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Original Article

Effect of visual information from binocular vision on the motor control of step over obstacles in walking with 90° turn

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Abstract. [Purpose] This study aimed to clarify the relationship between one-eye visual deprivation; thus, interfering with stereoscopic perception, and movement and obtain insights on the influence of visual perception on movement to step over obstacles. [Participants and Methods] Participants were 25 healthy individuals. There were two conditions of visual perception (stationary and approaching conditions) and two additional conditions of binocular and monocular visions. Under the four conditions, participants were asked to step over an obstacle immediately after a 90° turn while walking. Distance between the foot and obstacle, foot pressure distribution, and stance phase time were measured. [Results] Toe clearance was lower in the approaching condition than that in the binocular stationary condition. The trajectory length ratio was greater in the approaching condition than that in the stationary condition, and heel-ground contact, metatarsal-ground contact, and stance times were all shorter in the binocular condition. Additionally, heel contact, midfoot contact, metatarsal contact, and stance times were shorter in the approaching condition than that in the stationary condition. [Conclusion] In walking with a 90° turn, the binocular approaching condition provided more visual information and positively affected motor control of movements to step over an obstacle.

Key words: Stepping over motion, Obstacle, Binocular vision

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INTRODUCTION

Humans are highly reliant on vision to obtain information about the surrounding environment and to take appropriate actions[1)]. To perceive the 3-dimensional world, the visual system uses cues such as line perspective, atmospheric perspective, overlap, shading, convergence, texture, binocular disparity, and motion disparity[2, 3)]. Among these, binocular stereopsis is a brain process that perceives 3-dimensional space using binocular disparity as a cue for depth perception, playing an important role in spatial vision[4, 5)]. When processing visual stimuli in the brain, most of the information received by photoreceptors in the retina is transmitted to the lateral pallidum and then reaches the primary visual cortex. However, other brain regions are thought to be involved in visual perception, and the details of which brain regions perform processing and how these brain regions are connected to behavior remain unclear[4)].

In addition, although many studies have examined the roles, mechanisms, and importance of depth perception and binocular stereopsis[4, 5)], few have clarified the roles of binocular vision and depth perception in everyday tasks such as moving and avoiding obstacles. The present study focused on the movements involved in stepping over an obstacle, which is necessary for various situations in daily life because Patla et al. found that toe clearance in the movement to step over an obstacle becomes significantly larger when visual information is insufficient during the dynamic phase[6–15)]. Furthermore, toe clearance

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in the approaching condition, in which the participant approaches the obstacle by walking and then straddling the obstacle, was smaller than that in the stationary condition, in which the participant starts walking from a static standing position[16]. In addition, when walking in a straight line and stepping over an obstacle, toe clearance is larger when the walker is seeing through only one eye than when the walker is seeing through both eyes[12, 17]. Based on these findings, toe clearance may also be larger in walking with a 90° turn when vision through one eye is blocked. Another possibility is that the participant may perceive obstacles more stereoscopically in the approaching condition compared to the stationary condition even under the deprivation of vision from one eye.

The purpose of this study was therefore to clarify the relationship between deprivation of vision in one eye, which inhibits stereoscopic perception, and movement, and to deepen our knowledge of the influence of visual perception on movements to step over an obstacle.

Our hypothesis is that monocular visual deprivation renders stepover performance poor, indicating the importance of binocular vision when stepping over obstacle.

PARTICIPANTS AND METHODS

Participants were 25 healthy individuals (12 males, 13 females) between 18 and 64 years old, recruited through posters posted on bulletin boards. The number of participants was determined by calculation with G*Power (version 3.1.9.6; Faul F, Kiel, Germany). Exclusion criteria for participants were: a history of more than two falls within the preceding 12 months; or a history of visual impairment, orthopedic disease, or neurological disease. Mean (± standard deviation) background characteristics of participants were as follows: age, 21.4 ± 1.1 years; height, 165.8 ± 9.7 cm; weight, 59.9 ± 12.4 kg; and body mass index, 21.7 ± 3.1 kg/m^2.

This study was approved by the ethics committee of Akita University Graduate School of Medicine and Faculty of Medicine (approval no. 2854). The purpose, methods, and freedom to cooperate and withdraw were explained to the participants, and written consent to participate was obtained.

