International Conference on Artificial Reality and Telexistence
Eurographics Symposium on Virtual Environments (2019)
Y. Kakehi and A. Hiyama (Editor)

Generation of Walking Sensation by Upper Limb Motion

G. Sueta[1], N. Saka[1], V. Yem[1], T. Amemiya[2], M. Kitazaki[3], M. Sato[1] and Y. Ikei[1]

[1]Tokyo Metropolitan University, Japan
[2]The University of Tokyo, Japan
[3]Toyohashi University of Technology, Japan

Abstract

This paper proposes a method to generate a turning walk sensation to the user by an arm swing display. We assumed a hypothesis that the turning walk sensation is generated by providing different motion profiles of passive arm swing on the left and right arms. We show that turning walk sensation can be generated by presenting arm swing motion with a different flexion ratio of the shoulder joint, depending on the turning radius.

CCS Concepts

• ***Human-centered computing*** → Human computer interaction (HCI) → Interaction paradigms → Virtual reality*;* • ***Human-centered computing*** → Human computer interaction(HCI) → Interaction devices → Haptic devices*;*

1. Introduction

The sensation of motion in a space is essential for the application of VR space experience [SUS95]. If walking is used as a means of travel in a VR space, it is necessary to impart a physical sensation of walking consistent to flowing visual scene. We have developed a system to relive the walking sensation by presenting passive stimuli to the body. That was different from active walking performed for a VR space experience [IYN01] in that the goal was to transfer the other's experience and skills by reproducing the other's space experience without performing real walking motion.

In order to present VR walking sensation, we have used lower limbs motion and vestibular stimulations shown in previous researches. In the present study, we introduce the upper limb motion that is provided by mechanical levers. The arm swing motion in a real walk automatically cancels a twisting moment of the torso created by the lower limbs motion in walking as well as improves the efficiency of energy for a walk [BMBvD10]. We aimed to induce the sensation of a turning walk by using asymmetrical passive arm swing motion. The results was compared with the arm swing motion of a real walk.

Figure 1: *Arm swing display.*

Figure 1 shows our device that generates arm swing sensation during virtual walking. This device rotates the upper limb angle around the shoulder joint by the motors attached to the chair.

2. Arm Swing and its Perception in Real Walking

2.1. Arm swing in a real walk

We measured the profile of arm swing motion during a real walk of a turn by a motion capture system. The participants were 4 male students (mean age of 22.8 years old). The participant walked clockwise (right turn) and counter clockwise (left turn) on a circle of a radius of 1 m at a walk period (time for two steps) of 1200 ms.

There was no significant difference in both rotation angles of shoulder joints of left and right arms, and the flexion angle ratio of a shoulder joint. Here, the flexion angle ratio is the percentage of the swing angle to forward in a whole swing angle.

2.2. Perception of arm swing motion in real walking

We assessed how the arm swing motion was subjectively perceived during a real turning walk where the participant walked following a circle marked on the floor. The participants were 9 male students (23.1 years old). The participants were asked to walk straight and turned left or right on a circle with one of radii {1, 2, 3} m at a walk period of 1200 ms. After each walk, they rated the deviation of the arm swing angle between arms as subjectively perceived imbalance.

Figure 2 shows the results where a 100 of x-axis means right arm swing only, and zero balanced swing of left/right arms. A significant difference in the swing angle perception was observed in both the turn direction (left/right) and the radius ($ps<0.01$). The

DOI: 10.2312/egve.20191294

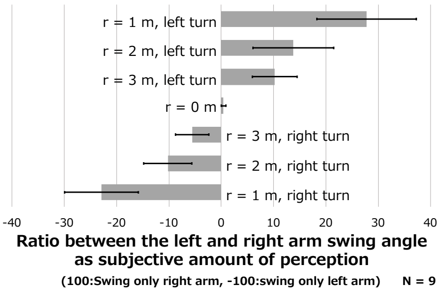

Figure 2: *Perceived (subjective) amount of arm swing motion.*

participant perceived unbalanced swing of am where the outer arm (left arm in a right turn) has moved larger than the inner arm (right arm in a right turn).

