Airflow for Body Motion Virtual Reality

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Abstract. The present study investigates the characteristics of cutaneous sensation evoked by airflow to the face of the seated and standing user during the real and virtual walking motion. The effect of airflow on enhancement of a virtual reality walk was demonstrated. The stimulus condition provided in the evaluation involved the airflow, the visual, and the vestibular presentations, and the treadmill and walk-in-place real motions. The result suggested that the cutaneous sensation of air flow was suppressed while the movement was performed actively with visual information provided. The equivalent speed of air flow for the participants was 5 $\sim$ 29% lowered from the air flow speed in the real walk.

Keywords: Airflow · Cutaneous sensation · Virtual walk

1 Introduction

Airflow in a virtual space has been developed to augment the quality of experience of a simulated environment [1–3]. It has also been used to impart tactile sensation to the hand [4–8] and to deliver scent to the nose [9, 10]. The sensation of airflow (sensation of wind) is one of the information sources for acquiring spatial experience in which we can perceive both the motion of the self-body and the condition of environmental air [11]. The airflow has a compelling effect on reality of translation or ground speed direction in the simulation of vehicles [12–14] or the experience of flight as a bird [15]. Airflow induces and augments vection when it is used with other modality presentation [16, 17]. These features are quite attractive when they are applied to a virtual environment in which the user is immersed, and specifically the sensation of motion is needed. Although many aspects have been investigated as shown above, the relation between the cutaneous sensation by airflow and the body motion state of the user has not been discussed in detail.

In the present research, we investigated basic characteristics of airflow perception on the face during the user is moving in the real and the virtual space. We intend to use airflow to replicate spatial experience of others who moved in a variety of interesting

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places of the world or who had a high level physical skill that could be very hard to pass to others. To transfer experience accurately, multisensory information needs to be reproduced as the past person received and felt. A multisensory display [18] has many components that interact with each other where the airflow specifically contributes to the perception of dynamic motion of the body [16, 17]. In order to design such a multisensory system, the relation between the perception of body motion and the airflow display effect in modalities needs to be elucidated.

In this paper, first we measure the walking sensation and the cutaneous sensation of airflow under visual and vestibular stimuli provided to a sitting participant. Since the cutaneous sensation of airflow changes by the existence of other stimuli, the equivalent airflow speed in those conditions was measured. Then, we show the airflow characteristics observed when the user is walking/walking in place on the treadmill and receives the visual stimulus moving through a corridor. We consider the results could provide the data for the optimal design of the airflow display.

2 Cutaneous Sensation, Walking Sensation and Air Velocity in a Seated Virtual Reality Walk

2.1 Objective and Participants

Airflow presentation characteristics in reliving of virtual reality walk for a seated user were investigated. The extent to which walking sensation and cutaneous sensation depend on airflow condition was measured. The subjectively equivalent airflow speed was adjusted to the real walk.

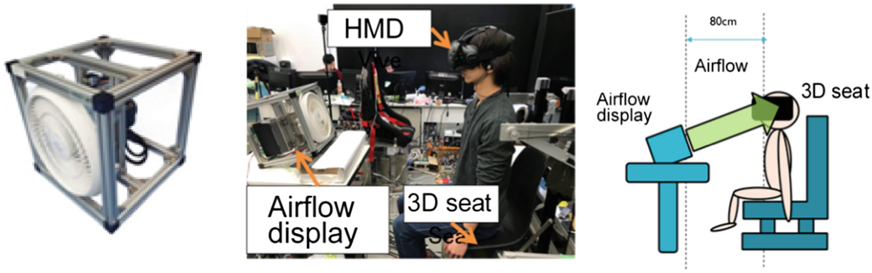
The participants of sensation intensity experiments were ten (under)graduate students of mean age of 23.1 years. Eight students measured the airflow speed of subjective equality.

