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Original Research

Effect of Visual and Vestibular Manipulation on Plantar Pressure during Gait

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ABSTRACT

The integration of visual, vestibular, and somatosensory play a vital role in postural control. The purpose of this study was to investigate the effect of visual and vestibular manipulation on plantar pressure during gait. 15 Health women aged 20 to 30 years participated in this study. They walked in a 10-meter path in three different conditions without visual and vestibular manipulation of sense, manipulation of visual sense, and manipulation of vestibular sense. Plantar pressures variables were measured during walking and recorded by the foot pressure device. Data were analyzed by analysis of variance (ANOVA) for repeated measures. Our study showed no significant difference in center of pressure displacement in the internal-external and anterior-posterior direction among condition ($p>0.05$). The standard deviation of the center of pressure in the anterior-posterior direction was higher in the non-manipulated condition than in the visual manipulation ($p=0.001$). There was a significant difference between the conditions with manipulation visual and vestibular in medial-lateral cop velocity. The result of cop Area showed no significant difference among condition ($P> 0.05$). It seems that decreases in center of pressure velocities in subjects with a lack of visual information due to the time-consuming processing of information of the Proprioception and vestibular system, and decrease in walking speed.In the absence of information of visual system, the nervous system uses information from the vestibular system to postural control and maintain balance. Although in this study, the visual system has a more dominant role than the vestibular system in posture control. It is recommended that in the design of exercise, to enhance balance function, improvement he function of Visual-vestibular reflex should be included in the exercise program of the people.

Keywords: Visual, Vestibular, Cop, Velocity of Cop

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INTRODUCTION

Posture control for stability and orientation needs the interaction of nervous and musculoskeletal systems. The effective neural components in posture control involve sensory processes (visual, vestibular, and proprioceptive systems), motion processes (neuromuscular synergy responses), as well as cognitive effects [1]. The central nervous system is informed of the position of the body's center of gravity relative to gravity and the support surface conditions using the visual, vestibular, and proprioceptive information. Then, it activates the suitable movement response in form of pre-planned motion patterns [2]. The existence of any disorder in any of the sensory systems can result in balance disorders and enhance the possibility of falling and the risk of injury [3-4]. Due to the importance and role of each sensory system in posture control, previous studies indicated that young people use balance strategies in the absence of the vision system in posture control although vision is the dominant system in posture control. In addition, these people use proprioception to control balance in the absence of visual and vestibular information [5]. The role of sensory synergies in balance and posture control has been determined in different studies. Vision is one of the most effective senses which helps with posture control. This system sends the visual information related to understanding the body position in relation to the environment, objects, and body parts to the brain. Such information is processed by the brain and helps the spatial orientation of the body with the information obtained from the vestibular and skeletal systems [6]. Hence, the lack of visual information on understanding the body position leads to instability [7]. The vestibular system recognizes the head movement in space and presents some reflexes for orientation which are critical for our daily activities [8]. In addition, the proprioceptive system sends the location and spatial information from inside and outside of the body via the receptors of muscles, skin, and joints to the brain to control balance [9]. Disorder in any of the above-mentioned senses leaves negative effects on posture control [10]. Based on the theory of systems, researchers argue that the components and systems affecting the balance control should be studied separately [11]. Since walking is considered a complicated set of interactions between sensory and motor functions [12], the change and disorder in any of these systems can endanger the balance during walking and increase the risk of falling [13]. Berno et al. (2018) studied the effect of visual and vestibular manipulation on spatial perception during walking. Findings revealed that the simultaneous disorder in both visual and vestibular systems can affect the spatial orientation and cause more instability of posture during walking [7]. Havch et al. (2003), investigated the postural control in people with vestibular system disorder in a static position and indicated that they can have a normal height deviation in the standing position when vision and depth sensory information are sent to the nervous system without any problem. On the contrary, they had difficulty with their posture control when the visual and proprioceptive information was insufficient [14].

