Research Article

Otolith Function in Young Skilled Football Players

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Short running title: Otolith Function in Young Skilled Football…

Highlights:

- Young skilled football players have stronger vestibular reflexes
- The leg-dominance of the players may influence the strength of vestibular reflexes
- The difference is evident in the peak-peak amplitude of cervical and ocular VEMP

ABSTRACT

Background and Aim: Regular physical activities, including sports, are associated with improved balance function. The objectives of our study were to conduct cervical Vestibular Evoked Myogenic Potentials (cVEMPs) and ocular VEMPs (oVEMPs) in young adult football players and to compare the test results with those who are not involved in regular physical activities as the control group.

Methods: We recruited 11 young football players (9 right-leg and two left-leg dominant) who have been playing football regularly since childhood and have participated in inter-school or college/university-level football tournaments. The age-matched control group consisted of 11 healthy participants not involved in any physical activities regularly or as a hobby. Participants in both groups underwent cVEMP and oVEMP tests in both ears.

Results: The peak-to-peak amplitude of both cVEMP and oVEMP were higher in football players than in the control group. The amplitude for left ear stimulation was higher than the right ear for both cVEMP and oVEMP in football players and it reached statistical significance for oVEMP in left ear stimulation ($p<0.05$). The n10 latency of oVEMP in both right and left ear stimulations and the p13 latency of cVEMP in left ear stimulation was significantly shorter in football players compared to the control group ($p<0.05$).

Conclusion: Regular football players have stronger vestibule-collic and translational Vestibulo-Ocular Reflexes (t-VOR). The reflex strength, measured as the higher peak-to-peak amplitude of VEMPs, might also be influenced by factors like leg/eye dominance.

Keywords: Vestibular function; football; adults; vestibular evoked myogenic potentials; balance function

Introduction

Athletes and sports persons must maintain their body posture and balance efficiently to execute targeted actions. It is achieved with the help of visual, proprioceptive, and vestibular systems inputs to the brainstem, cerebrum, and cerebellum, as well as their interconnections, including feedback networks [1]. The eyes are the sensors of visual system providing inputs related to movements that appear in the visual field, surrounding environment and body posture [2]. The inner ear, sensor of hearing-balance system, senses the movement and head location in three dimensions. Proprioceptors are essential in the stability of the joints and in maintaining equilibrium [3]. Hence, posture and balance are impacted by numerous internal and external elements due to the intricacy of balance.

Regular physical activity enhances balance control at rest and when combating physical fatigue [4]. Previous studies have shown better postural control in athletes, gymnastics, and other individual sports [5]. The balance system of football players undergoes regular exposure to challenges to stabilise and improve postural control against gravity. Skilled football players improve their internal representation of an upright posture and learn to switch the sensorimotor dominance from one to another with practice [6]. In addition, they develop higher sensory thresholds, better feedforward control, less reliance on attention, and increased autonomy [7].

Regular physical exercise, and sports can enhance dynamic posture control by improving vestibular sensitivity and reducing the influence of visual cues when conflicting [8]. Football players exhibit sudden short-fast for dribbling and constant gaze to track the ball during the game. This involves generating compensatory body and eye movements to maintain posture and gaze. Hence, among football players, Vestibule-Spinal/Collic Reflex (VSR/VCR) will undergo extensive training to coordinate the body and neck movement. Similarly, the players must constantly track the football under static and dynamic conditions to play efficiently. Hence, the translational Vestibule-Ocular Reflex (t-VOR) reflex pathway will also undergo extensive training to coordinate eye and head movement.

Previous studies focused on behavioral tests to assess balance function among sportspersons [9]. Researchers have used static and dynamic posture control tests with varying emphasis on visual, proprioceptive and vestibular inputs to induce conditions [10]. However, there is dearth of knowledge about the impact of sports and physical activities on electrophysiological measures of VSR/t-VOR. In addition, the effect of right-leg and left-leg dominance on balance and postural measures or vestibular reflexes are not explored among football players.

