Journal of Rehabilitation Sciences and Research

Journal Home Page: jrsr.sums.ac.ir

Original Article

Assessment of Balance Recovery Strategies during Manipulation of Somatosensory, Vision, and Vestibular System in Healthy and Blind Women

Mansour Sahebozamani[1], PhD; Asma Salari[1*], PhD candidate; Abdolhamid Daneshjoo[1], PhD; Fatemeh Karimi Afshar[2], PhD

[1]Department of Sport Injuries and Corrective Exercises, Faculty of Physical Education and Sport Sciences, Shahid Bahonar University of Kerman, Kerman, Iran
[2]Department of Sport Medicine, Kerman University of Medical Sciences, Kerman, Iran

ARTICLE INFO

Article History:
Received: 05/05/2019
Revised: 31/05/2019
Accepted: 14/08/2019

Keywords:
Perturbation
Blindness
Postural balance
Sensory systems

Please cite this article as: Sahebozamani M, Salari A, Daneshjoo A, Karimi Afshar F. Assessment of Balance Recovery Strategies during Manipulation of Somatosensory, Vision, and Vestibular System in Healthy and Blind Women. JRSR. 2019;6(3):123-129. doi: 10.30476/jrsr.2019.81543.1001.

ABSTRACT

Background: Individuals with vision loss are at an increased risk of falls. Understanding what factors contribute to postural instability within this population is a necessary step towards the development of training programs and rehabilitation targeted at reduction of falls in this population. The aim of this study was to assess the balance recovery during manipulation of somatosensory, vision, and vestibular system in healthy and blind persons.
Methods: This causal-comparative study, thirty healthy (28.18±0.47 years) and blind (29.22±0.24 years) subjects were selected as samples. Balance recovery strategies in various situations were recorded by six high-speed cameras after sudden movement of a treadmill. Independent T-test test was used for data analysis.
Results: The results of this study indicated that the mean of hip and ankle swings in different conditions was significantly higher in the blind group than in the healthy group, both in the anterior-posterior and posterior-anterior disturbances. There was also a significant difference between the ratio of hip/ankle ROM (the dominant strategy for balance recovery) in all situations ($P<0.05$).
Conclusion: The findings of this study revealed that both healthy and blind groups had different mechanisms and responses for balance recovery after anterior-posterior and posterior-anterior perturbation (the dominant strategy investigated in each position separately). Also, the results showed that blind individuals more resort to hip strategies to maintain their postural stability and prefer to rely on somatosensory information to restore balance as the dominant sensory system.

2019© The Authors. Published by JRSR. All rights reserved.

Introduction

Visual impairment is considered as one of the most common disabilities and reasons of functional disability among adults, affecting their mobility and daily activities [1]. According to the WHO statistics in 2004, nearly 40-45 million and 135 million blind and partially blind people live over the world, respectively, most of whom live mainly in low-income countries [2-4].

The visual impairment results in sedentary life of the blind, reduced motivation for involvement in physical activity, and diminished body fitness. This physical sedentary lifestyle affects the movement development and musculoskeletal situation of the blind, and causes

*Corresponding author: Asma Salari, Department of Sport Injuries and Corrective Exercises, Faculty of Physical Education and Sport Sciences, Shahid Bahonar University of Kerman, Kerman, Iran. **Tel:** +98 913 2969650; *Email:* asmasalari@yahoo.com

some difficulties such as movement problems, failure of body awareness, orientation, body image, and most importantly, balance weakness [5, 6].

