

Vestibular Exercises Combined with Table Tennis Exercises May Yield More Effective Outcomes: A Preliminary Randomized Study

 Kerem Ersin¹,  Cem Yeral²,  Serkan Eti¹,  Mustafa Bülent Şerbetçioğlu²

¹Istanbul Medipol University Vocational School, Department of Audiology, İstanbul, Türkiye

²Istanbul Medipol University Faculty of Health Sciences, Department of Audiology, İstanbul, Türkiye

Cite this article as: Ersin K, Yeral C, Eti S, Şerbetçioğlu MB. Vestibular exercises combined with table tennis exercises may yield more effective outcomes: a preliminary randomized study. J Acad Res Med. 2025;15(2):64-70

ABSTRACT

Objective: Conventional vestibular exercises (CVE) for patients with dizziness are sometimes not beneficial enough for the patients. It is thought that table tennis exercises may be beneficial in these patients, especially to improve the vestibular system and posture. The objective of our original study was to assess the vestibular exercises combined with table tennis exercises that can be done comfortably at home, are fun and cost-effective method on body posture.

Methods: In this preliminary study, healthy subjects with balance scores close to normal were recruited. CVE (n=36) and conventional vestibular exercises combined with table tennis (CVE-TT) (n=36) program was performed on two different groups for a 6-weeks. Individuals were evaluated with Sensory Organization Test pre and post the study.

Results: In the CVE-TT group, a statistically significant difference was found between Strategy 5-6, composite (COM) and vestibular (VEST) data scores before and after the study ($p<0.05$). There was a statistically significant difference between Strategy 6 and preference (PREF) data scores in the CVE group in the pre-post comparison ($p<0.05$), while there was a non-significant decrease in the CVE-TT group.

Conclusion: The findings demonstrate that the CVE-TT exercise programme leads to a more significant enhancement in balance performance when compared with CVE exercises. For individuals with dizziness (e.g., residual dizziness) it will be more efficient and entertaining to apply this new method that they can apply at home instead of the classical rehabilitation program.

Keywords: Balance, computerized dynamic posturography, table tennis, vestibular rehabilitation

INTRODUCTION

Balance is essential for many activities of daily living and balance problems (e.g., falls) are major public health problem. To prevent falls, individuals must control their center of mass location over the base of support during both voluntary movements, and in response to external, destabilizing forces (1). Postural stability is achieved by integrating vestibular, visual and somatosensory inputs to produce a motor response (2). The vestibular system plays various roles in postural control. The role it plays in the postural task varies according to the nature of the task and environmental conditions. Similarly, in situations where somatosensory information is less available and visual information is not available in the moment, vestibular information may play a dominant role in maintaining postural control (3).

Vestibular rehabilitation exercises improve quality of life by reducing the degree of handicap, improving the ability to perform daily tasks, and providing long-term postural stability. Rehabilitation programs offer a variety of benefits, including improvements in overall health and balance, a safer gait, and reduced disability due to dizziness (4). Rehabilitation strategies have been applied successfully in the last few decades to initiate central compensation of the tonus imbalance and facilitate substitution in different types of peripheral vestibular dysfunction (5).

Table tennis is an Olympic sports branch and one of the most widely played racquet sports. It requires complex visuospatial perception and movements, including balance control. Table tennis players have been shown to have shorter visual reaction

ORCID IDs of the authors: K.E. 0000-0002-9666-7867; C.Y. 0000-0003-2885-1483; S.E. 0000-0002-4791-4091; M.B.Ş. 0000-0002-5985-097X

Corresponding Author: Cem Yeral MSc;

E-mail: cem.yeral@gmail.com

Received Date: 06.12.2024 **Accepted Date:** 26.05.2025

Epub: 02.07.2025

Publication Date: 08.08.2025



Copyright© 2025 The Author. Published by Galenos Publishing House on behalf of University of Health Sciences Türkiye Gaziosmanpaşa Training and Research Hospital. This is an open access article under the Creative Commons AttributionNonCommercial 4.0 International (CC BY-NC 4.0) License.

times, better executive functions and visuospatial working memory than healthy individuals (6). Recreational table tennis has been associated with improved bone health, physical function and muscle strength. Positive cognitive effects of table tennis training have also been demonstrated (7).