Vestibular Evoked Myogenic Potentials (VEMPs), a non-invasive technique with exceptional repeatability and reliability, are used to objectively assess the otoliths in both adults and children [11]. The cervical VEMP (cVEMP) assess VCR and ocular VEMP (oVEMP) assess t-VOR. Through the vestibulo-collic reflex, the ipsilateral Sternocleidomastoid Muscle (SCM) initiates the cVEMP, an inhibitory response that assesses the saccule and inferior vestibular nerve integrity [12]. Through the t-VOR, the oVEMP, an excitatory response originating from the contralateral inferior oblique muscle, assesses the utricle, and the superior vestibular nerve [13]. Hence, the current study aimed to measure such effect objectively by evaluating the strength of VSR and t-VOR function in young regular football players using cVEMP and oVEMP.

Methods

Participants

The experimental group consisted of 11 regular young football players (9 right-leg and two left-leg dominant) with a mean age (SD) of 22.9±2.4 years (18–27 years). All the subjects play football regularly since childhood and participated in inter-school or college/university-level football tournaments. None of the players reported any history of sports related concussions. The control group consisted of 11 healthy participants with normal locomotor abilities but not involved in any physical activities regularly or as a hobby. The mean age (SD) of the control group was 22.8±2.6 years (18–27 years).

Procedure

The physical activity of both groups was assessed based on a questionnaire, short-form of International Physical Activity Questionnaire (IPAQ) [14]. The short form of this questionnaire consists of 7 items (for example, playing, cycling, lifting, walking, and sitting) with open-ended questions tapping different physical activities, duration and regularity. In addition to this, details of years of football practice, participation in school/college tournaments, training and continuity in football practice, and leg dominance were also collected through direct interviews.

All participants had pure tone hearing sensitivity of ≤15 dB HL for both air conduction and bone conduction tested in audiometric room, with A/As tympanogram, present normal acoustic reflexes, otoacoustic emissions and no history of any long-term middle ear problems. The auditory nerve integrity was assessed using auditory brainstem responses (ABR) performed at 11.1/sec and 90.1/sec repetition rate using click stimulus. The ABR was conducted to rule out any subtle neural dyssynchrony for auditory processing, which might also affect VEMPs due to the involvement of the vestibular nerve [15]. All participants had normal ABR responses at both repetition rates.

The vestibular system function was assessed using cVEMP, and oVEMP by performing it independently in both stimulation ears. The VEMP recordings were done using Neurosoft, neuro-audio diagnostic auditory evoked potential equipment. The protocol used for recording cVEMPs and oVEMPs was adopted from a study by Sinha and Sahu [16].

The cVEMP was recorded by placing the non-inverting electrode on the upper one-third of the sterno cleido mastoid muscle, the inverting electrode on the sternoclavicular junction (placed ipsilaterally), and the ground electrode on the forehead. Obtained responses were filtered between 10 Hz–1500 Hz and amplified 5000 times. During the test, participants were asked to turn their heads opposite to the stimulation ear such that they were able to maintain muscle potential at an adequate level by getting visual feedback from the recording screen. The same protocol was used for all the participants.

The oVEMP was recorded by placing the non-inverting electrode 1 cm below the eye, the inverting electrode 1 cm below the non-inverting electrode, and the ground electrode on the forehead. The non-inverting and inverting electrodes were placed contralateral to the stimulus ear. Obtained responses were filtered between 1Hz–1000 Hz. obtained Electromyography (EMG) responses were amplified 30,000 times. During the test, participants were asked to look upside without moving head to a bright point placed 30˚ above eye level to maintain adequate muscle potential. For both cVEMPs and oVEMPs, a 500 Hz tone burst was presented with a stimulus as a 4 msec rise/fall time and a 0 msec plateau time at 125 dB pe SPL through insert earphones. Two hundred stimuli were presented in an alternate polarity at a repetition rate of 5.1/second.