Generally, the balance is known as an ability for maintaining the center of gravity inside the supporting surface as one of the key and inseparable components in daily activities [7]. It is controlled and adjusted using complicated systems including vestibular, visual and somatosensory systems, as well as touch and pressure. Among these systems, the vestibular, visual, and somatosensory systems have received special attention [8]. The information sent from these receptors all over the body is organized by the central nervous system in relation to the body position in space and being mobile and immobile. Then, an appropriate movement response is issued in order to control the postural stability and maintenance of the body in the space [9, 10]. A review of previous studies suggests that the damages of falls in people affected by visual impairment are higher than for the normal people [11]. The visual impairment reduces the ability of balance maintenance, and may also increase the risk of falls causing repeated damages [11]. Therefore, the weak balance can have negative effects on the routine activities and training skills due to the increased risk of falls. As a result, these individuals encounter more problems when doing functional tasks with the center of gravity being outside of the supporting surface, and finally behave more cautiously [3]. On the other hand, if the information obtained from the vestibular, visual, and proprioceptive systems is sent simultaneously and coordinately to the central nervous system, the body is able to select an appropriate strategy for controlling the posture. It can also help maintain the center of gravity inside the supporting surface, and maintain the balance in different positions. Further, in this way people can prevent from falling, and can recover the postural stability again [12]. According to previous studies, each of the strategies employed for the balance recovery has a definite pattern of synergistic muscle involvement. These movement patterns are related to the compensatory mechanisms that are used in both movements, forwards and backwards, as the predictive behavior in order to maintain and recover the balance. These mechanistic approaches include fixed-support strategies such as the ankle and the thigh whose movement of pressure center is controlled at the supporting surface, and change-in-support strategies including stepping and grasping whose movement of pressure center is controlled when the supporting surface is altered [13]µ¦[Y.

Vision has a determinant role in processing and integrating other sensory inputs in order to select a strategy for maintaining the balance. Researchers have found that visual impairment has negative effects on the posture stability [14]. This factor which is associated to the destructive changes of neural, muscular, or skeletal mechanisms, results in increased falls, and consequently damages to these people [3, 15]. Hence, it seems that the transfer of these strategies toward the ankle joint can increase the abilities of these people when facing abrupt perturbations. However, no studies have been carried out on these issues, probably for the lack of sufficient information with regards to the strategies of the balance recovery. Further, the role of visual information is very important as the most important sensory source involved in the balance of people. In order to select a strategy, vision plays an important role in processing and integrating other sensory inputs [1]. Therefore, the people with visual impairment depend on the vestibular and somatosensory information in order to establish and connect to the movement patterns, and adjust their body position in the space for the compensation of those functional impairments associated with the visual system [16]. In other words, these systems are overlapped; that is, if the information of one system is incomplete or insufficient, the central nervous system sends the required order using the information obtained from these two systems [17].

There are some studies examining the effect of manipulated visual, Somatosensory and vestibular receptors on sighted people, and in rare cases, on blind people [17]. Regarding the interaction between visual, somatosensory and vestibular systems, these questions have remained unanswered how the somatosensory and vestibular systems can be directed in the people who are deprived of the visual system. Another question is what is the share of each system when selecting an appropriate strategy in order to recover the balance. It is also not clear which strategy is used for the balance recovery while manipulating the sensory systems involved in the balance because of imposed perturbations. Therefore, the purpose of this study is to assess of balance recovery strategies during manipulation of somatosensory, vision, and vestibular system in healthy and blind persons.

Methods

Participants

The present causal-comparative study was performed on the subjects selected from among 108 healthy and blind women after initial evaluation. According to the study inclusion and exclusion criteria, 30 women (15 healthy and 15 blind) were selected and evaluated as the study subjects through a targeted procedure. The sample size was determined based on previous similar studies [18, 19].

Some exclusion criteria were considered when selecting the subjects in the present study which were as follows: neurological failures or nervous system impairment, auditory failures or history of vestibular system impairment and balance problems, pathological symptoms, history of fractures, or operation and disease of joints in the lower limbs. On the other hand, the inclusion criteria were gender female, age range of 27 to 36 years, not being overweight (In both groups), and blind participants having a visual acuity 20/600 field of vision limited to 20°.

Meanwhile, before inclusion of the subjects in the study, their health was proved according to General Health Questionnaire. After explaining the aims and methods of this study, they were requested to sign the written consent form to participate in the study. Ethical clearance was obtained by the Ethics Committee of Kerman University of Medical Sciences, Kerman, Iran (Ethics Committee Number: IR.KMU.REC.1395.351).

