The Effect of Visual and Auditory Cueing on Obstacle Crossing Characteristics in Healthy Young Females

Fuengfa Khobkhun*, and Sunee Bovonsunthonchai

Faculty of Physical Therapy, Mahidol University, Nakhon Pathom, Thailand
*Corresponding author: Fuengfa Khobkhun email: fuengfa.kho@mahidol.edu

Abstract

It is well established that the sensory system plays a significant role in the control of movement. Obstacle crossing is one of the most complicated ambulatory tasks and requires coordinated control from both the musculoskeletal and sensory systems in order to perform the task successfully and safely. This study aimed to investigate the effect of visual and auditory cues on lower limb kinematics of the lead and trail limbs during obstacle crossing in healthy young females. Eleven healthy females with the age of 18-22 years old have participated in the study. A 3D motion analysis system was used to capture obstacle crossing characteristics. Four different conditions were considered: (1) crossing the obstacle with full vision and no sound (VNS), (2) crossing the obstacle with full vision and added sound (VS), (3) crossing the obstacle with blurred vision and no sound (BNS), and (4) crossing the obstacle with blurred vision and added sound (BS). Obstacle crossing characteristics included hip, knee, and ankle. Angles of the lead and trail limbs were recorded and maximum hip flexion angle of the lead limb (Max Hip-LL), maximum hip flexion angle of the trail limb (Max Hip-TL), maximum knee flexion angle of the lead limb (Max Hip-LL), maximum knee flexion angle of the trail limb (Max Hip-TL), maximum ankle plantarflexion angle of the lead limb (Max Ankle-LL), and maximum ankle plantarflexion angle of the trail limb (Max Ankle-TL) were analyzed. A Repeated measure ANOVA analysis with pairwise comparisons showed significant differences in the Max Hip-LL between the VNS and BS, and VS and BS conditions, and in the Max Hip–TL and Max Knee-LL between the VS and BNS, and VS and BS conditions. A significant difference was also seen in Max Knee-TL between the VNS and BS, VS and BNS, and VS and BS conditions. In addition, a significant difference was seen in Max Ankle-TL between VNS and BS condition. Modifications of movement control under different testing sensory conditions were demonstrated in healthy young females in both the lead and trail limbs.

Keywords: *obstacle crossing; vision; auditory; kinematics*

1. Introduction

Obstacle crossing is one of the most complicated ambulatory tasks and requires coordinated control from both the musculoskeletal and sensory systems in order to perform the task successfully and safely. The task involves postural control and balance, input from the somatosensory system, cardiovascular system endurance, and precise neuromotor control from the neuromuscular and musculoskeletal systems (Bovonsunthornchai et al., 2012; Galna et al., 2011). In an individual with muscle and joint injuries, obstacle crossing is often obstructed and impaired. Whereas an individual with neurological disorders often have somatosensory and balance problems which can also impair obstacle crossing ability (Bovonsunthornchai et al., 2012, Galna et al., 2011). For example, people with Williams syndrome (WS) have a visual disability, producing greater variability of foot placement and temporal-spatial deviations during obstacle crossing when compared to the healthy one (Bovonsunthornchai et al., 2012; Hocking et al., 2011). Temporal-spatial parameters in people with WS have been characterized as having slow movement of the trailing limb witha significantly slower pace and a shorter step length when compared to the controls (Hocking et al., 2011). It can be concluded that patients who suffer from WS have a visual disability that impairs obstacle crossing. In addition, a previous study highlighted thedeficits in obstacle crossing in people with Parkinson’s disease (PD), including a slower speed and taking shorter steps and some also express difficulty in lifting and placing their feet (Glana et al, 2010). Possible factors contributing to the difficulty in performing this task may include; impaired postural and balance control, impaired coordination, and loss of lower limb movement capability (Glana et al, 2010).

In addition, some studies suggested that a rhythmic auditory cue can be used to improve the quality of locomotion in an individual with PD (Brown et al., 2010).