2.2 Stimulus

Airflow was presented to the face of the participant by a fan display shown in Fig. 1a 80 cm in front of the face. The airflow speed was 0.92 m/s that was also the real walk speed. Three degree-of-freedom (lifting, pitching, rolling) motion seat built in-house presented vestibular stimulus. The motion of the seat was optimized beforehand to provide a walking sensation. An omnidirectional view in a virtual corridor translating at 0.92 m/s was presented by the head-mounted display (Vive, HTC Inc.). Three factors of cutaneous, vestibular and visual stimuli in two levels (presence or absence) were presented in a random order. In the equality adjustment experiment, the initial airflow speed was randomized within 0 to 3.2 m/s at each trial to cancel perceptual hysteresis.

2.3 Procedure

The participant wore the HMD and sat on the 3D motion seat as shown in Fig. 1b and c. The intensity of walking sensation and cutaneous sensation was evaluated by a visual analogue scale whose ends were indicated as ‘no sensation’ and ‘real walk equivalence



(a) Airflow display (b) Experiment scene (c) Schematic of experiment

Fig. 1. Airflow display and the experimental setup.

level'. A white noise was provided by earphones. The equivalent airflow speed was adjusted by the participant using a wheel on a mouse.

2.4 Results

Figure 2 shows the sensation of walking. The rating was highest when all the stimuli of airflow, visual and vestibular stimuli were provided. The main effect of all the three factors was significant ($p < 0.001$) based on the ANOVA. The interaction between the airflow and vestibular stimuli was observed. A simple main effect was significant when the vestibular stimulus was presented.

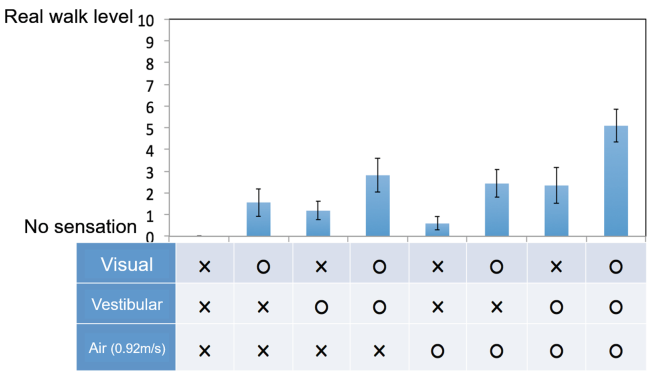


Fig. 2. Sensation of walking

Figure 3 shows the intensity of cutaneous sensation. The cutaneous sensation was larger in this virtual reality walk than the real walk. This is considered due to the sensory suppression that is activated in the case of the real walk. When the visual and vestibular stimuli were added, the cutaneous sensation decreased most to close to that in the real walk. The main effect of both the airflow and the vestibular stimulus was significant ($p < 0.001$). The interactions between the airflow and the visual stimulus and also between the airflow and the vestibular stimulus were observed. The simple main effect was detected for the visual stimulus ($p < 0.05$), and for the vestibular stimulus ($p < 0.001$) under the airflow stimulus.

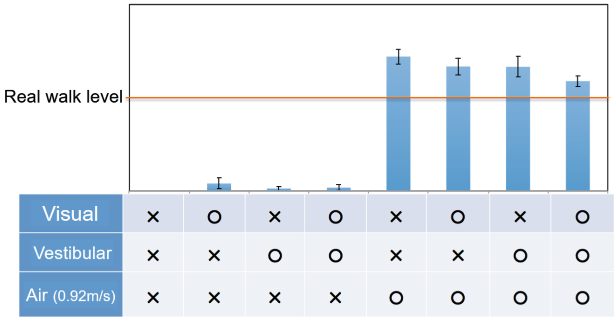


Fig. 3. Intensity of cutaneous sensation

Figure 4 shows the equivalent airflow speed. It depends on stimulus condition, and is lower than the real airflow speed, around 0.7 to 0.85 m/s. As the main effect of vestibular stimulus was significant ($p < 0.05$), it is suggested that the adjusted speed came closer to the airflow speed of the real walk when the vestibular stimulus was included.