Participants performed a 90° turn walking task and stepped over an obstacle. In one, a video camera recorded the distance between the foot and the obstacle when straddling the obstacle. This is based on the method of Fujisawa et al[16]. In addition, we measured the foot pressure distribution and the stance phase time of the first step after straddling by wearing a sheet for measuring the foot pressure distribution before walking.

Participants performed a task in which they walked along a walking path, changed direction by 90°, then crossed an obstacle. The walking path was 90 cm wide, indicated by tape on the floor on both left and right sides, and set up so that the participant had to change direction by 90° to the right.

Obstacles were 10 cm high, 15 cm deep, and 60 cm wide, placed along the walking path so that the participant could step over them immediately after the 90° turn (Fig. 1). The obstacles were made of polystyrene with air bubbles for safety in case the participant stumbled over them.

Two experimental walking conditions were set: a stationary condition; and an approaching condition. The stationary condition involved visual recognition of the obstacle while in a stationary standing position before starting to walk, then stepping over the obstacle. The approaching condition involved visual recognition while walking and approaching the obstacle, then looking ahead and stepping over the obstacle. In combination with these two walking conditions, two visual conditions

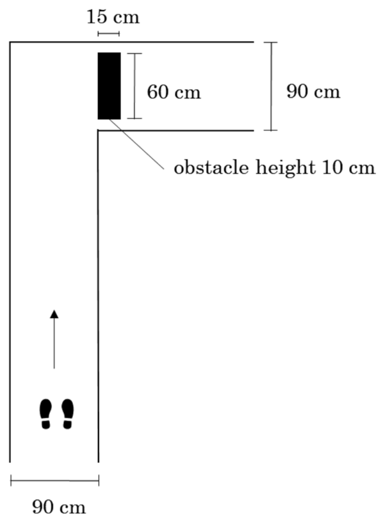

Fig. 1. Pathway and obstacle.

were set: one in which the right eye was covered by an eyepatch (monocular condition), and one in which no eyepatch was used (binocular condition). In the monocular condition, the right eye was covered because this was the side of the 90° change in direction. The order in which the resulting four conditions were performed was randomized.

For visual recognition of the obstacle, a previous study[11)] compared tasks of crossing an obstacle when the participant looked at the obstacle for 3 steps during the approaching condition and a similar duration of 1.5 s in the stationary condition. In this study, the following conditions were set for visual recognition of the obstacle, based on the previous studies[10, 11, 14)]. In the stationary condition, the participant viewed the obstacle from a static standing position at 5 steps from the obstacle. In the approach condition, the participant viewed the obstacle while walking 3 steps from the position 8 steps away from the obstacle to the position 5 steps away from the obstacle. In the stationary condition, the visual recognition time was set at 1–2 s to keep the recognition times the same between conditions. In the stationary condition, the participant walked 5 steps looking forward in the direction of travel without gazing at the obstacle immediately after looking at the obstacle for 1–2 s in the stationary standing position, while in the approach condition, the participant walked 3 steps toward the obstacle while looking at the obstacle, then walked 5 steps looking forward in the direction of travel without gazing at the obstacle, and stepped over the obstacle with the 6th step. Walking speed was set as the normal walking speed of the participant, and the participant was free to step over the obstacle with the left or right leg first. The starting position for walking was adjusted according to the stride length of each participant to reach the specified number of steps.

The distance between the foot and the obstacle was measured as the shortest vertical distance between the front upper edge of the obstacle and the toe (toe clearance) and between the rear edge of the obstacle and the heel (heel clearance). Foot motion trajectories were captured using a digital camera (EX-ZR1100; CASIO, Tokyo, Japan) with a sampling frequency of 240 Hz. The camera was fixed to a fixed object at approximately 50 cm to the side of the obstacle, and captured images were analyzed using Dartfish software (version 5.5; Dartfish, Tokyo, Japan). In addition, a foot pressure distribution measurement system (F-scan; NITTA, Osaka, Japan) was used to measure the trajectory length ratio (trajectory length to foot length) of the first step after stepping over the obstacle, the load center shift range index (shift in the load center of foot length), heel ground contact time, heel maximum load-to-weight ratio, midfoot ground contact time, midfoot maximum load-to-weight ratio, metatarsal ground contact time, metatarsal maximum load-to-weight ratio, and stance phase time under each condition.