The same protocol was used for all the participants. To ensure that the peak-to-peak amplitude difference of the VEMPs are not due to the random variations in the EMG levels, rectified amplitude was used for all amplitude-based analysis. For rectification, the recording equipment automatically performed the recording equipment automatically performed the EMG scaling procedure (for details, see [17]). However, the baseline EMG values were also noted down and reported along with the grand average waveforms.

Data analysis

In the cVEMP, the latency of the p13 peak, n23 peak, and rectified amplitude of the p13-n23 complex was measured for all the patients in both stimulation ears. For oVEMP, the latency of the n10 peak, p16 peak, and rectified amplitude of the n10-p16 complex was measured for all the participants in both stimulation ears. Descriptive statistics were done to calculate the mean and the standard deviation of the latency and the amplitude parameters of cVEMP and oVEMP. Further, the cVEMP and oVEMP amplitude asymmetry ratios were calculated. Shapiro-wilk test revealed normal distribution of data for majority (23/28, $p>0.05$) of the parameters, and hence parametric tests were performed subsequently. The comparison of latencies and amplitudes of cVEMP and oVEMP between football players and the healthy control group were done using one-way MANOVA. The between-subject analysis and pair-wise comparisons were done using Bonferroni's correction factor. One-way MANOVA was used for ear-wise comparison as well since the comparisons were made between groups. For the comparison of asymmetric ratios, an independent t-test was used. For EMG analysis, between groups and ears was done using independent t-tests and correlation analysis using Pearson's correlation test.

Results

Twenty-two subjects with normal neuro-motor abilities participated in this study, consisting of 11 football players in the experimental group and 11 individuals without regular physical activities in the control group.

Response rate of cVEMP and oVEMP.

Both cVEMP and oVEMP were present in all football players and healthy control groups, accounting for a 100% response rate of both VEMPs.

Response latencies of cervical vestibular evoked myogenic potentials and ocular cervical Vestibular Evoked Myogenic Potentials

The grand average waveform of the control group and experimental group for right ear and left ear stimulation (Figure1). The mean and standard deviation of p13 latency and n23 latency of cVEMP for football players and healthy control group (Table 1). For cVEMP, the descriptive data revealed shorter latency for p13 and n23 latencies among football players when compared to the healthy control group.

The Table 1 also depicts the mean and standard deviation of n10 latency and p16 latency of oVEMP for football players and healthy control group.

One-way MANOVA revealed a significant difference between the experimental and control groups [$F_{(6,37)}=6.71$, $p<0.01$; partial ɳ2=0.52] on cVEMP p13 latency, n23 latency, and oVEMP n1o latency, p16 latency, parameters. The pairwise comparison with the Bonferroni correction factor also confirmed the significant difference between the experimental and control groups for p13 latency ($p=0.01$) and n10 latency ($p<0.01$). However, there was no significant difference between cVEMP n23 latency [$F_{(1,42)}=2.60$, $p=0.11$ and oVEMP p16 latency [$F_{(1,42)}=3.67$, $p=0.06$].
Since we were also interested in finding out the ear-wise comparison, One-way MANOVA was conducted across experimental and control groups for each ear response separately. This revealed a significant difference between the experimental and control groups for the left ear [$F_{(6,15)}=4.20$, $p=0.01$; partial ɳ2=0.62]. Furthermore, between subject analysis revealed significant difference between cVEMP p13 latency [$F_{(1,20)}=6.57$, $p=0.01$], and oVEMP n10 latency [$F_{(1,20)}=15.8$, $p=0.01$]. The pairwise comparison with Bonferroni correction factor also confirmed the significant difference between the experimental and control groups for p13 latency ($p=0.02$) and n10 latency ($p=0.01$). However, there was no significant difference between cVEMP n23 latency [$F_{(1,20)}=2.60$, $p=0.11$], and oVEMP p16 latency [$F_{(1,20)}=3.67$, $p=0.06$]. Also, there was no significant difference between the experimental and control groups for the right ear [$F_{(6,15)}=2.16$, $p=0.10$; partial ɳ2=0.46].