Testing Conditions and Data Collection

All study assessments were performed in the physical training laboratory located in Shahid Bahonar University of Kerman. After measuring the subjects' heights and weights, the motion analysis system was used with 6 high-speed cameras (Raptor-H digital real time system, USA) in order to assess the motor domain of those joints used for the balance recovery (Figure 1).

This system consists of hardware and software components to obtain image data and process them. As the subject's movement must be recognized by the cameras, five sphere-shaped reflective markers were installed on ASIS projection, great trochanter in thigh bone, external epicondyle in thigh, external ankle, and the fifth metatarsal. Accordingly, a two-dimensional model was defined with four sections including leg, shin, thigh, and pelvis for calculating the sways of ankle joint and hip joint, while imposing perturbations in the sagittal plane (Figure 2). The ankle joint was assumed as an angle between foot and shin, but the hip joint was assumed as an angle between thigh and pelvis. During the test, every subject stood on the treadmill with naked feet, her hand being crossed on the chest, and the right side of body being directed to the cameras. The positioning was left to the subject's discretion depending to the leg place, to find her normal and comfortable position.

The subjects were asked to stand on the treadmill, once with their face toward the treadmill monitor, and another time their back to the treadmill monitor. The goal was to do movements under the planned movement directions and the imposed anterior-posterior perturbations while maintaining their straight posture despite the imposed abrupt velocity. Note that the monitor screen was covered with a medical tape in order to control the other visual confounders. During the test, the treadmill was abruptly started to run without any warning to the subject, and the perturbations were imposed in the anterior or posterior directions to the subject's posture. The subjects were requested to resist against the imposed perturbation without stepping, and when their feet were moved, the movement was required to repeat. The speed of treadmill was set at 1.1 m/s according to the pilot project (performing the test by the subjects before the original testing) for all subjects making a 40-cm movement in the treadmill. The cameras were installed 2 m away from the treadmill, recorded the sways of the hip and ankle joints for 5 s, after imposing perturbation. The recorded information was analyzed using Cortex software. Each subject did each movement in triplicate, and the mean of these repeated movements was evaluated for calculating the parameters and study variables. Note that a time interval of 30 s was considered for the rest between each repetition. In the last stage, the recorded information in the software was extracted as a file in Excel format and was studied further for calculating the kinematic changes in the ankle and hip ROM. The subjects were secured

Figure 1: 3D analyzer with 6 infrared optoelectronic cameras

Figure 2: The schematic diagram of reflective markers attached to the skin

with a supporting belt hanging from the roof to the middle of treadmill. The mentioned-above perturbations (anterior-posterior perturbations) were studied in different positions.

These positions are described as follows:

Position No. 1: The perturbed balance while standing on a stable surface (reference position): In this position, no manipulation was made in the vestibular and somatosensory systems. The subjects were asked to hold their heads naturally straight.

Position No. 2: The perturbed balance while standing on an unstable surface: In this position, the subjects were asked to stand on the treadmill with the foam-covered conveyor belt. After ensuring that the feet were placed in appropriate places on the foam, the subjects were asked to hold their heads naturally straight.

Position No. 3: The perturbed balance while standing on a stable surface with alternative head movements: In this position, the subjects were asked to move their heads alternatively before the treadmill running, and then to hold their heads in a hyperextension position during the test.

Position No. 4: The perturbed balance while standing on a stable surface wearing a blindfold: In this position, the blindfolded subjects were asked to stand on the treadmill and hold their heads naturally straight.

Statistical Analysis

Descriptive statistics were used to analyze the data collected which included the demographic characteristics and other study variables of the study population. The independent t-test was used in order to compare the subjects' scores in both groups. All statistical tests in the present work were interpreted at a significant level of 95% and the α value was supposed as 0.05 or lower.