Statistical processing included a comparison of binocular and monocular conditions in the stationary condition, comparison of binocular and monocular conditions in the approaching condition, comparison of stationary and approaching conditions in the binocular condition, and comparison of stationary and approaching conditions in the monocular condition. To identify differences in means, a paired t-test was used for data that followed a normal distribution, and the Wilcoxon signed rank test was used for data that followed a non-normal distribution. All statistical analyses were performed using SPSS version 26 software (Japan IBM, Tokyo, Japan) and significance was considered present at the 5% level.

RESULTS

Clearance comparisons are shown in Table 1. Significant differences in toe clearance were found between the stationary (9.00 ± 2.69 cm) and approaching (7.64 ± 2.27 cm) binocular conditions, with the approaching condition showing significantly smaller toe clearance closer to the obstacle. No significant differences were found among the other conditions.

Results from the foot pressure distribution measurement system are shown in Table 2. In the binocular condition, the trajectory length ratio was significantly greater in the approaching condition (73.26 ± 7.12%) than in the stationary condition (68.74 ± 8.79%). Significant differences were found in heel ground contact time (stationary: 0.73 ± 0.48 s; approaching: 0.48 ± 0.15 s), metatarsal ground contact time (stationary: 0.78 ± 0.45 s; approaching: 0.62 ± 0.17 s) and stance phase time (stationary: 0.99 ± 0.47 s; approaching: 0.78 ± 0.12 s). Significant differences were also found between stationary and approaching conditions in the monocular condition, with heel ground contact time (stationary: 0.65 ± 0.22 s; approaching: 0.53 ± 0.14 s), midfoot ground contact time (stationary: 0.59 ± 0.30 s; approaching: 0.39 ± 0.21 s), metatarsal ground contact time (stationary: 0.76 ± 0.20 s; approaching: 0.61 ± 0.16 s) and stance phase time (stationary: 0.93 ± 0.16 s; approaching: 0.73 ± 0.13 s) all significantly shorter in the approaching condition. The only significant difference between the binocular and monocular conditions was the midfoot ground contact time (binocular: 0.55 ± 0.20 s, monocular: 0.39 ± 0.21 s) in the approaching condition.

Table 1. Comparison of clearance conditions

	Stationary condition/ Binocular vision	Stationary condition/ Monocular vision	Approaching condition/ Binocular vision	Approaching condition/ Monocular vision
Toe clearance (cm)	9.00 ± 2.69	9.24 ± 2.68	7.64 ± 2.27*	8.12 ± 2.57
Heel clearance (cm)	6.32 ± 2.38	6.40 ± 2.50	6.92 ± 2.24	6.72 ± 2.26

Values represent mean ± standard deviation.
*$p<0.05$; Comparison with stationary condition/binocular vision, Wilcoxon signed-rank test.

Table 2. Comparison of items measured by the foot pressure distribution measurement system (F-scan)

	Stationary condition/ Binocular vision	Stationary condition/ Monocular vision	Approaching condition/ Binocular vision	Approaching condition/ Monocular vision
Trajectory length ratio (%)	68.74 ± 8.79	66. 13 ± 11.86	73.26 ± 7.12[a]*	70.27 ± 13.02
Load center shift range index (%)	27.96 ± 12.29	30.28 ± 14.01	32.76 ± 11.97	31.32 ± 12.01
Heel ground contact time (s)	0.73 ± 0.48	0.65 ± 0.22	0.48 ± 0.15[b]**	0.53 ± 0.14[b]†
Heel maximum load-to-weight ratio	51.50 ± 16.35	50.21 ± 16.19	45.34 ± 19.03	46.32 ± 18.21
Midfoot ground contact time (s)	0.69 ± 0.41	0.59 ± 0.30	0.55 ± 0.20	0.39 ± 0.21[b]**, [a]§§
Midfoot maximum load-to-weight ratio	11.06 ± 10.27	12.62 ± 11.29	12.22 ± 9.27	10.84 ± 12.38
Metatarsal ground contact time (s)	0.78 ± 0.45	0.76 ± 0.20	0.62 ± 0.17[b]*	0.61 ± 0.16[a]††
Metatarsal maximum load-to-weight ratio	48.88 ± 19.53	44.74 ± 22.75	47.82 ± 16.13	44.83 ± 17.40
Stance phase time (s)	0.99 ± 0.47	0.93 ± 0.16	0.78 ± 0.12[b]**	0.73 ± 0.13[b]††

Values represent mean ± standard deviation.
*$p<0.05$, **$p<0.01$: Comparison with stationary condition/binocular vision.
†$p<0.05$, ††$p<0.01$: Comparison with stationary condition/monocular vision.
§§$p<0.01$: Comparison with approaching condition/binocular vision.
[a]Paired-samples t-test; [b] Wilcoxon signed-rank test.