3. Walking Sensation in VR Walking

We measured the sensations of straight walking, of left turn walking, and of right turn walking at the same time using a 0-100 scale. Nine stimulus conditions of three swing angle pairs (left and right angles) and three flexion ratio pairs were provided. Six participants (mean of 23.5 years old) evaluated the sensations. The arm swing angle pair was selected randomly from {(30, 45), (30, 30), (45, 30) degree} for (left, right) arms. The flexion ratio of shoulder joint was from {(30, 90), (60, 60), (90, 30)} % for (left, right) arms.

Figure 3 shows the results. A two-way analysis of variance shows that the walking sensation had a significant main effect by the flexion ratio. For straight walking sensation, a significant difference on the flexion ratio of shoulder joint ($p<0.01$) was observed. The almost balanced swing for left and right arms was naturally effective to evoke the straight walking sensation. For left turning walk sensation, a difference tendency on the flexion ratios was detected at $p<0.1$, and the right turning walk sensation changed significantly at $p<0.05$. From this result, it is suggested that turning walk sensation can be evoked by providing different flexion ratio of the left and right arms where the opposite side arm to the circle center was swung larger than the same side arm.

4. Optimal Arm Swing Profile in VR Waking

The optimal flexion ratio of the VR arm swing was investigated by the method of adjustment. Fifteen participants (22.7 years old) volunteered the experiment. After walked a left/right turn on a circle of a radius out of {1, 2, 3} m, the participant adjusted the flexion ratio of the left and right arm swings of the display.

Figure 4 shows the adjustment results. Pearson's correlation coefficient between the curvature (x-axis) and the adjusted flexion ratio was high; for left arm: $r = 0.71$, $p<0.01$, and right arm: $r = -0.64$, $p<0.01$. As a result of regression analysis, the flexion ratio (y) is approximated by the following equations of the curvature (x):

$$\text{Right arm:} \quad y = 9.2x + 62.01 \ (R^2 = 0.40) \quad (1)$$

$$\text{Left arm:} \quad y = -10.19x + 62.68 \ (R^2 = 0.51) \quad (2)$$

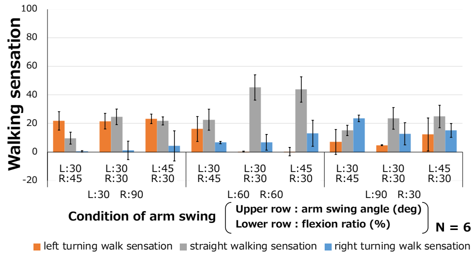

Figure 3: *Walking sensation under different arm swing profiles of left/right arms.*

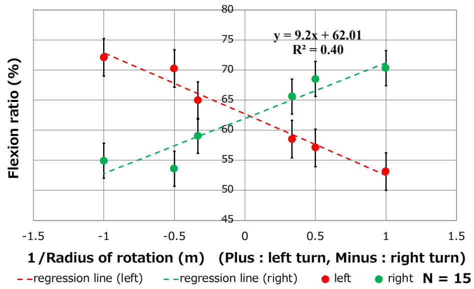

Figure 4: *Flexion ratio as a function of curvature of circles walked.*

These clearly show the optimal flexion ratio of arm swing display that created the sensation of turning walk is reversed in arms for rotational direction (left/right turns).

5. Discussion

It was suggested that the turning walk sensation may be presented by the symmetric motion consistent to subjective motion perception, although the real walking had no difference in the amount of arm swing between the left and right.

The sensation of turning walk depended on the flexion ratio of a shoulder joint, not on the amplitude of arm swing. The reason for this is still unclear, however we consider that the trunk was twisted due to the difference of flexion ratios of both shoulder joints which directed the body toward the center of curvature.

Acknowledgment

This work was partially supported by the MIC/SCOPE #141203019, JSPS KAKENHI Grant Number JP26240029, 18H04118, JP18H03283, NICT #143U101, and JKA projects.

References

[BMBvD10] Bruijn S. M., Meijer O. G., Beek P. J., van Dieën J. H.: The effects of arm swing on human gait stability. *Journal of experimental biology 213*, 23 (2010), 3945–3952. 1

[IYN01] Iwata H., Yano H., Nakaizumi F.: Gait master: A versatile locomotion interface for uneven virtual terrain. In *Proceedings IEEE Virtual Reality 2001* (2001), IEEE, pp. 131–137. 1

[SUS95] Slater M., Usoh M., Steed A.: Taking steps: the influence of a walking technique on presence in virtual reality. *ACM Transactions on Computer-Human Interaction (TOCHI) 2*, 3 (1995), 201–219. 1