Results

The demographic and physical characteristics recorded for the subjects were are for each group in Table 1. For determining the homogeneity of the demographic characteristics recorded for both studied groups, independent t-test was used, with the results being presented in Table 1. The results do not show any significant differences between age, height, mass, and BMI in the studied groups; therefore, both groups showed homogeneity in these variables.

Also, Table 2 reports the information of the sways measured at the ankle and thigh joints after imposing the anterior-posterior and posterior-anterior perturbations for the subjects in different positions per group. Note that the proportion of the hip sway to ankle sway was used to study the preference of the ankle and hip strategies among the subjects. It is suggested that the higher this proportion, the more thigh strategy is required to recover the balance, and the lower this proportion, the more ankle strategy is needed to meet it.

The results of this study indicated that the mean sway measurements of the ankle and thigh joints were higher in different positions in the blind group compared to the healthy group, in both anterior-posterior and posterior-anterior perturbations ($P>0.05$). Also, there was a significant difference between sways from hip to ankle (dominant strategy in balance recovery) in all positions except for position No. 4 ($P<0.05$).

In position No. 1 (Table 2) with no manipulation in visual, vestibular, and proprioceptive systems, there were significant differences between sway measurements of ankle and hip joints obtained from subjects in both groups. The sway measurements of the studied joints were higher in response to anterior-posterior and posterior-

Table 1: The differences of demographic characteristics using the independent t-test in the blind and healthy groups

	Healthy Group	Blind Group	P value
Age (Years)	28.18±0.47	29.22±0.24	0.568
Height (m)	1.65±8.64	1.85±6.55	0.385
Mass (kg)	58.74±0.27	57.92±0.41	0.699
BMI (kg/m^2)	23.23±5.50	23.34±5.91	0.936

Table 2: The compared sway measurements of the ankle and the hip joints in the blind and healthy groups in position No. 1

		Group	Mean±SD	P value
Hip sway	A/P perturbation	Blind	2.65±2.05	0.012
		Healthy	1.41±0.88	
	P/A perturbation	Blind	2.37±1.30	0.024
		Healthy	1.52±1.34	
Ankle sway	A/P perturbation	Blind	2.36±0.87	0.012
		Healthy	1.36±0.95	
	P/A perturbation	Blind	2.45±1.40	0.025
		Healthy	1.97±1.16	
Hip sway/ankle sway	A/P perturbation	Blind	1.31±0.35	0.038
		Healthy	0.87±0.95	
	P/A perturbation	Blind	1.19±0.63	0.054
		Healthy	0.89±0.44	

AP: Anterior-posterior; PA: Posterior- anterior

Table 3: The compared sway measurements of the ankle and the hip joints in the blind and healthy groups in position No. 2

		Group	Mean±SD	P value
Hip sway	A/P perturbation	Blind	2.85±2.07	0.019
		Healthy	1.75±0.75	
	P/A perturbation	Blind	3.88±1.55	0.002
		Healthy	1.65±0.68	
Ankle sway	A/P perturbation	Blind	2.56±1.59	0.044
		Healthy	1.46±1.28	
	P/A perturbation	Blind	3.38±1.19	0.006
		Healthy	2.04±0.93	
Hip sway/ankle sway	A/P perturbation	Blind	1.85±0.88	0.034
		Healthy	0.80±0.39	
	P/A perturbation	Blind	0.65±0.99	0.054
		Healthy	0.87±0.53	

AP: Anterior-posterior; PA: Posterior- anterior

anterior perturbations in the blind group compared to the healthy group. Also, the findings showed that there was a significant difference between the hip sway to ankle sway proportion, with the dominant strategy for the balance recovery being the ankle strategy in the healthy group. However, the blind subjects mostly resorted to the thigh strategy for balance recovery. Considering positions No. 2 and 3 (Tables 3 and 4), there were significant differences for the perturbations affecting the vestibular and somatosensory systems between the ankle join and hip join sways recorded for the subjects in both groups, respectively. Further, there was a significant difference between the proportion of the hip to ankle sways, where the dominant strategy for balance recovery in the healthy group was mostly the ankle strategy; however, in the blind group, the hip strategy was mostly emphasized. In position No. 4 (Table 5), despite a significant difference found between the proportion of the hip join to ankle join sways for subjects of both groups through the perturbation in the vision system, no significant differences were observed between the proportion of sways recorded for the studied joints in response to anterior-posterior and posterior-anterior perturbations. Note that the major sway measurements were recorded in the position using perturbation in the somatosensory system, and the minimal ones were recorded in the position using no perturbation in sensory systems compared to the reference position in the blind group. In addition, the results showed that the principal sway measurements were found in the healthy group using perturbation in the visual system compared to the other positions.