Analysis of lower limb joint kinematics provides a greater insight into the joint movement of the hip, knee, and ankle when performing complex tasks. The pattern and range of movement in each joint depends on the shape and height of the obstacle (Lu et al., 2006). A previous study exploring obstacle crossing in elderly participants indicated that they adopted a greater hip flexion angle than younger participants. The elderly participants also demonstrated a greater deviation in lower limb joint angles to maintain balance whilst crossing the obstacle. Therefore, the function and coordination of the hip, knee, and ankle, can be used to assess the quality of movement, which includes the smoothness of movement, which in turn can be associated with the ability to cross an obstacle, although this may also be affected by external factors, for instance, different walkway surfaces, visual impairment, and sound disturbance.

The present study focused on the effect of rhythmic sound on the hip, knee, and ankle kinematics in the lead and trail limbs when performing an obstacle crossing task in an individual who had simulated limited vision, with the view to improve our understanding of the effect of impaired sensory systems on kinematic characteristics during obstacle crossing. We hypothesized that by experimentally simulating the impairment of the visual system in the healthy young female will result in alteration of the hip, knee, and ankle kinematics in the lead and trail limbs. Indeed, the adaptation mechanism of the sensory deprivation may be expressed differently between people with and without the disease. This information may help to provide an important basis for further studies in people with the disease. In addition, factors that may affect the results of the study, such as gender and age, should be controlled in order to clearly demonstrate the effect of visual and auditory cue on an obstacle crossing pattern.

As mentioned above, the study aimed to investigate the effect of visual and auditory cues on lower limb kinematics of the lead and trail limbs during obstacle crossing in healthy young females.

2. Materials and methods

2.1 Participants

Eleven healthy young females with the age between 18 to 22 years were recruited from a student population at Mahidol University. The selected participants had met the study inclusion criteria as following: had a dominant right leg, were able to follow verbal commands, had no musculoskeletal or neurological problems, had no vision and hearing problems, and had no loss of or impaired sensation.

2.2 Instruments

The obstacle is made from the wood with the dimension of 10 x 60 x 10 cm. Furthermore, the hip, knee, and ankle kinematics during obstacle crossing were captured using a six camera Vicon™ motion analysis system (Oxford Metrics Ltd., Oxford, UK) at 100 Hz and filtered using a 5 Hz low pass Butterworth filter.

2.3 Procedures

Participants were given questionnaires to assess their demographic data, hearing and vision, and other assessments as required by the inclusion criteria. Sixteen retroreflective markers were attached to selected bony prominences and anatomical locations on the participants by the researcher following the lower body plug-in-gait (PIG) model. These were; the left and right ASIS', PSIS', thigh wand, lateral condyles of the femur, tibia wand, lateral malleoli, heels, and second metatarsals.

To consistently control the increasing of walking speed for all individuals, a metronome was used to set the walking cadence 10% faster than each individual's normal cadence. An obstacle was then placed in the middle part of a 10-meter walkway. To avoid injury from tripping or falling, participants were allowed to practice the obstacle crossing until they were familiar with the task. Participants were then instructed to walk by following a set rhythm using a metronome. Participants were instructed to cross the obstacle with their dominant leg as the lead limb and non-dominant as the trailing limb. Three trials of walking and crossing the obstacle were recorded for each of the four testing conditions. A five-minute break between conditions was allowed to prevent fatigue or tiredness.

2.4 Testing conditions

Four conditions were measured randomly; crossing the obstacle with normal vision and no sound (VNS), crossing the obstacle with normal vision and sound (VS), crossing the obstacle with blurred vision and no sound (BNS), and crossing the obstacle with blurred vision and sound (BS).