Christensen et al. (8) demonstrated that a 6-week vestibular exercise program improved vestibular function on healthy adolescents. Cone et al. (1) demonstrated in their study, which included 40 healthy young, that a 6-week Wii Fit training improved dynamic balance. These studies are rare studies with normal individuals. To our knowledge, there are no studies on the effect of vestibular exercises combined with table tennis on balance.

There are studies in literature showing the effect of sports on balance (9). However, despite the results of these studies, there are very few studies in which these sports are added to balance exercises. In this study, we studied table tennis, a sport that has not been added to balance exercises before. Since table tennis has a fun aspect as well as positive effects on multisensory systems, we hypothesized that combining it with CVE would yield better results. Our study has a unique value in this respect.

METHODS

Study Population

The study was conducted between March 2023 and April 2023 on healthy individuals aged 18-21 years. The study was explained to each participant, and written informed consent was obtained. All described procedures were conducted following the Declaration of Helsinki. Ethical approval was obtained from the Non-Invasive Clinical Research Ethics Committee of İstanbul Medipol University Non-Interventional Clinical Research Ethics Committee Presidency University with the decision no: 380 and date: 27.06.2018.

Nineteen female and nineteen male individuals (ages: 20.4 ± 1.3 years) were included in the CVE group. Twenty female and sixteen male individuals (ages: 20.2 ± 1.1 years) were included in the study group (F. The individuals did not have any major illness (otologic or neurologic pathology) and/or extensive experience in physical exercises. None of the test subjects were diagnosed with balance disorders, and none of them needed glasses, contact lenses, or hearing aids.

Sample Size and Randomization

Power analysis was performed using G*Power to ascertain whether the sample size would sufficiently detect significant differences. The power analysis revealed a power of 90% with an effect size of 0.50 (large) at a significance level of 0.05, indicating that a sample size of 36 (10). However, since we have two groups, the minimum sample size is calculated as $36 \times 2 = 72$. The effect size equals 0.5 according to Effect size index d_z . After this, we randomly assigned a total of 40 patients to the CVE group and 40 patients to the CVE-TT group. A total of 6 people (4 in the CVE group and 2 in the CVE-TT group) dropped out of the study for personal reasons (Figure 1).

Balance Training Program

The exercise program of both groups consisted of three phases. Each phase of the exercise program was performed twice a week for six weeks. Exercises of both groups are shown in Tables 1 and 2. The exercises of the CVE-TT group are demonstrated in Figure 2. In this study, two cushions, one small ball, one table tennis racket and ball, one balance board, one pilates ball and two pilates mats were used. Balance status of the individuals was evaluated with CDP pre and post the study.

Measurements of Postural Control

A NeuroCom Balance Manager (Natus Medical Inc., Seattle, WA) was used to assess postural stability. Sensory Organization Test (SOT), which are subtest of Computerized Dynamic Posturography (CDP), was performed to objectively assess postural stability. This test is used to assess the individual's use of somatosensory, visual, and vestibular input to maintain balance.

Participants were secured in a safety harness and positioned barefoot on the NeuroCom Balance Manager, with their foot placement standardized relative to their height. Data collectors followed standardized written instructions for the SOT protocol, including verbal cues for each trial of each condition. Individuals stood with arms relaxed at their sides, looking straight ahead as still as possible. Participants performed all six SOT conditions, repeating each 20-second trial three times. The individual is presented with six conditions of varying sensory input including eyes open with fixed support (Condition 1), eyes closed with fixed support (Condition 2), sway surround with fixed support (Condition 3), eyes open with sway support (Condition 4), eyes closed with sway support (Condition 5), and sway surround with sway support (Condition 6). In this way, different SOT conditions create sensory discrepancies. The systems (somatosensory, visual and vestibular) that the patient actively uses while maintaining balance, the overall balance score (composite) and the preference for the visual system while maintaining balance are shown at the