Discussion

The results obtained from this study showed that in all studied positions, the sways measured for the ankle and thigh joints in response to anterior-posterior perturbations were higher in the blind group compared to the healthy group. Compared to the other positions, the measured sways were lower in position No. 1 with no manipulations in visual, vestibular, and proprioceptive systems. Also, in position No. 2 with some perturbation in the somatosensory system, the proportion of the ankle to hip sways as well as the ankle to hip joint sways were higher in the blind group compared to other studied positions in the same group. However, in the healthy group, the measured sways in position with the perturbation in visual system were higher compared to the other studied positions. The role of visual input is so important that it can be proved with a simple test performed on a normal blindfolded subject while standing, as the measured sways increased from 20 to 70% compared to the position in which eyes are opened [20].

In the standing position, the postural sways induce not only visual feedback through changes made along the muscles, but also use the reflective adjustments to maintain posture. These adjustments will become active

Table 4: The compared sway measurements of the ankle and the hip joints in the blind and healthy groups in position No. 3

		Group	Mean±SD	P value
Hip sway	A/P perturbation	Blind	2.24±1.02	0.017
		Healthy	1.48±0.55	
	P/A perturbation	Blind	2.78±1.23	0.001
		Healthy	2.23±0.70	
Ankle sway	A/P perturbation	Blind	2.71±1.81	0.044
		Healthy	1.65±0.74	
	P/A perturbation	Blind	2.35±1.34	0.001
		Healthy	1.99±0.47	
Hip sway/ankle sway	A/P perturbation	Blind	1.61±0.96	0.019
		Healthy	0.86±0.65	
	P/A perturbation	Blind	1.23±0.67	0.054
		Healthy	0.82±0.41	

AP: Anterior-posterior; PA: Posterior- anterior

Table 5: The compared sway measurements of the ankle and the hip joints in the blind and healthy groups in position No. 4

		Group	Mean±SD	P value
Hip sway	A/P perturbation	Blind	2.45±1.15	0.033
		Healthy	1.85±1.15	
	P/A perturbation	Blind	2.86±4.11	0.032
		Healthy	1.78±1.47	
Ankle sway	A/P perturbation	Blind	2.18±3.34	0.058
		Healthy	1.50±0.68	
	P/A perturbation	Blind	2.58±5.53	0.059
		Healthy	2.14±1.23	
Hip sway/ankle sway	A/P perturbation	Blind	1.23±0.99	0.442
		Healthy	0.89±0.67	
	P/A perturbation	Blind	1.18±0.67	0.929
		Healthy	0.91±0.75	

AP: Anterior-posterior; PA: Posterior- anterior before any feedbacks from other senses being transmitted to the central nervous system [21]. Nevertheless, vision is considered one of the original sources as a dominant sensory source in most individuals because of sending information to the central nervous system about how to keep and recovery balance; the information obtained via this source forms the main part of sensory feedback when performing exercise skills. Also, given the role of peripheral vision in the posture control, subjects can decrease the posture sways by fixing the peripheral vision; on the other hand, once vision is omitted, these sways are changed and the balance is affected severely [22]. However, reflective adjustments remain still active for posture control. Nevertheless, as shown in the present work, the effect that it imposed cannot compensate for the lack of vision. Thus, according to previous studies, it can be suggested that while the vestibular and somatosensory systems provide some information for the balance control, the decreased or omitted vision as a perturbation in the most central sensory source leads to substantially negative effects on the movement control [23].