Peak to peak amplitude of cervical vestibular evoked myogenic potentials and ocular vestibular evoked myogenic potentials

Figure 2 demonstrates the mean and standard deviation of the rectified peak-to-peak amplitude of cVEMP and oVEMP among football players and the control group in the right and left ears separately. For cVEMP, the descriptive data revealed larger p13-n23 peak-to-peak amplitude among football players when compared to the healthy control group. However, the ANOVA revealed no significant main effect for the group for p13-n23 peak to peak amplitude ($F_{(1,20)}=2.87$, $p=0.05$) and for ear ($F_{(1,20)}=0.11$, $p=0.91$).
For oVEMP, the descriptive data revealed larger n10-p16 peak to peak amplitude among football players when compared to healthy control group (Figure 2). ANOVA revealed significant main effect for group and ear for n10-p16 peak to peak amplitude ($F_{(1,20)}=2.58$, $p=0.04$). The n10-p16 peak to peak amplitude was higher in football players compared to control group in the left ear stimulation ($p=0.04$) but not for right ear stimulation ($p=0.08$).

Amplitude asymmetric ratio of cervical vestibular evoked myogenic potentials and ocular vestibular evoked myogenic potentials

The Figure 3 demonstrates amplitude asymmetric ratio of cVEMP and oVEMP across football players and healthy normal control group. The amplitude asymmetric ratio was higher among football players than the healthy control group for both cVEMP and oVEMP. However independent t-test revealed no significant difference between the two groups for cVEMP ($p=0.12$) and oVEMP ($p=0.42$).

Electromyography analysis

Since VEMPs amplitude in our study are corrected for EMG activity and these rectified amplitude values are used for analysis across the groups and ears. Table 2 represents the mean and standard deviation of EMG levels used for scaling during cVEMPs and oVEMPs recording in each ear separately in this study. A separate analysis was done for the EMG activity which showed no difference between ears ($p>0.05$), no correlation between EMG values and rectified amplitudes across conditions ($p>0.05$) and significantly higher value in control group than experimental ($p<0.05$, in contrast the rectified amplitude was high in experimental group). Hence all these findings suggest the difference seen in our study are unrelated to EMG activity but related to the changes in neuronal activity of VCR and t-VOR elicited by acoustic stimulus.

Discussion

The current study aimed at assessing the VCR and t-VOR strength in football players with the help of cVEMP and oVEMP tests. We hypothesised that football players likely to have better t-VOR and VCR when compared to healthy controls not involved in regular exercises.

Response rate of vestibular evoked myogenic potentials

To our knowledge, no studies in the literature compared the VEMP performance of football players with healthy control group. But researchers have used VEMPs in comparing the sports-related concussion among children and adult professional football players and found the response rate as 50–85% [18]. Hence, a 100 % response rate in this study ensured our participants had an undamaged vestibular system.

Amplitude and latency responses of vestibular evoked myogenic potentials

The peak to peak amplitude of both cVEMP and oVEMP towards higher in football players than in the control group. This difference was statistically significant for oVEMP in left ear stimulation with missing significance in right ear stimulation. The difference did not reach statistical significance for cVEMP in both ear stimulations. However, the numerical data shows a higher peak-to-peak amplitude of cVEMP in both stimulation ears.

The higher oVEMP peak to peak amplitude reflects the football practice-induced strengthening of the t-VOR reflex in football players. In this study, nine players were right-leg and right-hand dominant. These players use their right eye extensively to track the football during dynamic conditions, heading and executing targeted actions, especially in the air. The t-VOR is a contralateral pathway, and regular football practice might improve this reflex. The measured oVEMP amplitude is higher for left ear stimulation.

Similarly, the higher cVEMP peak to peak amplitude reflects the football practice-induced strengthening of the VCR (also VSR) reflex in football players. The players extensively utilise their legs to move faster, dribbling, and kick. The results in a constant shift in the centre of mass of their body during dynamic conditions. This sway needs to be compensated and the body stability has to be brought by making additional postural adjustments to maintain the body posture, avoid falling, and execute the intended action effectively. The VSR is an ipsilateral reflex generated to control the same side of the head and trunk muscles to maintain body posture. This may explain the higher VCR amplitude, which is a part of VSR, in football players.