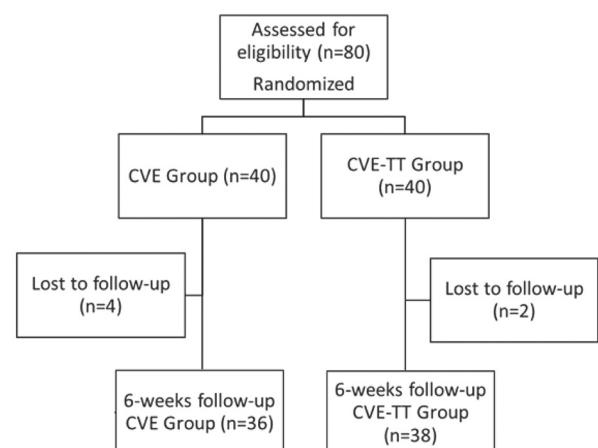


Figure 1. Participants at each stage of the trial
CVE-TT: Conventional vestibular exercises combined with table tennis

Table 1. Conventional vestibular exercises program**EXERCISE PROGRAM 1 (1st-2nd week)**

1. Walking back and forth on the soft surface (e.g. cushion, mat) with eyes closed.
2. Standing on one foot on firm surface.
3. Standing on a cushion, with eyes closed, and sitting down standing up continuously.
4. Shaking the head while standing on firm surface with gaze fixation (Rotates the head side to side horizontally with gaze fixed on a stationary target. Side-to-side head movement of w60 at a speed of 90/s, 1.5 hz).
5. Shaking the hand while standing on firm surface with gaze fixation (Extends one arm forward and make the thumb-target-up and turn the arm side to side while focusing on the thumb. Keep the head still and moves only the eyes).

EXERCISE PROGRAM 2 (3rd-4th week)

1. March in place with eyes closed.
2. Standing on the balance board with eyes open.
3. Shaking the head while standing on the soft surface (e.g. cushion, mat) with eyes closed.
4. Standing on the mat with one leg with hands on waist and eyes closed.
5. Walking back and forth on a soft surface (e.g. cushion, mat) with gaze fixation.

EXERCISE PROGRAM 3 (5th-6th week)

1. Walking to the right and left with sharp or wide turns with eye closed.
2. Standing on the balance board with eyes closed.
3. Shaking the head while walking back and forth on the soft surface (e.g. cushion, mat) with gaze fixation (Rotates the head side to side horizontally with gaze fixed on a stationary target. Side-to-side head movement of w60 at a speed of 90/s, 1.5hz).
4. Shaking the head while standing on a soft surface (e.g. cushion, mat) with eyes closed.
5. Shaking the head while sitting on a pilates ball on a soft surface (e.g. cushion, mat) with eyes closed

Table 2. Conventional vestibular exercises combined with table tennis exercises program**EXERCISE PROGRAM 1 (1st-2nd week)**

1. Walking back and forth on the soft surface (e.g. cushion, mat) with eyes closed.
2. Standing on a firm surface on a one leg.
3. Standing on a cushion, with eyes closed, and sitting down standing up continuously.
4. Shaking the head while standing on firm surface, (Rotates the head side to side horizontally with gaze fixed on a stationary target. Side-to-side head movement of w60 at a speed of 90/s, 1.5 hz).
5. Table tennis ball bounce with table tennis racket.

EXERCISE PROGRAM 2 (3rd-4th week)

1. March in place with eyes closed.
2. Standing on the balance board with eyes open.
3. Shaking the head while standing on the soft surface (e.g. cushion, mat) with eyes closed.
4. Standing on the mat with one leg with hands on waist and eyes closed.
5. Playing table tennis between a table and a wall (see picture).
6. Controlling the ball on the racket and walking without bouncing it.

EXERCISE PROGRAM 3 (5th-6th week)

1. Walking to the right and left with sharp or wide turns with eye closed.
2. Standing on the balance board with eyes closed.
3. Shaking the head horizontally with gaze fixation on a stationary target while walking back and forth on the soft surface (e.g. cushion, mat) (Side-to-side head movement of w60 at a speed of 90/s, 1.5 hz).
4. Shaking the head while standing on a soft surface (e.g. cushion, mat) with eyes closed.
5. Bouncing the ball between the racket and the table (see the picture).
6. Bouncing a ball with a racket against the wall (without using the table) (see the picture).

end of the test. Participants must compensate for these sensory discrepancies and maintain their balance. Each person completed the tests as shown in Figure 3.