DISCUSSION

To deepen our knowledge of the influence of visual perception on the movement to step over obstacles, we measured toe clearance and heel clearance, trajectory length ratio, load center shift range index, heel ground contact time, heel maximum load-to-weight ratio, midfoot ground contact time, midfoot maximum load-to-weight ratio, metatarsal ground contact time, metatarsal maximum load-to-weight ratio, and stance phase time.

Toe clearance values were smaller in the approaching condition than in the stationary condition with binocular vision, indicating that the foot was significantly closer to the obstacle. Patla et al.[11–13)] showed that toe clearance increased significantly when visual information was insufficient during the approach stage, indicating that visual information during the approach stage is important for stepover movements. In this study, it was shown that vision in the approach condition is superior to vision in the stationary condition. Our results are consistent with those of Patla et al.[11–13)], and we believe that the same considerations can be made. In the binocular approaching condition, the obstacle becomes larger as the participant approaches, and the distance between the object and the obstacle gradually reduces, making the texture of the object clearer and enabling stereopsis through perspective. On the other hand, with monocular vision, no difference in toe clearance values was seen between stationary and approaching conditions. Under monocular viewing conditions, visual information was blocked more in this study compared to the binocular viewing conditions, because the participant's vision was blocked on the side of the 90° change in direction. This presumably did not allow the participant to obtain sufficient recognition of the obstacle because less visual information was provided with the perspective method to perceive the object in 3 dimensions even in the approaching condition as compared to the binocular viewing conditions.

In addition, no significant differences were seen between binocular and monocular viewing conditions in the stationary and approaching conditions, except for midfoot ground contact time. This result differed from our initial prediction that clearance would be greater under monocular conditions compared to binocular conditions. As suggested by Fujisawa et al.[16)], a 90° turn when walking allows obstacles to be perceived from three directions, and more visual information can be obtained even under monocular conditions compared to straight walking. This may explain the lack of differences.

In terms of the items measured using the foot pressure distribution measurement system, heel and metatarsal ground contact times were shorter in the binocular vision condition, despite the longer trajectory length ratio of the preceding limb in the approaching condition, and stance time was shorter, reflecting this. In other words, a large shift in the load center of foot length was observed, and the short time required for this shift means that the step-over action of the hindlimb was performed quickly and widely. On the other hand, although there was no difference in trajectory length ratio between stationery and approaching conditions in the monocular view, heel ground contact time, midfoot ground contact time, and metatarsal ground contact time were shorter in the approaching condition, and stance time was shorter, reflecting this. These results suggest that the crossing motion of the hindlimb was performed in a shorter time in the monocular view as well.

Based on the results of toe clearance measurement and the foot pressure distribution measurement system, toe clearance of the leading limb was less in the approaching condition than in the stationary condition in the binocular view, and quick movement of the trailing limb occurred. With monocular vision, no difference in toe clearance was seen between the stationary and approaching conditions, but a quick movement of the trailing limb occurred in the approaching condition. In other words, no effect on the leading limb was seen with monocular vision, only on the trailing limb. We believe that this result may have been influenced by differences in visual input from peripheral vision during the process of crossing over the obstacle. In this study, the participant was instructed not to gaze at the obstacle from 5 steps before stepping over the obstacle, but the obstacle was within the field of peripheral vision. In the process of stepping over the obstacle, peripheral vision, including in the downward direction, was largely available to binocular observers. In contrast, with monocular vision, the right eye, as the eye on the side of the 90° change in direction, was visually occluded, so the left eye rapidly received a large amount of peripheral visual information regarding the obstacle. In other words, the timing of obtaining peripheral visual information on the obstacle was delayed with monocular vision compared to binocular vision, and less visual information was obtained. We speculate that the time difference and magnitude of visual information supplied to the peripheral vision had desirable effects on both leading and trailing limbs in binocular vision, but a desirable effect only on the trailing limb in monocular vision.