The n10 latency of oVEMP in both right and left ear stimulations and the p13 latency of cVEMP in left ear stimulation was significantly shorter in football players compared to the control group. These findings augment the strengthening of both t-VOR and VCR reflexes in football players and indicate possible plasticity of the vestibule-saccular and vestibule-ocular pathways [19]. Researchers have found the peak-peak amplitude of VEMPs to be the most consistent indicator of physical activity-based strengthening of vestibular reflexes [20].

The result of this study is comparable with previous literature regarding sports-related improvements in balance and posture. Soccer players are noticeably more adept at balancing than people who have never played the sport since it demands a high level of body awareness and solid balancing skills [21]. Football players exhibit better postural control in bipedal and uni pedal stance tasks [22], and their postural control skill improves with higher-level higher levels of training and practice [7].

Though most sports involve inputs from proprioceptive, visual and vestibular systems, the improvement seen in vestibular reflex is consistent across studies [6]. Football game involves frequent translational and rotatory movements for ball control, fending off physical interference from an opponent or anticipatory action. This reduces the proprioceptive information as the foot contact with the ground is not fixed. So, the primary signal sources for the central nervous system are the ocular and vestibular systems. The head-turning movements are among the activities that excite the vestibular system more during sports since it is sensitive to every accelerating movement of the head [23].

Since the head-turning provides conflicting inputs from the visual system, the central nerves system may rely more on vestibular inputs during the game, and over time, the related reflexes get strengthened.

Right-footers' prevalence among football players is around 65–75% [24]. Carey et al. [24] reported that right-footers consistently use right leg to pass the ball, taking shots, dribbling and kicking. During mobilization pedal skills (like kicking a ball), the dominant leg actively produces intended movements during the game. Whereas the non-dominant leg stabilizes the body balance. Even for difficult task like force and direction control movements in timing to approach or trap ball, juggling, strength and accuracy to kick the ball are executed perfectly with stable support from the non-dominant leg to reduce the variability in accomplishing the targeted movements during football [25]. The difference between dominant and non-dominant leg performance has also been reported among dancers [26]. To maintain balance while using single leg or change in platform, dancers achieve new center of gravity sooner and towards the non-dominant leg. A similar mechanism has been postulated in soccer players as well to overcome the perturbations caused by the moving leg by anticipating the movements and making a better internal representation of the body position.

Similar to handedness and footedness, the dominant eye (eyedness) is also reported in the general population as well as among players; around 65–70% of players are right-eyed [27]. The dominant eye processing sensory information more accurately and faster [28]. Sighting dominance of one eye (mostly the right eye for right-handed individuals) is reported consistently in literature [29]. Sighting dominance is frequently encountered in football games in terms of kicking the ball, tracing the ball, and observing opponents' movements. This kind of dominance of one eye allows for rapid initiation and coordination of the two optical axes during ocular saccades, which is crucial in sports like football, where the ball moves quickly and unexpectedly during play [30].

During an aiming task (like kicking, passing the ball, or shooting in football), the fovea of the dominant eye brings the visual representation of the space, anchor points for an egocentric frame referenced to the body [31].

Such lateral dominance allows the system to avoid the disruptive effects of binocular rivalry when precise and rapid visuo-motor adjustments are required.

However, there are also reports of cross-eye-hand dominance where right-handed people show left-eye dominance [32]. Hence, detailed controlled experimental studies are called to confirm these findings and examine the postulations.

There was a trend of more amplitude asymmetry among football players compared to control group for both cVEMP and oVEMP with missing significance. This also supports the observation of this study about the stimulation of ear-specific differences in the vestibular reflex strength due to the right leg and eye dominance in football players. Since the left ear stimulation –left VCR (ipsilateral pathway) and right t-VOR (contralateral pathway) –are more robust in football players than the right ear stimulation, resulting in higher asymmetry than the control group.