Many studies have examined the ability to maintain the balance in the blind especially those who have never received any visual stimuli. They have indicated that the blind people, who are not able to use the visual input in order to keep postural stability, are predicted to have much more difficulties in controlling the balance and doing functional tasks when their centroids lie outside the supporting surface. Meanwhile, the patients with visual failure are required to use vestibular and somatosensory information in order to establish and connect with movement patterns, as well as for adjusting the body posture in the space and compensation for the failure of visual system functions. Given the perturbation imposed on one of these systems, the data input provided for the central neural system is reduced. Thus, the sways increase and corrective commands with short precision will be made, and finally, the hip and ankle sways occur more frequently [24].

Given the mentioned-above description, our study results indicated some consistency with Rutkowska et al. (2007), Zylka et al. (2013), Davarpanah et al. (2016), Schmidt et al. (2007), and Jafari, et al. (2011) [1, 6, 8, 14, 25]. For example, Schmidt et al. (2007) reported higher sways and movements in the blind group being probably a clue for the weak balance among these individuals [1]. It can be interpreted that other sensory inputs cannot replace the long-time absence of visual information and the vision plays an essential role in processing and integrating other sensory inputs when selecting the strategy type in the balance control [25]. Also, in the blind people, the stored movement information and correct movement patterns are reduced in the central nervous system due to the lack of vision. In general, it affects the balance of a blind's performance and causes them to function weakly in balance control compared with their peers who are sighted; it can reduce the chances of successful recovery in these individuals [14].

The findings obtained in this study revealed that both study groups applied different mechanisms and responses for the balance recovery after imposing the abrupt perturbations in anterior-posterior and posterior-anterior directions; the blind group indicated higher sways because of weakness in the balance functions compared to the control group. Apparently, it can be considered a risk factor for falls in these individuals encountered with external perturbations. Also, the normal people used their ankle joints more to maintain and recover the body balance after imposing perturbation and abrupt velocity, while the blind people used their hip joints more. As mentioned above, according to the results obtained from previous studies[11, 26], the joints close to the supporting surface are the main player in maintaining balance. Accordingly, it can be concluded that normal individuals have abilities to overcome the external postural perturbation and maintain their balance through employing the joints that are close to the supporting surface. However, the increased sways in the blind people result in their increased use of hip joint strategy as it can be an appropriate transfer for maintaining and recovering the balance [11, 26]. Research limitations included the impact of installing markers on subjects' performance, gender of the subjects (female only), lack of control over subjects' accuracy in performing tests, lack of control over the daily activities and rest of the subjects, and lack of control for the level of motivation and psychological factors of the subjects during the tests.

Conclusion

The systems involved in the transfer of the balance recovery strategies from the hip joint to the ankle joint should be known for the performance of rehabilitation plans. Accordingly, the investigations designed for this subject can significantly aid in preventing the falls for the blind, while also improving the quality of life in this group of the community. According to the results, the maximum level of sways in the blind people was observed compared to the reference position with a disturbance imposed on the somatosensory data. Then, it can be suggested that when the blind encounter a sensory disturbance or immediate perturbation, they probably rely on the somatosensory information as a preferred and superior balance system for better control of body posture and the balance recovery. Thus, the roles played by the visual and vestibular systems are of secondary importance. Therefore, for training and rehabilitation programs for the blind, it is better to improve not only the somatosensory system but also other balance systems. Future research should focus on dynamic conditions and situations that further complicate attention to postural control by increasing the processing demands through employing cognitive tasks (i.e. divided attention) and determining if this further predisposes visually impaired adults to falls. Determining the physical and cognitive contributions to postural stability is vital to both understanding the risk of fall and deriving components of future interventions aimed at reducing postural instability in individuals with profound vision loss.

Acknowledgements

We highly appreciate kind cooperation of all subjects in this study.

Conflict of interest: None declared.

