DT-VA1	92.96 ± 5.55	1.00	69.97 ± 7.99	**0.001****
	DT-VA2	66.06 ± 13.49	**0.027***	59.35 ± 11.74	**0.001****
	DT-VA3	91.06 ± 3.19	1.00	69.56 ± 9.83	**0.001****
	DT-VA4	91.80 ± 3.27	1.00	69.77 ± 9.95	**0.001****
	ST	94.6 ± 2.1	1.00	85.81 ± 6.3	1.00
DT-VA1	DT-VA2	66.06 ± 13.49	**0.005***	59.35 ± 11.74	**0.001****
	DT-VA3	91.06 ± 3.19	1.00	69.56 ± 9.83	1.00
	DT-VA4	91.80 ± 3.27	1.00	69.77 ± 9.95	1.00
	DT-AA	91.53 ± 3.06	1.00	85.51 ± 5.85	**0.001****
	ST	94.6 ± 2.1	**0.001****	85.81 ± 6.3	**0.001****
DT-VA2	DT-VA3	91.06 ± 3.19	**0.025***	69.56 ± 9.83	**0.005***
	DT-VA4	91.80 ± 3.27	**0.007***	69.77 ± 9.95	**0.004***
	DT-VA1	92.96 ± 5.55	**0.005***	69.97 ± 7.99	**0.001****
	DT-AA	91.53 ± 3.06	**0.027****	85.51 ± 5.85	**0.001****
	ST	94.6 ± 2.1	**0.001****	85.81 ± 6.3	**0.001****
DT-VA3	DT-VA4	91.80 ± 3.27	0.83	69.77 ± 9.95	1.00
	DT-VA1	92.96 ± 5.55	1.00	69.97 ± 7.99	1.00
	DT-VA2	66.06 ± 13.49	**0.025***	59.35 ± 11.74	**0.005****
	DT-AA	91.53 ± 3.06	1.00	85.51 ± 5.85	**0.001****
	ST	94.6 ± 2.1	**0.001****	85.81 ± 6.3	**0.001****

ST: single task, DT: dual task, AA: auditory attention, VA: visual attention, SD: standard deviation, P: probability.
* Significance < 0.05.
** < 0.01.

When the ST and DT-AAT scores of all SOT were compared, there was no statistically significant difference between ST and DT-AAT scores ($p > 0.05$) in SOT except C3 ($p = 0.011$) (Table 3). When ST-C2 (eyes closed ground fixed) and DT-VAT scores were compared; a statistically significant difference was found in all four VATs (Table 4). However, a statistically significant difference was found only in DT-VAT2 scores when ST-C5 and DT-VAT scores were compared ($p < 0.01$).

A significant difference was found between the sway energy scores of DT-AAT and ST in the ADT up condition ($p < 0.01$). While there was a significant difference between DT-VAT and ST and DT-AAT ($p < 0.01$), no statistically significant difference was seen between ST and DT-AAT in the ADT down ($p = 0.321$). The ADT results are shown in Table 5.

4. Discussion

There was a significant difference between SOT C4 and C1 scores with visual attention tasks and auditory dual task and single task scores, but the differences with C1 scores did not have a clinical significance exception of VA2 task. There were no significant differences between the SOT and SOT-AA scores. The DT-ADT conditions did have

Table 3
Comparison of the mean equilibrium scores on the SOT between the single task and dual tasks with auditory attention.

SOT scores							
Task	C1	C2	C3	C4	C5	C6	Comp
	Mean ± SS	Mean ± SS	Mean ± SS	Mean ± SS	Mean ± SS	Mean ± SS	Mean ± SS
ST	94,6 ± 2,1	92,87 ± 2,81	92,6 ± 2,4	85,81 ± 6,3	67,53 ± 10,0	64,5 ± 11,7	79,97 ± 5,47
DT-AA	92,96 ± 5,55	91,96 ± 2,67	91,2 ± 3,1	85,51 ± 5,85	69,76 ± 8,66	66,06 ± 13,5	80,2 ± 6,03
t	1,53	2,03	2,71	−0,28	−1,46	−0,25	−0,25
p	0,137	0,051	**0,011***	0,780	0,154	0,430	0,804

ST: single task (SOT), DT-AA: dual task-auditory attention, SD: standard deviation.
* Significance < 0.05.