The inferences of this study can easily be translated to vestibular rehabilitation by incorporating sports-related activities as a part of it, either during the sessions or as a routine habit. Football is an enthusiastic game that can be played even in a restricted space, with few people and minimal investment. This attracts it over regular exercises, which the patients might find boring over time [33]. In addition, football games involve moves that stimulate translational and rotatory movements as well as cognitive skills, which will ultimately help the patients achieve balanced goals and lead a quality life.

The missing significance of some of the parameters in this study may be attributed to the inclusion of two left-leg dominant players in the football group and the relatively small sample size. Future studies may focus on including one more group with left-leg dominant players, other tests of semicircular canal responses and central vestibular system tests and an elderly age group to explore these relationships further.

Conclusion

The study aimed to assess the vestibulo-collic and vestibulo-ocular reflexes among young, skilled football players with the help of cervical Vestibular Evoked Myogenic Potentials (cVEMP) and ocular vestibular evoked myogenic potentials tests. The results showed higher peak-to-peak amplitude of both the VEMPs among football players compared to the healthy control group. Also, latencies of p13 and n23 peaks of cVEMP were shorter in football players. The differences in strength of vestibular reflexes obtained by stimulating the right and left ear are attributed to football players' dominant leg and eye usage, selectively strengthening one side's reflexes over the other. The higher peak-to-peak amplitude of VEMPs suggests that playing football regularly strengthens the vestibular reflexes. Since the total sample size is smaller and cannot make comments on left-right foot or eye dominance conclusively, further large sample size studies are called for the consistency of these results and to investigate the possibilities of recommending sports activities as part of vestibular rehabilitation to improve vestibule-collic reflex and t-vestibulo-ocular reflexes reflexes thereby maintaining body posture and balance.

Ethical Considerations

Compliance with ethical guidelines

All procedures performed in this study were in accordance with the ethical standards of the institutional research committee (AIISH ethics committee for biobehavioral research) of All India Institute of Speech and Hearing, Mysuru, Karnataka, India (SH/EC/ARF-2/2023-2024 dated 22.09.2023). The participants were informed about the entire procedure, and informed consent was obtained from all participants.

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Authors' contributions

AB: Study design, interpretation of the results, reviewing the manuscript, statistical analysis; PT: Data collection, drafting the manuscript, interpretation of the results, statistical analysis; SA: Data collection, drafting the manuscript, interpretation of the results.

Conflict of interest

The authors declare no conflict of interest.

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Table 1. Mean and standard deviation of p13 and n23 latencies of cervical vestibular evoked myogenic potentials and n10 and p16 latencies of ocular vestibular evoked myogenic potentials in football players and healthy control group

			Mean(SD)			
	cVEMP parameters (in ms)	**Stimulation ear**	**Football players**	**Control group**	**F**	**p**
cVEMP	**p13 latency**	**Right**	13.59(1.39)	14.54(2.08)	1.25	0.27
		Left	13.88(1.09)	15.55(2.00)	5.91	0.02
	n23 latency	**Right**	22.20(1.16)	22.70(1.28)	1.38	0.25
		Left	21.72(1.11)	25.31(8.05)	2.09	0.16
oVMP	**n10 latency**	**Right**	9.96(0.61)	9.36(0.33)	7.79	0.01
		Left	9.96(0.58)	9.40(0.40)	6.92	0.01
	p16 latency	**Right**	15.39(0.90)	14.66(0.90)	2.91	0.17
		Left	15.14(0.79)	14.87(0.90)	0.56	0.46

cVEMPs; cervical vestibular evoked myogenic potentials, oVEMP; Ocular vestibular evoked myogenic potentials

Table 2. Mean and standard deviation of electromyogenic levels used for scaling during cervical vestibular evoked myogenic potentials and ocular vestibular evoked myogenic potentials recording in each ear separately