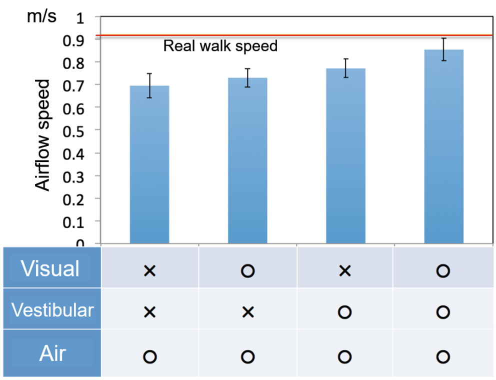


Fig. 4. Equivalent airflow speed for a seated participant

These results provided the optimal airflow speed in the experience of the walk virtual reality. It was suggested that the cutaneous sensation was suppressed when the visual and the vestibular stimulus were involved.

3 Cutaneous Sensation in a Standing Virtual Reality Walk

3.1 Objective and Participants

The intensity of cutaneous sensation and environmental reality were evaluated when the standing user received the airflow and visual stimuli during walking and walking in place on a treadmill. The cutaneous sensation was compared with that in the real walk. The airflow speed equivalent to the real walk was adjusted by the participant.

Nine (under)graduate students 22.8 years old in average participated in the evaluation. Nine students of the average age of 23.1 years performed the adjustment of subjective equality.

3.2 Stimulus

Two airflow displays were placed at the both sides of a monitor screen (80 inches) as shown in Fig. 5 where the airflow comes from the screen. The two airflows converge at 200 mm front of the face, and the airflow is directed normal to the face. The speed of the airflow was 0.92 m/s that was equal to the real walk speed. The cycle time of walk (in place) steps on the treadmill was 0.7 s. The visual stimulus was a monocular movie clip of a first person view going down a campus corridor at 0.92 m/s. The initial speed of airflow in the adjustment was randomly set between 0 to 3.2 m/s.

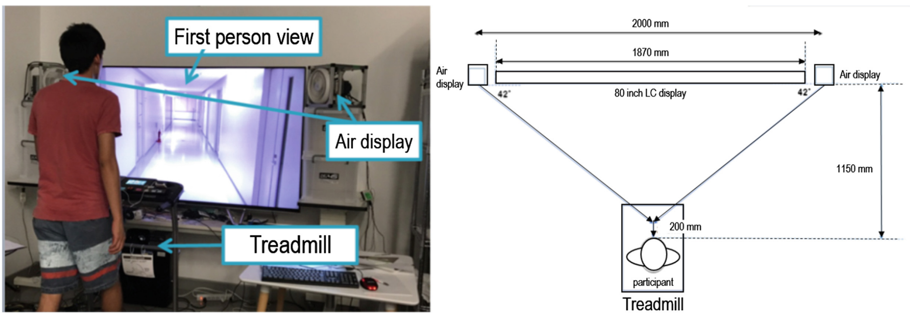


Fig. 5. Apparatus for standing on a treadmill

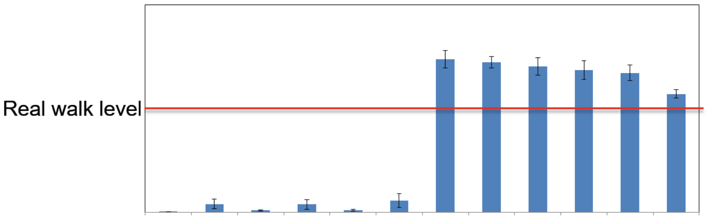
Twelve test stimuli from four factors of airflow, visual, walking in place and walking on the treadmill with two levels each of them were presented to the participant in a random order. The treadmill walk and the walk in place are mutually exclusive.