Table 4
Comparison of the mean equilibrium scores on the SOT (C2 and C5) between the single task and dual tasks with visual attention.

ST	C1	Mean ± SD	*p*
C2	DT-VA1	92.96 ± 5.55	**0.001****
	DT-VA2	66.06 ± 13.49	**0.001****
	DT-VA3	91.06 ± 3.19	**0.001****
	DT-VA4	91.80 ± 3.27	**0.014***
ST	C4	Mean ± SD	*p*
C5	DT-VA1	69.97 ± 8	0.174
	DT-VA1	59.35 ± 11.74	**0.001****
	DT-VA1	69.56 ± 9.83	0.269
	DT-VA1	69.77 ± 9.95	0.223

ST: single task (SOT), C1 Condition 1, C2: Condition 2, C4: Condition 4, C5: Condition 5, DT-VA: dual task-visual attention, SD: standard deviation, P: probability.
* Significance < 0.05.
** < 0,001.

Table 5
Comparison of the sway energy scores on the ADT (up and down) between the single task and dual tasks.

ADT	Task		Mean ± SD	*p*
Up	ST	DT-AA	58.98 ± 13.52	**0.001****
		DT-VA	77.86 ± 18.82	0.129*
	DT-AA	ST	71.70 ± 16.27	**0,001****
		DT-VA	77.86 ± 18.82	**0.001****
Down	ST	DT-AA	42.44 ± 8.74	0.321
		DT-VA	57.38 ± 17.93	**0.001****
	DT-AA	ST	44.27 ± 8.14	0.321
		DT-VA	57.38 ± 17.63	**0.001****

ST: single task (ADT), DT-VA: dual task-visual attention, DT-AA: dual task-auditory attention, SD: standard deviation, P: probability.
* Significance < 0.05.
** < 0,001.

significant decreases in DT-AAT sway energy scores, but there was a significant increase in ADT down condition scores in DT-VAT. The increase in the ADT scores shows that VA adversely affects the adaptation process and vice versa in AA.

More recent investigations have begun to shed light on cognitive mechanisms and their relationship with the vestibular system. Several studies have shown that the verbal responses to the cognitive tasks in the standing position worsen the performance of postural control, but they also need to detect a visually presented stimulus that improves postural control [15,16]. Perceptual load level is an important factor in the case of attention. While high perceptual load decreases distractor interference, dual task coordination load increases it. Accordingly, during more difficult tasks, distracting stimuli in the environment are less stringently processed [17,18]. Confidence in the vestibular control of the balance increases when the cognitive load increases [19]. In our study, virtual reality conditions increased the cognitive load and decreased the balance performance.

Attention to color activates the regions in the collateral sulcus and dorsolateral occipital cortex. Attention to shape activates the collateral sulcus (similar to color) as well as the fusiform and parahippocampal gyrus and the temporal cortex along the superior temporal sulcus [20]. In this study, participants were asked to pay attention to the shape of the objects in some tasks and the colors in other tasks so that all of these regions were activated during the postural tasks.

Horlings et al. [21] reported that the increase in postural sway with VR was not different from the increase seen in the eyes closed position— especially on a foam surface. These results are supported by sensory conflict theory, which states that disequilibrium occurs as a result of contradictory visual and vestibular inputs causing visual-vestibular conflict. Here—when the SOT scores in the eyes closed conditions and dual task with VR scores were compared—the VR scores were different from the eyes closed situation on fixed surface; however, there was no significant difference on non-fixed surfaces similar to Horlings et al. [21]. This shows that the given three-dimensional visual stimuli have the same effect with complete inhibition of the visual sensation in humans.