2.5 Kinematic variables

Six kinematic variables were recorded; maximum hip flexion angle of the lead limb [Max Hip-LL], maximum hip flexion angle of the trail limb [Max Hip-TL], maximum knee flexion angle of the lead limb [Max Hip-LL], maximum knee flexion angle of the trail limb [Max Hip-TL], maximum ankle plantarflexion angle of the lead limb [Max Ankle-LL], and maximum ankle plantarflexion angle of the trail limb [Max Ankle-LL].

3. Statistical Analysis

All data were analyzed using SPSS Version 18.0, S/N 5082368 NY, US. The Kolmogorov-Smirnov Goodness-of-Fit Test was used to test the data distribution and all data presented as normal distributions. Demographic characteristics were analyzed and presented using descriptive statistics. Repeated measures ANOVAs were used to analyze the data between testing conditions. The statistical significance level was set at a *p*-value of less than 0.05.

4. Results

Eleven healthy young females participated in this study. Their ages were between 19–22 years with height between 1.55–1.64 meters. Other demographics and assessments are presented in Table 1.

Table 1 Participant characteristics

Number	Weight (kg)	Height (m)	Age (yr)	Muscle strength (grade)	Normal cadence	110% cadence
1	54.95	1.64	22	5	102	112.2
2	56.15	1.64	20	5	100	110
3	51.9	1.55	20	5	116	127.6
4	56	1.61	22	5	96	105.6
5	58.35	1.605	19	5	102	112.2
6	53.15	1.595	20	5	100	110
7	49.1	1.55	21	5	104	114.4
8	51.7	1.59	22	5	126	138.6
9	50	1.6	22	5	110	121
10	47.5	1.575	20	5	112	123.2
11	51.6	1.58	19	5	84	92.4
Mean	52.76	1.59	20.64	5	104.73	115.2
SD	3.32	0.03	1.21	0	11.07	11.61
Max	58.35	1.64	22	5	126	138.6
Min	47.5	1.55	19	5	84	92.4

As shown in Table 2 below, the comparisons of kinematic data between the testing conditions showed significant differences in the Max Hip-LL, Max Hip-TL, Max Knee-LL, Max Knee-TL, and Max Ankle-TL ($p<0.05$). Furthermore, Boferroni post hoc analysis demonstrated significant differences ($p<0.05$) for the Max Hip-LL between the VNS and BS and between the VS and BS conditions. For Max Hip-TL and Max Knee-LL, significant differences ($p<0.05$) were found between the VS and BNS and between the VS and BS conditions. For the Max Knee-TL, significant differences ($p<0.05$) were found between VNS and BS, VS and BNS, and VS and BS conditions. Moreover, for the Max Ankle-TL, there was a significant difference ($p<0.05$) between VNS and BS conditions.

Table 2 Comparison of kinematic variables among testing conditions

Variables (degrees)	Conditions				MS	SS	df	F	*p*-value
	VNS	VS	BNS	BS					
Max Hip-LL	61.41±10.68	60.17±8.29	64.62±11.71	64.82±11.07	112.112	178.621	1.593	4.313[a]	**0.039***
Max Hip-TL	44.67±6.42	44.00±6.88	46.55±9.03	46.45±7.66	18.047	54.140	3	3.529[b]	**0.027***
Max Knee-LL	96.19±11.83	96.57±8.79	100.39±12.18	99.48±10.84	48.228	144.683	3	3.287[b]	**0.034***
Max Knee-TL	101.24±5.84	100.08±8.34	105.91±11.12	106.63±9.44	118.635	355.905	3	7.085[b]	**0.001***
Max Ankle-LL	14.50±7.59	14.55±5.84	14.23±7.77	13.50±7.03	2.583	7.748	3	0.214[b]	0.886
Max Ankle-TL	21.01±4.86	18.07±7.12	20.72±5.01	16.77±9.47	46.830	140.491	3	3.142[b]	**0.040***

Note: *significant difference tested by the Repeated Measure for ANOVA
[a] Greenhouse-Geisser correction
[b] Sphericity is assumed

Conditions; (1) VNS = crossing the obstacle with full vision and no sound, (2) VS = crossing the obstacle with full vision and added sound (3) BNS = crossing the obstacle with blurred vision and no sound, and (4) BS = crossing the obstacle with blurred vision and added sound.