Liao et al. (2009) compared the static and dynamic balance performance in young, middle-aged, and elderly healthy individuals. The obtained results indicated that young adults rely on vision in order to control their postural [15]. Parisa Hejazi and Parvaneh Shamsipour Dehkordi (2015) evaluated the impact of sensory information adjustment (visual, vestibular, proprioceptive) on the static balance of individuals with below-the-knee amputation. In addition, they came to the conclusion that the balance of such individuals decreases by removing two or all three sensory information [16]. Asma Salari and Fatemeh Karimi Afshar (2019) conducted a study on the evaluation of balance recovery strategies while manipulating proprioceptive, visual, and vestibular system among the blind and healthy individuals during walking on a treadmill. The obtained findings reported that both healthy and blind groups had various mechanisms and responses for improving the balance after anterior-posterior and posterior-anterior disorders. Furthermore, the blind mostly sought to hip joint strategies to control their stability and preferred to rely on proprioceptive information to restore balance [17].

Javad Shaviklu et al. (2019) compared the efficiency of the sensory systems involved in posture control of congenitally deaf and blind people. In the absence of the visual system, blind people find the maximum dependence on the proprioceptive system [17-18]. Nevertheless, deaf people rely more on the data obtained from visual information for balance control and the proprioceptive system plays the second role in such individuals [18]. Previous studies indicated that vestibular information plays a small role in posture control during standing [19], since the sway are less than the vestibular system stimulation threshold in this position [20]. Whitney (2006) reported that the risk of falling among the patients whose vestibular system was disturbed had no not increase compared to the healthy group [21]. Another study showed that disorder in the vestibular system is one of the risk factors of falling [21]. The role of vestibular entry and its interaction with visual and sensory signs for controlling the human body posture is not well understood, and most of the studies in the field of the role of sensory systems are about static balance. In addition, few studies have evaluated the role of sensory systems during walking. In spite of the conducted studies, it is not clear to what extent the disorder in any of the vestibular and visual systems can increase the sway in COP and postural instability, and consequently increase the risk of falling? Understanding the mechanism used in balance control can help nurses develop strategies and rehabilitation techniques to improve patients' balance. Thus, this study aims to investigate the impact of visual and vestibular manipulation on plantar pressure variables and postural control in gait.

MATERIAL AND METHODS

Participants

The present study was semi-experimental and laboratory. The population included the healthy women with an age range of 20-30 years in Hamedan. The number of subjects was considered to be 15 based on the estimation of G*power software with statistical power of 0.80, effect size of 0.35, and significance level of 0.05 [22]. The demographic information of the subjects is presented in Table 1.

Table 1. . Demographic characteristics of the subjects

Number	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m2)	Navicular Drop(mm)	Domenant Leg
15	24.42± 3.4	160± 5	59±8.5	23.23±3.8	6.7±0.9	Right

Inclusion criteria were having a normal musculoskeletal system, having normal vision and hearing, and not taking the drugs affecting the central nervous system. The subjects with orthopedic abnormalities such as leg length difference (more than 5 mm), abnormal foot structure (pes planus and pes cavus) and a history of diseases like convulsions and vertigo were excluded from the study. The required information about the objective and method of the study was given to the subjects in written and oral forms to declare their readiness to participate in the study. Soccer ball shooting test was used for recognizing the dominant leg of the subjects. RSScan foot pressure device made by R-Scan Company in Belgium with dimensions of 40x100 cm, 8192 sensors, and sampling frequency of 300 Hz was used to record the plantar pressure variables. The protocol of this study was approved by the committee of Bu-Ali Sina University of Hamadan, and the code of ethics has been received under the number IR.BASU.REC.1399.030.