	Control group		**Football group**	
EMG levels in µV	**Right ear stimulation**	**Left ear stimulation**	**Right ear stimulation**	**Left ear stimulation**
cVEMPs	59.58±9.36	57.73±10.63	51.78±4.73	48.66±4.71
oVEMPS	4.56±1.54	4.09±0.97	6.84±3.13	6.02±3.52

EMG; electromyogenic, c; cervical, o; ocular, VEMPs; vestibular evoked myogenic potentials

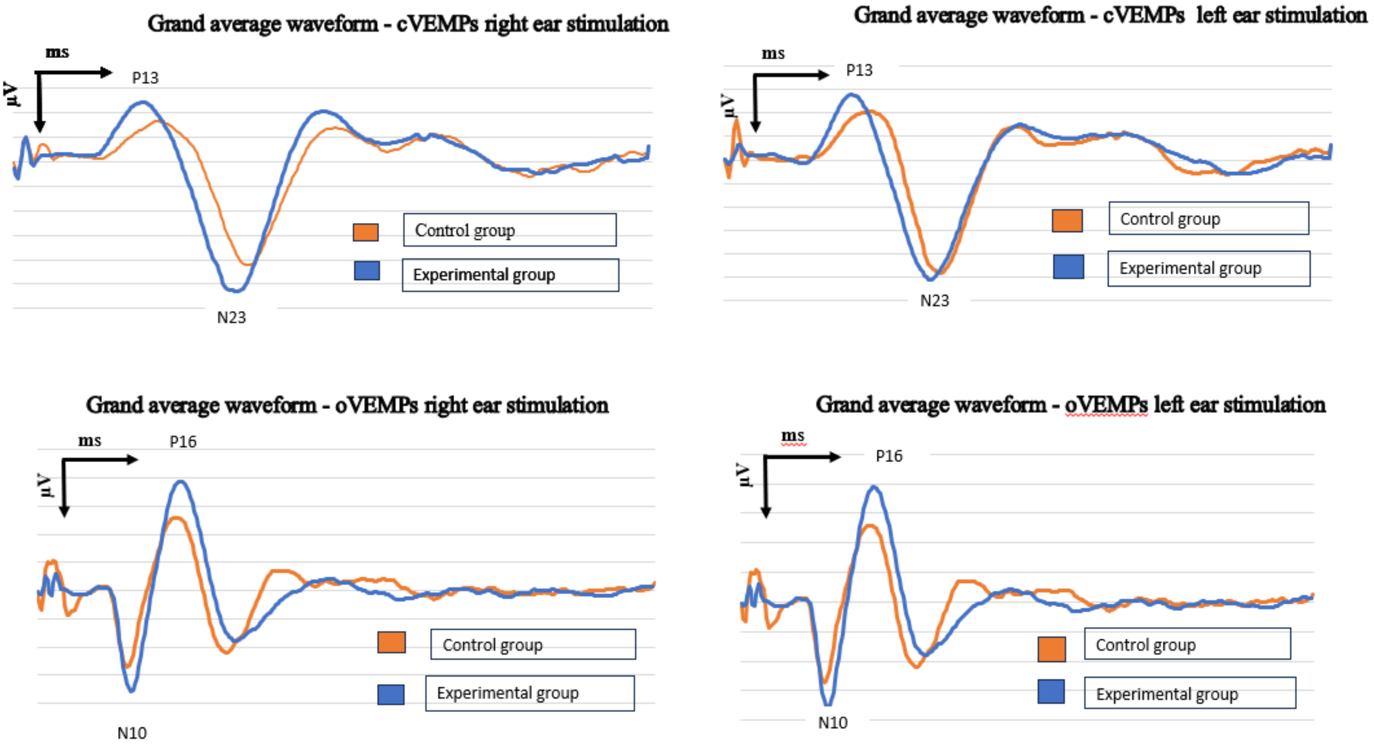

Figure 1. The grand average waveforms of cervical vestibular evoked myogenic potentials and ocular vestibular evoked myogenic potentials for both control group and experimental group. C; cervical, o; ocular; VEMP; vestibular evoked myogenic potential