A balance score is obtained based on staying within 8.5 degrees in the anterior direction and 4 degrees in the posterior direction, previously determined on the SOT and measured by the automatic device. Less postural sway indicates better postural stability in the sagittal plane and produces a proportional balance score (greater is better). If the participant falls or gets a negative value by swaying out of a total of 12.5 degrees, they receive 0 balance points for that trial. More difficult conditions (3-6) receive larger weights and an overall COM score uses a weighted average of all scores. A higher COM score indicates better postural control. Specific sensory systems are identified using ratio combinations of the average balance scores for each condition. Postural strategy scores are determined between 0-and 100, with 0 indicating the usage of only hip strategy, while 100 indicates the usage of sole ankle strategy. The better one maintains balance (i.e., the less sway), the more ankle is used.



Figure 2. Table tennis exercises samples. A) Bouncing the ball between the racket and the table (CVE-TT/3rd Exercise Program/5th exercise). B) bouncing a ball with a racket against the wall (without using the table) (CVE-TT/3rd Exercise Program/6th exercise). C) Controlling the ball on the racket and walking without bouncing it (CVE-TT/2nd Exercise Program/6th exercise). D) Playing table tennis between a table and a wall (CVE-TT/2nd Exercise Program/5th exercise)

CVE-TT: Conventional vestibular exercises combined with table tennis

Statistical Analysis

Statistical analysis was performed using SPSS IBM 22.0 program. The normal distribution of the values was assessed using the One-Sample Kolmogorov-Smirnov test. The descriptive statistics are reported as mean and standard deviation for normally distributed variables and median and interquartile ranges for non-normally distributed variables. Paired Student's t-test was used to determine whether there was a significant difference between the groups for normal distribution, otherwise Wilcoxon test is used. The significance value was taken as 0.05 (8). A randomized Two-Group Pretest-Posttest Design was performed. Mann-Whitney U test was performed to see that the pre-exercise values of the CVE group and CVE-TT group were similar. Wilcoxon test was used to investigate whether there was a significant difference between the CVE and CVE-TT groups for the pre- and post-study groups.

RESULTS

In the CVE-TT, a statistically significant difference was found between Strategy 5, Strategy 6, COM and VEST data scores pre and post the study ($p < 0.05$, $p < 0.01$). No significant difference was found in Strategy 1, Strategy 2, Strategy 3, Strategy 4, somatosensorial (SOM), visual (VIS) and PREF data scores pre- and post the study ($p > 0.05$) (Table 3, Figure 4).

In the CVE, a statistically significant difference was found between Strategy 6 and PREF data scores pre and post the study ($p < 0.05$). No significant difference was found in Strategy 1, Strategy 2, Strategy 3, Strategy 4, Strategy 5, COM, SOM, VIS, and VEST data scores pre and post the study ($p > 0.05$) (Table 3).

Post study results between CVE and CVE-TT were compared, a statistically significant difference was found between Strategy 4 scores of CVE and CVE-TT post study ($p < 0.05$). Although the post study scores of CVE-TT were higher than those of CVE, no significant difference was found in the post-study Strategy 1, Strategy 2, Strategy 3, Strategy 5, Strategy 6, COM, SOM, VIS, PREF and VEST scores of CVE and CVE-TT ($p > 0.05$) (Table 3).

DISCUSSION

Vestibular, visual, and somatosensory systems provide information to the central nervous system (CNS) to orient the body relative to itself and the external environment. This information is highly integrated into multiple CNS levels, allowing the system to modify the output based on the reliability of the input received (11). Preliminary researches have demonstrated that vestibular rehabilitation positively affects cognitive skills, especially for patients with central disorders (12). In the study of Schaefer and Scornaieni (13) it was seen that playing table tennis for a long time provides cognitive benefits. Because of these results, we thought that table tennis might also be cognitively beneficial in vestibular rehabilitation. The increase of COM data in our study may be associated with this hypothesis.