Procedure

The calibration of the foot pressure device was performed before data collection based on the weight of each subject. The weight and height of the subjects were measured when they referred to the laboratory and the consent form was completed by the subjects. Each subject was placed on a digital scale without shoes with minimal clothes so that the weight was equally distributed on both foot and the head and eyes were parallel to the horizon. The weight of the subjects was recorded in Newton. Then, the subjects were asked to stand straight without shoes with their back to the wall measuring device so that the weight was distributed equally on both legs, the shoulders were at the same level, and the head and eyes were parallel to the horizon. In this regard, the height of each subject was recorded in centimeters. The navicular drop test was used to determine the structure of foot and the individuals with normal foot were selected. For this reason, the subjects were asked to sit on a chair with bare feet and put their foot in a weightless position. Then, the bump of the navicular bone that was located below and in front of the inner ankle was recognized and marked. In this case, the distance between the bump of the navicular bone and floor was measured using an anthropometric ruler in millimeters. After that, the subjects were asked to stand straight and distribute their weight equally on both feet In this case, the height of the navicular bone to the floor was measured three times and recorded. The difference between the two factors was the criterion for determining the foot structure.

If the difference in the size of these two positions was 10 mm or more, the person would have pes planus foot, if it was 4-9 mm, the person would have a normal foot, and if it was less than 4 mm, the person would have pes cavus [23]. This test was repeated three times for both feet of the subjects and the mean was calculated. Before conducting the main test, the subject walked the 10-meter route several times to familiarize with the test and determine the starting state. Every subject was required to perform the task of walking in the following three conditions:

A) Reference state: In this state, no manipulation was conducted in vestibular and visual senses and the subjects kept their heads in a straight position with eyes open and then walked on a 10-meter path.

B) Visual sense manipulation: In this situation, a disturbance was created in the subjects' sense of vision by closing the eyes with a blindfold [7] and the subject walked a 10-meter path while the head was in a normal and straight position. At this stage of the test, a guide rope was placed along a10-meter path at the height of the subjects' waist to prevent them from falling [24].

C) Manipulation of the vestibular sense: In this situation, the subject caused a disorder in the vestibular sense by side-to-side head movements (left-right or right-left) [1].

In this situation, the subject walked a 10-meter path with eyes open. Appropriate walking effort involves the full impact of the foot on the middle part of the foot pressure device. If the subject’s foot was incompletely placed on the device at any stage of the test, then the subject was asked to adjust the starting point of the step and the test was repeated again. The subjects walked the 10-meter path at their select velocity, and three correct walking attempts were recorded for each subject in each situation. The rest periods between each walking attempt was regarded to be 30 seconds. Eventually, the average effort was calculated.

Posture Sway index variables were extracted in the dominant leg of the subjects. The variables included: displacement of COP in medial-lateral(M-L) and anterior-posterior(A-P), standard deviation of COP in (M-L) and (A-P)direction, velocity of COP in (M-L) and (A-P) direction, standard deviation of COP (M-L) and (A-P) direction, and total mean velocity of COP in two AP and ML directions and the Area of movement for COP (Area) during the Stance phase of gait which were calculated according to the formula in Table 2.

Data analysis

The Shapiro-Wilk test was used to check the normality of data distribution and repeated measures analysis of variance was used in three different conditions for data analysis. Bonferroni post-hoc test was used for pairwise comparison. The significance level was considered to be α=0.05. All of the analysis steps were conducted using SPSS version 24 software.

Table 2. Formula for calculation of the COP Index

Name of variable	Formula	Unit
COPx	COPx = Xmax - Xmin	**mm**
COPy	COPy = Ymax - Ymin	**mm**
SDx	SDx = $\sqrt{\frac{\sum_{i=1}^{N}(X_i-\bar{X})^2}{N-1}}$	**mm**
SDy	SDy = $\sqrt{\frac{\sum_{i=1}^{N}(Y_i-\bar{Y})^2}{N-1}}$	**mm**
Vx	Vx = $\frac{\Delta x}{\Delta t}$	**mm/s**
Vy	Vy = $\frac{\Delta y}{\Delta t}$	**mm/s**
SDvx	SDvx = $\sqrt{\frac{\sum_{i=1}^{N}(Vx_i-\bar{V})^2}{N-1}}$	**mm/s**
SDvy	SDvy = $\sqrt{\frac{\sum_{i=1}^{N}(Vy_i-\bar{V})^2}{N-1}}$	**mm/s**
TMV	$\bar{V} = \frac{1}{T}\sum_{1}^{T}\sqrt{(X_{t+1}-X_t)^2+(Y_{t+1}-Y_t)^2}$	**mm/s**
Area	$Area = 2\pi F_{0.05[2,N-2]}\sqrt{\sigma_X^2\sigma_Y^2-\sigma_{XY}^2}$	**mm2**

RESULTS

The mean and standard deviation of the center of pressure (COP) sway index among three different conditions (control, visual sense manipulation, vestibular sense manipulation) are given in Table 3.