Reference

1. Schmid M, et al. Equilibrium during static and dynamic tasks in blind subjects: no evidence of cross-modal plasticity. Brain, 2007. 130(8): 2097-2107.
2. Velázquez R. Wearable assistive devices for the blind. In Wearable and autonomous biomedical devices and systems for smart environment. Springer Berlin Heidelb; 2010.
3. Salari A, M Sahebozamani, and H Daneshmandi, The effect of core stability training program on balance in blind female athletes. Journal of Health and Development 2013. 20(6): 585-595.
4. Fitzgerald H. Disability and youth sport: Routledge; 2009.
5. Bhambhani Y. Overview of physical training in athletes with disabilities: focus on long term athlete development [Electronic resource]. Access mode: https://www. athletics. ca/List or references. 1: 23-28.
6. Jazi S D, et al. Effect of selected balance exercises on the dynamic balance of children with visual impairments. JVIB. 2012. 106(8): 466-474.
7. Park R-Y, et al. Effect of dominant versus non-dominant vision in postural control. Ann Rehabil Med, 2011. 35(3): 427-437.
8. Jafari Z, et al. Static and dynamic balance in congenital severe to profound hearing-impaired children. Audiology, 2011. 20(2): 102-112.
9. Juodžbalienė V and K Muckus. The influence of the degree of visual impairment on psychomotor reaction and equilibrium maintenance of adolescents. Medicina, 2006. 42(1): 49-56.
10. Vali-Zadeh A, et al. Comparison of static balance among blind, deaf and normal children in different conditions. Arch Phys Med Rehabil, 2014. 14(4): 106-112.
11. Wiszomirska I, et al. The impact of a vestibular-stimulating exercise regime on postural stability in people with visual impairment. Biomed Res Int 2015.2015.(1):8-15
12. Beyranvand R, et al., The Role of Vision on Balance Recovery Strategies in the Elderly. JRSR, 2017. 5(9): 95-103.
13. Horak F, and Jane M. Macpherson. Postural orientation and equilibrium in Comprehensive physiology. 2011: 255-292.
14. Zylka J, U Lach, and I Rutkowska. Functional balance assessment with pediatric balance scale in girls with visual impairment. pediatr phys ther, 2013. 25(4): 460-466.
15. Amiridis I G, V Hatzitaki, and F Arabatzi. Age-induced modifications of static postural control in humans. Neurosci. Lett, 2003. 350(3): 137-140.
16. Tomomitsu M S, et al. Static and dynamic postural control in low-vision and normal-vision adults. Clinics, 2013. 68(4): 517-521.
17. Szymczyk D, et al. Balance and postural stability in football players with hearing impairment. 2012.16(3):258-263.
18. Bagheri H. The effect of 8-weeks aquatic exercise on balance strategy and knee joint position sense of 60-70 year old people. SBUK 2014.
19. Lange MR, Schmidli H. Analysis of clinical trials with biologics using dose–time-response models. Stat Med. 2015. 34(22):3017-28.
20. Paul M, S K Biswas, and J S Sandhu. Role of sports vision and eye hand coordination training in performance of table tennis players. Braz. J. Biomotricity, 2011. 5(2): 106-116.
21. Schmidt R A and T D Lee. Motor learning and performance: From principles to application. Human Kinetics. 2013:25-95.
22. Gimmon Y, et al. The effect of plantar flexor muscle fatigue on postural control. J Electromyogr Kinesiol, 2011. 21(6): 922-928.
23. Mousavi S, et al. A Comparison the Role of Vision System on Dynamic Postural Stability on Young Women and Men Elite Athletes. Modern Rehabilitation, 2014. 7(4).1-7
24. Kulmala J. Visual acuity in relation to functional performance, falls and mortality in old age. University of Jyväskylä. 2010:152.
25. Rutkowska I and W Skowroński. A comparison of body balance of blind children aged 7-16 years in sex and age categories. Studies in Physical Culture & Tourism, 2007. 14:284-292
26. Kerwin D G and G Trewartha. Strategies for maintaining a handstand in the anterior-posterior direction. MSSE, 2001. 33(7): 1182-1188.