Table 3. Comparison between conventional vestibular exercises group and conventional vestibular exercises with table tennis exercises group of vestibular data and composite data in sensory organization test sensory analysis

Mean				p-value			
	CG Pre-exercise	CG Post-exercise	TG Pre-exercise	TG Post-exercise	Pairwise pre- and post- exercise of CG	Pairwise pre-and post- exercise of TG	Pairwise post- exercise of CG and TG
COM					0.340	0.004**	0.096
Mean±SD	78±3.74	79.50±4.74	77.80±5.89	84.28±5.41			
SOM					0.893	0.224	0.815
Median (IQR)	97 (1.91)	96 (2.32)	95 (3.40)	100 (3.40)			
VIS					0.917	0.204	0.102
Median (IQR)	71 (10.39)	86 (14.35)	80 (10.00)	93 (7.50)			
PREF					0.028*	0.821	0.710
Median (IQR)	93 (6.90)	100 (6.52)	94 (10.85)	98 (11.40)			
VEST					0.249	0.003**	0.066
Mean±SD	68.79±9.14	72.06±8.39	70.68±9.37	81.45±8.63			
Strategy I					0.705	0.113	0.182
Median (IQR)	93 (3.00)	92 (3.12)	91 (3.10)	97 (1.00)			
Strategy II					0.140	0.968	0.053
Median (IQR)	93 (2.50)	90 (2.60)	93 (2.50)	98 (2.10)			
Strategy III					0.892	0.588	0.349
Median (IQR)	93 (4.25)	91 (2.75)	90 (2.95)	95 (2.55)			
Strategy IV					0.104	0.465	0.046*
Median (IQR)	89 (2.37)	85 (6.05)	87 (5.60)	94 (4.10)			
Strategy V					0.893	0.023*	0.085
Median (IQR)	77 (12.62)	79 (10.82)	77 (8.80)	85 (7.70)			
Strategy VI					0.028*	0.008**	0.540
Median (IQR)	78 (9.00)	84 (7.80)	77 (8.75)	88 (8.80)			

*p<0.05; **p<0.01, CG: Conventional vestibular exercises group, COM: Composite data, IQR: Interquartile range, PREF: Preference data, SD: Standard deviation, SOM: Somatosensorial data, TG: Conventional vestibular exercises combined with table tennis group, VEST: Vestibular data, VIS: Visual data

In the 1940s, Cawthorne-Cooksey's early studies in vestibular rehabilitation revealed that physical exercise positively affected balance function. However, the repetition of the study and the patients' boredom during these studies led the academicians to develop other various exercises. We thought that table tennis exercises, which can be done comfortably at home, are fun and cost-effective, could be the solution. It has been thought that table tennis is a beneficial sport for balance, mainly because of its quick response to sudden reactions and the requirement of rapid eye follow-up, directing the eye to ball-tracking instead of the task of balance control, thus increasing the effectiveness of the vestibular system in maintaining balance.

In this study, there was an increase in vestibular data due to our use of CVE-TT. Our main theme is to design CVE-TT for those whose balances did not develop sufficiently only through vestibular rehabilitation exercises. In addition to the development of the vestibular system, the increase in the results of the SOT strategy score for fifth and sixth conditions indicates that the person uses the ankle strategy better while balancing and has been effective

in decreasing the oscillation of the person, and this showed that when vestibular exercises are used in combination with table tennis, it is associated with less oscillation as the vestibular system develops in difficult balance conditions.

While there was a significant difference in VEST and COM values in the study group, COM and VEST values increased in the group where only vestibular exercises were performed, but this increase was not statistically significant. This shows that CVE-TT significantly improve the vestibular system and posture control. In the CVE group, the increase in PREF data showed an increased dependence on the visual system, and this shows that in the absence of table tennis, trust in the visual system comes to the fore rather than the vestibular system.

There was a significant increase in PREF values in the CVE group in the pre-post comparison, while there was a decrease in the CVE-TT group. The reason for this is that the PREF data is to rely on eye information. In other words, we increased confidence in the vestibular system and decreased eye dependence in line with the CVE-TT exercises we performed.