Table 3. Mean and standard deviation of COP fluctuation indices in three different conditions

	Control	Visual	Vestibular
Cop X(mm)	26.49±8.7	30.42±6.8	28.96±7.3
Cop Y(mm)	226.39±7.6	223.93±9.5	225.70±10.4
SD Cop X(mm)	6.77±1.9	7.51±2.1	6.82±2.4
SD Cop Y(mm)	64.03±3.5 **α**	61.41±4.1	62.04±5.2
Vcop x(mm/s)	0.57±0.1	0.52±0.2	0.69±0.1 **γ**
Vcop y(mm/s)	1.1±0.3	1.1±0.2	1.2±0.2
SD Vcop x(mm/s)	0.13±0.02	0.14±0.04	0.12±0.02
SD Vcop y(mm/s)	0.22±0.05	0.20±0.04	0.23±0.05
TMV(mm/s)	0.31±0.03 **α, β**	0.26±0.04	0.29±0.04 **γ**
Area(mm^2)	5863.82±1908.4	6288.56±1426.1	5837.57±1941.6

The results of the present study indicated no significant difference in the displacement of COP in any of the three different conditions in in anterior-posterior and medial-lateral directions (P>0.05). Nevertheless, the standard deviation of COP data (A-P) direction had a significant difference between the conditions without manipulation and visual sense manipulation (P=0.001) so that the standard deviation of COP in the condition without manipulation increased by 4% compared to the condition of visual sense manipulation. However, there was no significant difference between the conditions without manipulation and vestibular sense manipulation. Furthermore, the results indicated no significant difference in the standard deviation of COP data in (M-L) direction in these three conditions (P>0.05). The findings of comparing the displacement velocity of COP in medial-lateral direction in three different conditions showed that such a velocity has a significant difference between the visual and vestibular sense manipulation conditions (P=0.010) so that the displacement velocity of COP in vestibular sense manipulation is almost 33% higher than the visual sense manipulation. In other conditions, no significant difference was found in medial-lateral direction (P>0.05). In addition, the displacement velocity of COP in anterior-posterior direction was not significant in any of the three conditions (P>0.05). The results of comparing the total mean velocity in three different conditions showed a significant difference in the total mean velocity of the displacement of COP in the conditions without manipulation and visual sense manipulation (P=0.001) so that the displacement velocity in condition without manipulation was 19% higher than the condition of visual sense manipulation. The results of comparing the conditions without manipulation and vestibular sense manipulation indicated that the total mean velocity in the condition without manipulation was 7% higher than the condition of vestibular sense manipulation. Further, the findings revealed a significant difference in comparing the total mean velocity in the conditions of manipulation of visual sense and vestibular sense (P=0.007) so that the total mean velocity in vestibular sense manipulation was about 12% higher than visual sense manipulation. Moreover, the area of movement for COP (Area) during the support phase of walking was not significantly different in any of the three different conditions (P>0.05).

DISCUSSION

Based on the systems theory, three sensory, motion, and skeletal-muscular systems attempt to maintain body stability and balance. Among such systems, the vestibular, visual and proprioceptive senses are highly considered to control balance and stability [25]. The lack of information on each of these three sensory systems affects posture fluctuations in the standing position. In this study, the fluctuation indices including the displacement of COP, standard deviation of COP displacement, displacement velocity of COP, total mean velocity, and the area of movement for COP (Area) were evaluated.