In conclusion, with the 90° change in the direction of walking, the binocular approach to the obstacle appears more useful for visual recognition of the obstacle. Moreover, the binocular approach provides more visual information, which is thought to have positive effects on the motor control of movements to step over the obstacle.

One of the limitations of this study is that it is a laboratory study and it is not clear whether it has applicability in real life. Another limitation is that there is some scene setting (stepover motion) in relation to the input of visual information and the movement. Further research is desired to clarify how visual perception by “approaching” and “binocular vision” is affected in the actual living environment and other visual objects (e.g., crossing ditches and walking on rough roads).

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

REFERENCES

1) Tanabe S, Fujita I: The neural representation of stereoscopic depth. J Jpn Neural Netw Sci, 2004, 11: 64–73 (in Japanese).
2) Shioiri S, Watanabe Y: Perception of motion in depth and two cues. Jpn J Vis Sci, 2009, 30: 64–74 (in Japanese).
3) Kobayashi Y: Spatial cognition and vergence eye movement. J Jpn Biomechanisms Sci, 2017, 41: 159–164 (in Japanese).
4) Takeuchi R, Osakada F: Neural circuit mechanisms underlying spatial visual perception and visually-induced behavior. Folia Pharmacol Jpn, 2020, 155: 99–106 (in Japanese). [CrossRef]
5) Fujita I: Neural basis of stereoscopic depth perception. Jpn Orthoptic J, 2006, 35: 31–32 (in Japanese). [CrossRef]
6) Patla AE, Prentice SD, Robinson C, et al.: Visual control of locomotion: strategies for changing direction and for going over obstacles. J Exp Psychol Hum Percept Perform, 1991, 17: 603–634. [Medline] [CrossRef]
7) Patla AE, Rietdyk S: Visual control of limb trajectory over obstacles during locomotion: effect of obstacle height and width. Gait Posture, 1993, 1: 45–60. [CrossRef]
8) Patla AE, Adkin A, Martin C, et al.: Characteristics of voluntary visual sampling of the environment for safe locomotion over different terrains. Exp Brain Res, 1996, 112: 513–522. [Medline] [CrossRef]
9) Patla AE, Rietdyk S, Martin C, et al.: Locomotor patterns of the leading and the trailing limbs as solid and fragile obstacles are stepped over: some insights into the role of vision during locomotion. J Mot Behav, 1996, 28: 35–47. [Medline] [CrossRef]
10) Patla AE, Vickers JN: Where and when do we look as we approach and step over an obstacle in the travel path? Neuroreport, 1997, 8: 3661–3665. [Medline] [CrossRef]
11) Patla AE: How is human gait controlled by vision? Ecol Psychol, 1998, 10: 287–302. [CrossRef]
12) Patla AE, Niechwiej E, Racco V, et al.: Understanding the contribution of binocular vision to the control of adaptive locomotion. Exp Brain Res, 2002, 142: 551–561. [Medline] [CrossRef]
13) Mohagheghi AA, Moraes R, Patla AE: The effects of distant and on-line visual information on the control of approach phase and step over an obstacle during locomotion. Exp Brain Res, 2004, 155: 459–468. [Medline] [CrossRef]
14) Patla AE, Greig M: Any way you look at it, successful obstacle negotiation needs visually guided on-line foot placement regulation during the approach phase. Neurosci Lett, 2006, 397: 110–114. [Medline] [CrossRef]
15) Marigold DS, Weerdesteyn V, Patla AE, et al.: Keep looking ahead? Re-direction of visual fixation does not always occur during an unpredictable obstacle avoidance task. Exp Brain Res, 2007, 176: 32–42. [Medline] [CrossRef]
16) Fujisawa S, Kaneko R, Sasaki M: Effects of different methods of visual perception on stepping-over motion while walking in a straight line or turning 90 degrees. Rigakuryoho Kagaku, 2009, 24: 555–559 (in Japanese).
17) Hayhoe M, Gillam B, Chajka K, et al.: The role of binocular vision in walking. Vis Neurosci, 2009, 26: 73–80. [Medline] [CrossRef]