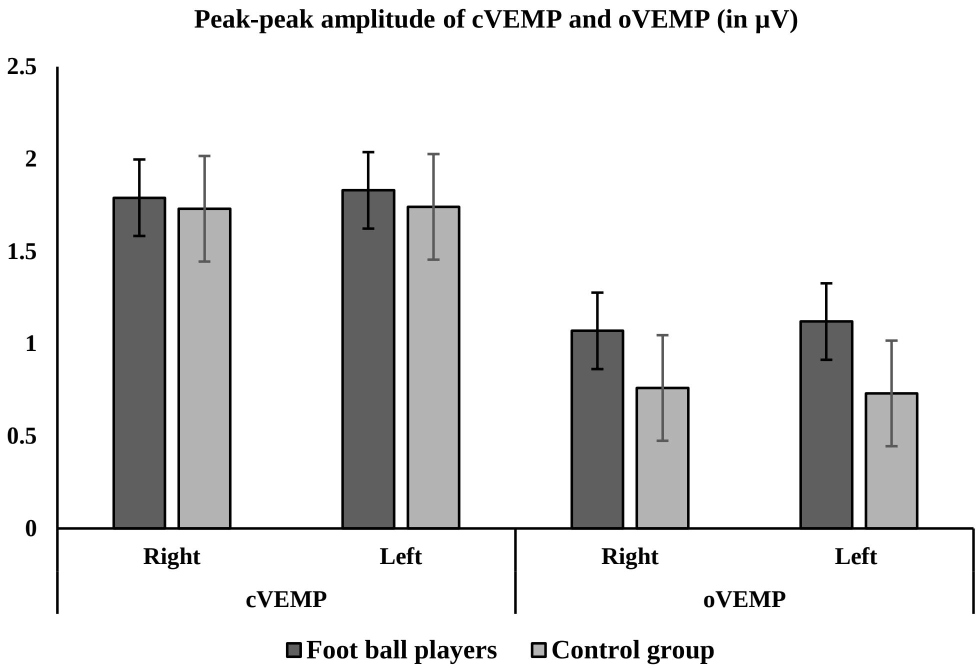

Figure 2. The peak-to-peak amplitude of cervical vestibular evoked myogenic potential and ocular vestibular evoked myogenic potential across group. c; cervical, o; ocular; VEMPs; vestibular evoked myogenic potentials

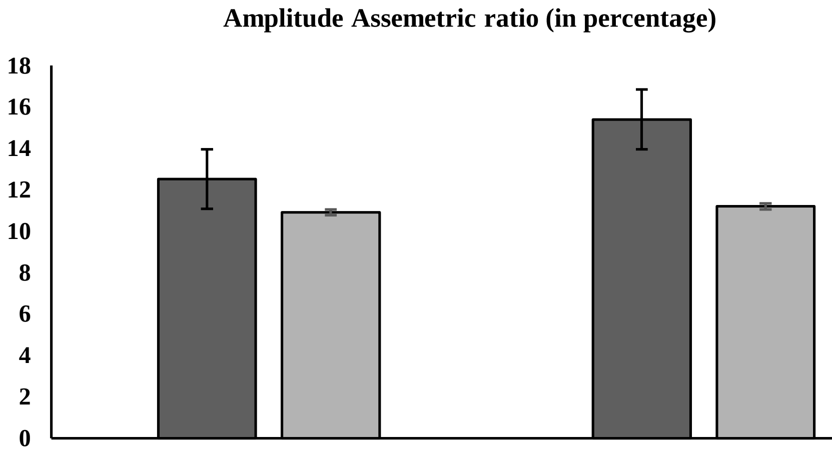

Figure 3. The amplitude asymmetric ratio of cervical vestibular evoked myogenic potential and ocular vestibular evoked myogenic potential across group. c; cervical, o; ocular; VEMPs; vestibular evoked myogenic potentials