The results indicated that the displacement of COP in three conditions of without manipulation, visual sense manipulation, and vestibular manipulation were somewhat similar. Nevertheless, the standard deviation for the displacement of COP in anterior-posterior direction and the total mean speed of displacement of COP in the condition without manipulation were 4 and 19% respectively, higher than visual sense manipulation,. Jafaranjad et al. (2017) compared the displacement of COP in blind and sighted people and showed that the displacement of COP in the anterior-posterior direction is more among sighted people than the blind and this result is consistent with a part of the present results. In addition, this researcher and his colleagues reported a reduction in walking speed among the blind people [24, 26, 27]. Almost half of the normal sensory information of the brain is lost when the visual system is disturbed [28]. In the normal state and without disorder in vision system, the vestibular and proprioceptive information is processed very quickly in the nervous system as unconsciously. But, when the correct visual information is not available, the nervous system should consciously and allocate attention process the information of the vestibular and proprioceptive system to control the posture and balance. It should be noted that processing this information is conscious compared to the unconscious processing takes a lot of time and is long [29].

The walking velocity of people with visual impairment and the absence of this information reduces due to the time-consuming processing of the conscious information related to the deep sensory and vestibular system. As a result of the reduced walking velocity, the displacement velocity of COP among the people with the lack of visual information reduces more than those with a lack of vestibular information. Moreover, abnormal postural reflexes and movement patterns are created in such people, leading to abnormal distribution of muscle forces in the body, as well as postural and balance defects (Barlo, 1959; Jeon and Cha, 2013; Ross, 1977) [30, 31]. To fix this postural disorder in the body, these people reduce their speed because of the fear of falling to control their balance better. As a result, the displacement velocity of COP reduces and the balance is retained. In addition, some researchers stated that the blind have weaker neuro-muscular coordination than the healthy people and that is why such people have less displacement of COP to control better walking performance [26]. Comparing the fluctuation in two conditions of visual and vestibular sense manipulation indicated that the displacement velocity of COP in the medial-lateral direction and the total mean velocity of COP in vestibular sense manipulation were 33 and 12% more than the visual sense manipulation, respectively. In other words, the displacement velocity of COP was more than the visual sense manipulation when the vestibular sense was disturbed. Previous studies reported that postural fluctuations increase when the eyes are closed in a static state. It has been well proved that visual information is more dominant for body posture control in comparison to vestibular or proprioceptive information [30]. Any disorder in the vestibular system causes false information for reaching the cerebellum and leads to some errors in the calculations of the cerebellum to correct the voluntary movement commands of the brain. The nervous system uses information from the visual system to compensate the lack of information or false information of the vestibular system. Such information automatically and without allocate attention goes to the nervous system and the nervous system sends a message to correct the posture by quickly processing this information so that people's balance is controlled. In the absence of visual system information, the cerebellum has no enough information to create balance but applies vestibular and proprioceptive information. Furthermore, processing this information is longer than automatic information [32]. Thus, the people with vestibular disorder and lack of sufficient information for this system require less time in their own movement task to process compensatory information. In conclusion, the displacement velocity of COP in the absence of vestibular information is more than the displacement velocity of COP in the absence of visual information [33].

Farahpour and Kiyani (2015) reported that the elimination of visual inputs had a significant impact on the increase of balance irregularities so that disturbance in the visual system of all the subjects caused an increase in posture fluctuations than other systems involved in balance [34]. Friedrich et al. (2008) showed that 80% of a person's sensory perception is provided through the visual system in balance tasks in static and dynamic states. As a result, this information integrates with the information of other balance devices and provides an appropriate balance strategy [35].

The studies on people with vestibular disorders showed that the occurrence of falling in people is related to the degree of losing the vestibular sensation [36, 37]. However, the symptoms of lack of control may not be highly obvious in mild lesions [32]. Andreas et al. (2017) indicated that postural instability while shaking the head was more in patients and such result is not consistent with the results of the present study [38]. The inconsistency between the results is because the degree of the vestibular sense manipulation was not enough. The results of the present study indicated that the area of movement for COP (Area) during the support phase of walking has no significant difference in any of the three different conditions and the results were somehow similar. No study was found on the Area sway index in the manipulation conditions. For this reason, it is impossible to directly compare the results of this study with other studies.