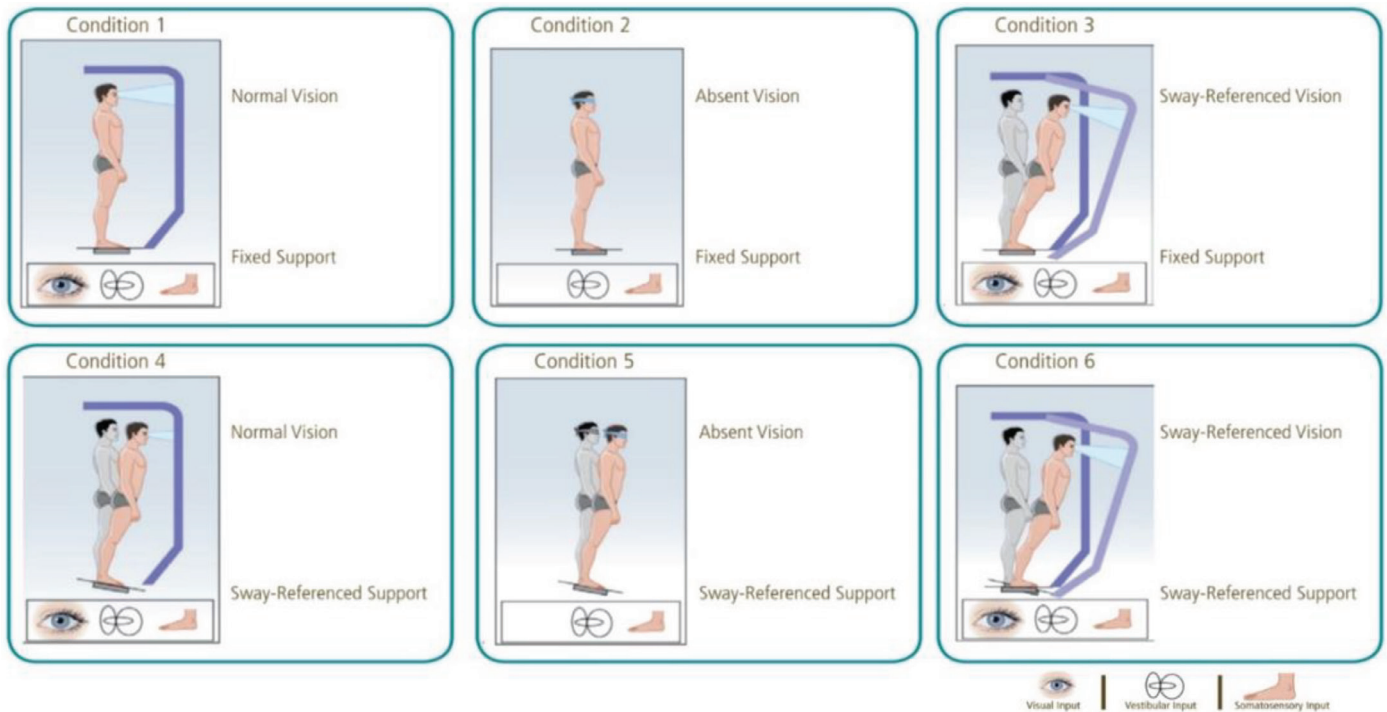


Figure 3. Sensory organization test conditions

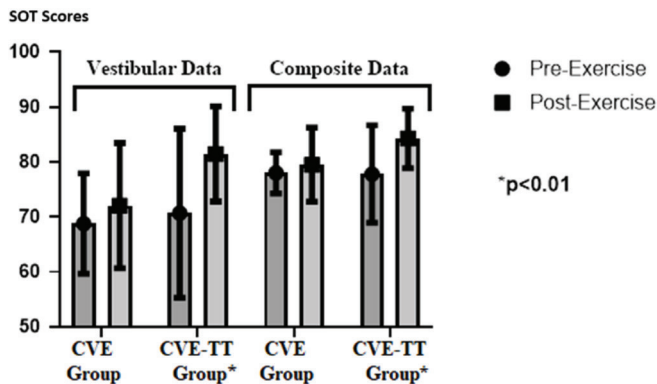


Figure 4. Comparison between CVE group and CVE-TT group of vestibular data and composite data in sensory organization test sensory analysis