3.3 Procedure

The cutaneous sensation and the reality of environment were evaluated. The anchor of the VAS for cutaneous sensation was from ‘no sensation’ to ‘equivalent to real walk’, while for environmental reality from ‘sensation on the treadmill in the laboratory’ to ‘sensation of walking down the corridor in the campus’. The sound of a metronome with 0.7 s period was provided via earphones to muffle the sound of the treadmill. In the adjustment session, the participant modified the airflow speed by a wheel on a computer mouse.

3.4 Results

Figure 6 shows the cutaneous sensation. It came to most close to that of the real walk in the condition with the airflow, the visual stimuli and the treadmill walk. The closest condition was statistically different with the condition of airflow and visual stimuli. This indicates that the active motion (treadmill walk) suppressed cutaneous sensation.



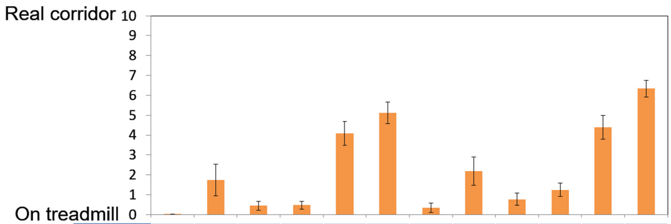
VISION	×	○	×	×	○	○	×	○	×	×	○	○
Walk in place	×	×	○	×	○	×	×	×	○	×	○	×
Treadmill	×	×	×	○	×	○	×	×	×	○	×	○
Airflow	×	×	×	×	×	×	○	○	○	○	○	○

Fig. 6. Cutaneous sensation

Figure 7 shows the reality of the environment. The reality rating of walking down the actual corridor was the highest at the stimulation level where the airflow, the vision, and the treadmill walk were involved. It is the same as the cutaneous sensation. It looks that the reality was increased with the airflow.

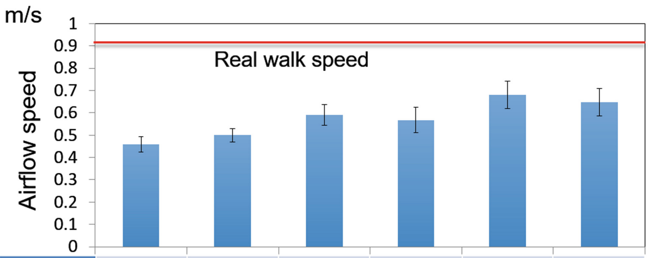
Figure 8 shows the equivalent airflow speed obtained by the adjustment by participants regarding the stimulus conditions. The speed was from 0.65 to 0.87 m/s, although it depends on the stimulus condition. These values are smaller by 5 to 29% than the airflow speed of the real walk. The equivalent airflow speed at the condition of the airflow, the visual, and the treadmill walk was significantly ($p < 0.001$) higher than the airflow single stimulus.

This result is consistent with the fact that the cutaneous sensation was suppressed during active motion shown in Fig. 6. The result provided us with the optimum airflow speed for conditions including a walk VR, and the suppression of cutaneous sensation during active motion was confirmed.



VISION	×	○	×	×	○	○	×	○	×	×	○	○
Walk in place	×	×	○	×	○	×	×	×	○	×	○	×
Treadmill	×	×	×	○	×	○	×	×	×	○	×	○
Airflow	×	×	×	×	×	×	○	○	○	○	○	○

Fig. 7. Reality of environment



VISION	×	○	×	○	×	○
Walk in place	×	×	○	○	×	×
Treadmill	×	×	×	×	○	○
Airflow	○	○	○	○	○	○

Fig. 8. Optimum airflow speed in sitting posture

4 Conclusion

In the present research, the effect conveyed by the airflow in a virtual space was investigated. It was suggested that the airflow to the face of the participant had a positive effect in providing the walking sensation and the environmental reality, although the conditions used are limited. In addition, the suppression of the cutaneous sensation during an active walk was observed in the experiment.

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