CONCLUSION

According to the results of the present study, the vestibular system has a lesser role in controlling posture than the vision system. The nervous system applies vestibular information for postural control in the absence of visual information. However, sending false information from the vestibular system had less effect on postural sway index than sending false information from the visual system. Since the visual sense can compensate some of the errors or the lack of vestibular system information and the cerebellum performs its calculations correctly or almost correctly using visual information, but the cerebellum no longer has sufficient information by removing this information; Thus, the balance is disrupted which can be a proof for the dominance of the visual system in balance control. Hence, it is recommended to sports coaches that include the improvement of visual-vestibular reflex performance in their training program to increase balance performance.

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Institutional Review Board Statement: The protocol of this study was approved by the committee of Bu-Ali Sina University of Hamadan, and the code of ethics has been received under the number IR.BASU.REC.1399.030.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data will be available at request.

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اثر دستکاری حس بینایی و وستیبولار بر کنترل پوسچر حین راه رفتن

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چکیده:

تعامل سیستم بینایی، وستیبولار و حس عمقی نقش بسیار مهمی در کنترل پوسچر افراد دارد. هدف از این مطالعه بررسی تأثیر دستکاری بینایی و وستیبولار بر متغیرهای فشارکف پایی در حین راه رفتن بود. ۱۵ زن سالم ۲۰ تا ۳۰ سال شهر همدان ، در مطالعه حاضر شرکت نمودند. آزمودنی‌ها در یک مسیر ۱۰ متری، در سه شرایط مختلف بدون دستکاری حس بینایی و وستیبولار، دستکاری حس بینایی، و دستکاری حس وستیبولار راه رفتند. متغیرهای فشار کف پایی در حین راه رفتن توسط دستگاه فوت پرشر اندازه گیری و ثبت شد. از آزمون تحلیل واریانس با اندازه‌های تکراری برای تجزیه و تحلیل استفاده شد($\alpha=۰/۰۵$).نتایج پژوهش حاضر نشان داد که جابه‌جایی مرکز فشار در جهت داخلی- خارجی و قدامی- خلفی در هیچ یک از سه شرایط مختلف، اختلاف معنی‌داری ندارد($P >۰/۰۵$). انحراف استاندارد جابه‌جایی مرکز فشار در جهت قدامی- خلفی، در شرایط بدون دستکاری بیشتر از دستکاری حس بینایی بود($P=۰/۰۰۱$). سرعت جابه‌جایی مرکز فشار کف‌پا در جهت داخلی- خارجی بین شرایط دستکاری حس بینایی و وستیبولار اختلاف معناداری داشت($P=۰/۰۱$). محدوده حرکت مرکز فشار در طی فاز اتکای راه رفتن در هیچ یک از سه شرایط مختلف، اختلاف معنی‌داری نداشت($P >۰/۰۵$). به نظر می رسد کاهش سرعت جابجایی مرکز فشار در افراد با فقدان اطلاعات بینایی، به دلیل زمان بر بودن پردازش اطلاعات سیستم حس عمقی و وستیبولار و کاهش سرعت راه رفتن می‌باشد.سیستم عصبی در نبود اطلاعات حس بینایی جهت کنترل پوسچر و حفظ تعادل، از اطلاعات حس وستیبولار استفاده می‌کند. اگرچه در این مطالعه، سیستم بینایی نقش غالب تری نسبت به سیستم وستیبولار در کنترل وضعیت بدن دارد. توصیه می شود که در طراحی تمرینات به منظور افزایش عملکرد تعادلی، بهبود عملکرد رفلکس بینایی– وستیبولار در برنامه تمرینی افراد گنجانده شود.

واژه های کلیدی: بینایی، وستیبولار، جابه‌جایی مرکز فشار، سرعت جابه‌جایی مرکز فشار