Tekin Dal et al (14). compared the effects of activity-based home program and Cawthorne Cooksey exercises in 75 patients aged 18-65 years with chronic unilateral peripheral vestibular disorders. They found a statistically significant improvement in Strategy 5, Strategy 6 and composite data scores in the activity group compared to the exercise group (15). In our study, we found a statistically significant difference between pre- and post-study Strategy 5-6, COM and VEST data scores in the CVE-TT group. Although the two studies have similar and different aspects, the advantages of activity-based programs that can be applied at home have emerged. In our study, unlike the study of Tekin Dal et al. (14) table tennis was applied as the main component of the program.

In their study on adolescents, Christensen et al. (8) showed that a 6-week vestibular exercise program improved vestibular function. While the VEST data improved significantly in the group in which CVE-TT were applied, the difference was not statistically significant in the group where only CVE were applied, and this has shown that table tennis exercises can be a helpful method for the development of the vestibular system of individuals.

Rogge et al. (15) study shows that balance training leads to neuroplasticity in brain regions associated with visual and vestibular self-motion perception. Because these regions (especially the hippocampus) are known for their role in spatial orientation and memory, stimulating visual-vestibular pathways during self-movement can mediate the beneficial effects of physical exercise on cognition (15). Therefore, since table tennis and balance exercises stimulate visual-vestibular pathways, it is predicted that the patient's balance would benefit from this interaction. Elite expert table tennis players show stronger cortico-cortical communication between right-temporal and premotor areas than amateurs (16). In addition to these findings on coincidence anticipation performance, visuomotor reaction experiments revealed faster reaction times in table tennis players when compared to non-athletes as well as experienced tennis players (6). These results prove that table tennis activates different structures in the brain and makes the person more balanced depending on mobility. This situation supports the increase in our study's COM score.

Öztürk et al. (17) evaluated individuals with VEMP and vHIT tests in the presence of visual illusions. According to this study, an increase was observed in the VEMP amplitudes of the individuals when the visual illusion was given, and significant increases were observed in the gains of some semicircular canals. This showed that the vestibular system works more efficiently with the stimulation of the visual system. Consistent with this study, the better output of vestibular data can be explained by the inclusion of a sport such as table tennis, where visual attention is critical in vestibular rehabilitation (17).

Study Limitations

There are several limitations in this study. In this study, young adults were included as the age group. These individuals were university students. However, considering that BPPV is more common in middle and older age groups, healthy individuals in this age group could have been included.

This is a preliminary study. Thus, instead of testing a study of unknown effects on patients, we first tested it on healthy subjects so that we could see improvement even in healthy subjects whose data were within normal limits. The use of healthy subjects may not be a weakness for this study, but these results may not be reflective for a sample of people with persistent postural perceptual dizziness (PPPD) or residual dizziness (RD). Therefore, its application to these patient groups is recommended as a suggestion for further studies.

CONCLUSION

As a result, it has been shown that table tennis exercises, which are not difficult to implement, are low cost, can be played alone (against the wall or table), and will be more beneficial for general balance and vestibular system development than conventional methods. This method assumes that people who do not have a pathological condition in objective tests but still feel unbalanced (dizzy) can also develop. In this period, especially for individuals with balance problems, a rehabilitation program that they can implement at home rather than going to the clinic will be more efficient, amusing, and risk-free. We think that the rehabilitation program, will be a healthy option for individuals with subjective balance problems. For further research, it is suggested that this approach may objectively benefit patients with subjective dizziness such as PPPD or RD.

Ethics

Ethics Committee Approval: Ethical approval was obtained from the Non-Invasive Clinical Research Ethics Committee of Istanbul Medipol University Non-Interventional Clinical Research Ethics Committee Presidency University with the decision no: 380, date: 27.06.2018.

Informed Consent: The study was explained to each participant, and written informed consent was obtained.

Footnotes

Author Contributions: Concept – K.E.; Design – K.E., C.Y., M.B.Ş.; Data Collection and/or Processing – K.E., C.Y., Analysis and/or Interpretation – K.E., C.Y., S. E., M.B.Ş.; Literature Search – K.E., C.Y., S. E., M.B.Ş.; Writing – K.E., C.Y., S. E., M.B.Ş.