In this study, SOT and ADT tests of the CDP (Neurocom) were used to assess the postural control. CDP can evaluate balance components, and it is the gold standard. Similarly, Müjdeci et al. [22] gave auditory and visual cognitive tasks with SOT to 20 healthy adults. They reported an increase in the body sway of participants with task difficulty during dual tasks of SOT-C2, C3, and C4. In contrast, we only noted increased postural sway during visual tasks.

One of the most important reasons why the cognitive dual task results differ, is that the tasks can be auditory or visual with varying difficulty levels. We reviewed studies similar to ours with auditory attention [23–25] and noted that participants showed better performance in balance tasks when a cognitive task was added. This is likely because of automatically corrected postural control [23]. These people presented a cognitive task similar to our auditory attention task. This work counted the high frequency tones over 1 min via a balancing task standing on a force-measuring plate. Rosso et al. [24] showed that the neural resources devoted to postural control decreased during dual tasks that require attention. Potvin-Desrochers et al. [25] compared the continuous and discrete cognitive tasks given during the standing position and reported an increase in the automation of postural control and decreased sway area for participants. However, in contrast to our results, additional auditory attention tasks did not change the balance performance.

Various hypotheses and models (constrained action, low-level, and level of alertness hypotheses as well as the task prioritization, limited attention sources, and U-shaped nonlinear interaction models) have been developed to explain why individuals exhibit less sway under easy dual tasks than single tasks. According to these hypotheses, balance

performance may increase due to activation of postural automatic control processes and increased alertness during dual tasks [26]. However, the limited attention sources model and the U-shaped non-linear interaction model argue that postural stability will decrease due to difficulties in the secondary task [27].

Bonnet et al. [28] stated that there are functional synergies between visual and postural processes, and these synergies create a greater demand for attention. The most common limitation of these models is that the easy and difficult tasks are not clearly defined. We suspected that no effect of postural stability would be seen with auditory attention tasks. The decrease in performance with visual attention tasks was likely caused by the fact that VOR involvement was more important in visual attention tasks than auditory tasks. Thus, the study results are compatible with the limited attention sources model and the U model hypotheses.

An important problem with virtual reality technology is that some users show symptoms similar to classical motion sickness after the VR experience [29]. This disease, called cybersickness, means that, the user is inactive but has a sense of movement that makes itself felt through the movement of visual images. This is not seen in movement disease. Cybersickness is seen in patients who have been extensively exposed to VR conditions for a long time. It results from a visual movement situation without inertia movement in VR [29]. In a study of VR, approximately 60% of participants reported symptoms of weakness, dizziness, nausea, and headache after 20 min or more of VR. These symptoms resolve within 5 h after VR [30]. Thus, in this study, participants were asked about symptoms such as discomfort, fatigue, headache, dizziness, vertigo, sweating, nausea, and blurred vision after the VR tests. However, several studies have shown that VR tests have high validity and are acceptable even in patients with neurological disorders at higher risk for cyber disease [31,32].

Finally, the research findings into virtual reality suggest that it is useful if it is presented under ideal conditions. The tasks presented in the VR environment should be prepared at different levels of difficulty and intensity considering the differences in the individuals' tolerance levels. However, the studies highlight the need for more information about the relationship between virtual reality and the effects of balance performance.

5. Conclusions

In conclusion, our results explain the effect of additional visual attention tasks on the motor and sensory responses in maintaining dynamic balance changes by using a virtual reality environment simultaneously in healthy young adults. The adaptation process slows when balance performance decreases with visual attention tasks in a virtual reality environment. In the motor response of the balance and adaptation processes, additional auditory attention tasks have a positive effect and accelerate the adaptation process, but there is no significant effect on the sensory response of balance. Thus, future studies should examine the postural control system of patients with vestibular problems under conditions of virtual reality of dual-tasks to detect the effects of balance. Although there have been studies in VR, more researches are needed especially about the effects of long time exposure the VR conditions on vestibular and cognitive systems.

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Declaration of competing interest

All authors declare that they have no conflicts of interest.

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