Variables; (1) Max Hip-LL = maximum hip flexion angle of the lead limb, (2) Max Hip-TL = maximum hip flexion angle of the trail limb, (3) Max Hip-LL = maximum knee flexion angle of the lead limb, (4) Max Hip-TL = maximum knee flexion angle of the trail limb, (5) Max Ankle-LL = maximum ankle plantarflexion angle of the lead limb, and (6) Max Ankle-TL = maximum ankle plantarflexion angle of the trail limb.

6. Discussion

This study explored the effects of obstacle crossing under different sound conditions with and without a visual limitation on the hip, knee, and ankle kinematics. To the authors' knowledge, no study has explored the effects of sound rhythms with and without visual limitations during obstacle crossing. Significant differences were seen in the movements of the hip and knee in both the lead and trail limbs which would indicate a change in proximal joint strategy with greater flexion angles seen in both the hip and knee under the visual limitation conditions when compared to having no visual limitation conditions (Galna et al., 2009 and 2010). Therefore, crossing the obstacle without visual input requires the participants to flex their hip and knee more than usual in order to guarantee a safe crossing, which means, visual information is an essential sensory input to allow the correct control for the movement and any visual deficit will cause adaptive strategies (Buckley et al., 2005). The deficiency in visual information affects accurateness and velocity of task's object on the flexion angles of hip, knee, and ankle at the time of the broad practice in the task of obstacle crossing. The reduced visual information can cause an alteration of the locomotion pattern and increases the motorized experience through repetition (Kamram & Diaz, 2020). Moreover, the management of study objectives was anticipated to explain the effects of age and accuracy commutation on obstacle crossing in accordance with the visual ability (Sho & Okada, 2019). The analysis of sensitivity was employed to allow or put up motor adjustments in connection to the non-existent of visual and practice (Heijnen et al., 2014). Observation of the obstacle during study seemed to facilitate the required memory to direct obstacle crossing, especially on the effects of sound on the angles of the hip, knee, and ankle.

The influence of sound on motion or postural control may be comparable to the other kinds of sense. The effect of sound on various motion control patterns may vary according to the studies. From the study of Buckley and colleagues in 2005, they found that sound rhythm had no significant effect on the flexion angle of the hip, knees, or ankle in either the lead or trail limbs during obstacle crossing (Buckley et al., 2005).There was also no effect of sound on the postural control in young adults (Bovonsunthonchai et al, 2018), however, the effect of sound was found to improve postural balance in the frontal plane for the elderly (Hengsomboon et al., 2019).

Blind people seem to have difficulties to adjust or familiarize themselves with locomotion and obstacles to cross during their daily activities. However, congeniality visually impaired people in a bipedal upright position do not have a substantial difference in sway velocity in comparison to people with visual abilities (Alison & Deshpande 2014). Variations of upright position center of pressure and how the body sways in blind people are different from people with visual abilities since blind people implement postural approaches with adapted and improved perception of the surroundings (Siouda et al., 2019). Besides, people with visual abilities have better suppleness and flexibility since they can assess information about the size of the obstacle in comparison to the surroundings (Diaz et al., 2018). Moreover, people with visual ability are extra careful when approaching obstacles and when stepping over the obstacles.

However, no significant change was seen in Max Ankle-LL. The reason might be that the movements of the ankles during obstacle crossing are smaller than those of the hip and also because of a higher standard deviation of flexion of the ankles. This study included the participants only in healthy young females with the limitation of a small number of samples. A larger number of participants is still needed in a future study to provide a precise correction and larger generalization.

7. Conclusion

Visual limitation affects the control of the hip and knees on both lead and trail limbs during obstacle crossing. In addition, the limitation of vision accompanying auditory can also affect the ankle motion of trail limb during obstacle crossing. These changes indicate the adaptive mechanism of various lower extremity joint control during obstacle crossing in healthy young females.