Conflict of Interest: The authors have no conflict of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

REFERENCES

1. Cone BL, Levy SS, Goble DJ. Wii Fit exer-game training improves sensory weighting and dynamic balance in healthy young adults. *Gait Posture*. 2015; 41: 711-5.
2. Yılmaz O, Ersin K, Öztürk ŞT, Şerbetçioğlu MB. Use of hip strategy in patients with vestibular disorder: a retrospective study. *IAAOJ*. 2023; 9: 43–54.
3. Hain TC, Helminski JO. Anatomy and physiology of the normal vestibular system. In: Susan J. Herdman, editor. *Vestibular Rehabilitation*. 3rd ed. USA: F. A. Davis Company; 2007. p. 2–18.
4. Meli A, Zimatore G, Badaracco C, De Angelis E, Tufarelli D. Vestibular rehabilitation and 6-month follow-up using objective and subjective measures. *Acta Otolaryngol*. 2006; 126: 259–66.
5. Basta D, Singbartl F, Todt I, Clarke A, Ernst A. Vestibular rehabilitation by auditory feedback in otolith disorders. *Gait Posture*. 2008; 28: 397–404.
6. Hülndünker T, Ostermann M, Mierau A. The speed of neural visual motion perception and processing determines the visuomotor reaction time of young elite table tennis athletes. *Front Behav Neurosci*. 2019; 13: 165.
7. Olsson K, Franzén E, Johansson A. A pilot study of the feasibility and effects of table tennis training in parkinson disease. *Arch Rehabil Res Clin Transl*. 2020; 2: 100064.
8. Christensen IK, Sakthivel S, Paiwand GS, Devantier L, Ovesen T. Impact of a six weeks training program on postural stability in adolescents. *Hearing Balance Commun*. 2019; 18: 199–203.
9. Yılmaz O, Ersin K, Öztürk ŞT, Yasak I, Yavuz A, Şerbetçioğlu MB. Theeffect of sport on balance functions. *Ovidius University Annals, Series Physical Education and Sport/Science, Movement and Health*. 2018; 18: 197–202.
10. Ersin K, Gürlek E, Güler H, Kalaycı Ertugay Ç, Şerbetçioğlu MB. Appropriate image selection with virtual reality in vestibular rehabilitation: cross-sectional study. *JMIR Serious Games*. 2023; 11: e40806.
11. MacKinnon CD. Sensorimotor anatomy of gait, balance, and falls. *Handb Clin Neurol*. 2018; 159: 3–26.
12. Hall CD, Herdman SJ, Whitney SL, Cass SP, Clendaniel RA, Fife TD, et al. Vestibular rehabilitation for peripheral vestibular hypofunction: an evidence-based clinical practice guideline: from the american physical therapy association neurology section. *J Neurol Phys Ther*. 2016; 40: 124–55.
13. Schaefer S, Scornaienzi D. Table Tennis experts outperform novices in a demanding cognitive-motor dual-task situation. *J Mot Behav*. 2020; 52: 204–13.
14. Tekin Dal B, Bumin G, Aksoy S, Günaydın RÖ. Comparison of activity-based home program and Cawthorne-Cooksey exercises in patients with chronic unilateral peripheral vestibular disorders. *Arch Phys Med Rehabil*. 2021; 102 :1300–7.
15. Rogge AK, Röder B, Zech A, Hötting K. Exercise-induced neuroplasticity: Balance training increases cortical thickness in visual and vestibular cortical regions. *Neuroimage*. 2018; 179: 471–9.
16. Wolf S, Brölz E, Keune PM, Wesa B, Hautzinger M, Birbaumer N, et al. Motor skill failure or flow-experience? functional brain asymmetry and brain connectivity in elite and amateur table tennis players. *Biol Psychol*. 2015; 105: 95–105.
17. Öztürk ŞT, Şerbetçioğlu MB, Ersin K, Yılmaz O. The impact of optical illusions on the vestibular system. *J Audiol Otol*. 2021; 25: 152–8.