8. Acknowledgement

The authors would like to thank Aummarat Panyapasuk, Paveena Molkul and Chayanan Inkliang for assistance with data collection. Also, the authors would like to give special thanks to Professor Jim Richards, School of Sport and Health Sciences University of Central Lancashire, UK for his excellent guidance, proofreading, grammar checking, editing and support throughout the development of this work.

9. References

Alison, N. C. & Deshpande, N. (2014). Effects of aging on whole body and segmental control while obstacle crossing under impaired sensory conditions. *Human Movement Science, 35*, 121–130.

Bovonsunthonchai, S., Hiengkaew, V. & Vachalathiti, R. (2012). Obstacle crossing characteristics in the healthy young female and elderly female subjects. *Siriraj Medical Journal, 64*, 52-56.

Bovonsunthonchai, S., Hengsomboon, P., Tangluang, S., Anusri, P., Chotikul, P., Phiwmou, W. (2018). The effect of sound and vibration on postural balance in healthy young adults, *Walailak Journal of Science and Technology*, 16(12), 975-983.

Brown, L. A., Bruin de, N., Doan, J., Peng, S. O & Hu, B. (2010). Obstacle crossing among people with Parkinson disease is influenced by concurrent music.*Journal of Rehabilitation Research and Development*, *47*, 225–232.

Buckley, J. G., Heasley, K. J., Twigg, P. & Elliott, D. B. (2005). The effects of blurred vision on the mechanics of landing during stepping down by the elderly. *Gait & Posture*, 21, 65-71.

Diaz, G. J., Parade, M. S., Barton, S. L. & Fajen, B. R. (2018). The pickup of visual information about size and location during approach to an obstacle. *PLOS ONE*, 13(2), 1-26.

Galna, B., Peters, A., Murphy, A. T. & Morris, M. E. (2009). Obstacle crossing deficits in older adults: a systematic review. *Gait & Posture*, *30*(3), 270-275.

Galna, B., Murphy, T. & Morris, M.E. (2010). Obstacle crossing in people with Parkinson’s disease: Foot clearance and spatiotemporal deficits. *Human Movement Science*, *29*, 843–852.

Hengsomboon P., Hiengkaew V., Hsu W.L., Bovonsunthonchai S. (2019). Effect of sound on standing postural stability in the elderly with and without knee osteoarthritis. *Acta of Bioengineering and Biomechanics*, 21(3), 99-108.

Heijnen, M. J. H., Romine, N. L., Stumpf, D. M. & Rietdyk, R. (2014). Memory-Guided Obstacle Crossing: More Failures Were Observed for the Trail Limb versus Lead Limb. *Experimental Brain Research*, *232* (7), 2131–2142.

Hocking, D. R., Rinehart, N. J., McGinley, J. L., Galna, B., Moss, S. A. & Bradshaw, J. L. (2011). Gait adaptation during obstacle crossing reveals impairments in the visual control of locomotion in Williams syndrome. *Neuroscience*, *197*, 320-329.

Lu, T. W., Chen, H. L. & Chen, S. C. (2006). Comparisons of the lower limb kinematics between young and older adults when crossing obstacles of different heights. *Gait & Posture*, *23*, 471–479.

Kamran, B. and Diaz, G. J. (2020). Assessment of an augmented reality apparatus for the study of visually guided walking and obstacle crossing. *Behavioural Research Methods*, *51*(2), 523–531.

Sho, K. & Okada, S. (2019). Contribution of vision and its age-related changes to postural stability in obstacle crossing during locomotion. *Gait & Posture*, *70*, 284–288.

Siouda, R., Khalifaa, R. & Houelb, N. (2019) Auditory cues behind congenitally blind subjects improve their balance control in bipedal upright posture. *Gait & Posture*, *70*, 175–178,